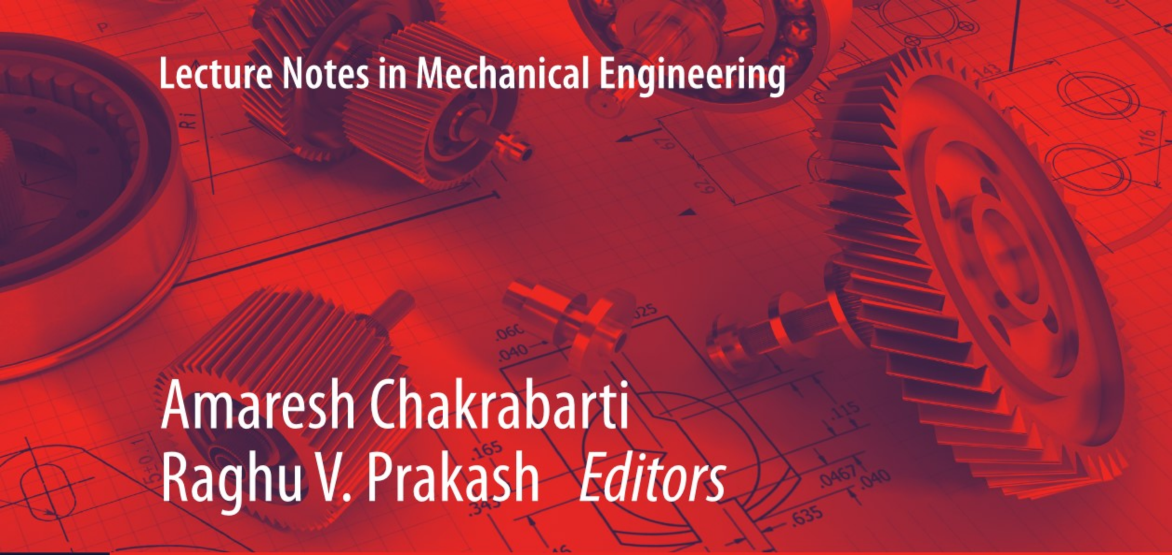


Lecture Notes in Mechanical Engineering

Amaresh Chakrabarti
Raghu V. Prakash *Editors*

ICoRD'13

Global Product Development

Part 1

Springer

Lecture Notes in Mechanical Engineering

For further volumes:
http://www.springer.com/series/11236

Amaresh Chakrabarti · Raghu V. Prakash
Editors

ICoRD'13

Global Product Development

Springer

Editors
Amaresh Chakrabarti
Centre for Product Design
and Manufacturing
Indian Institute of Science
Bangalore, Karnataka
India

Raghu V. Prakash
Mechanical Engineering
Indian Institute of Technology Madras
Chennai, Tamil Nadu
India

ISSN 2195-4356 ISSN 2195-4364 (electronic)
ISBN 978-81-322-1049-8 ISBN 978-81-322-1050-4 (eBook)
DOI 10.1007/978-81-322-1050-4
Springer New Delhi Heidelberg New York Dordrecht London

Library of Congress Control Number: 2012954861

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

Design is ubiquitous, yet universal; it pervades all spheres of life, and has been around ever since life has been engaged in, purposefully changing the world around it. While some designs that matured many centuries ago still remain in vogue, there are areas in which new designs are being evolved almost every day, if not, every hour, globally. Research into design and the emergence of a research community in this area has been relatively new, its development influenced by the multiple facets of design (human, artefact, process, organisation, and the micro- and macro-economy by which design is shaped) and the associated diversification of the community into those focusing on various aspects of these individual facets, in various applications. Design is complex, balancing the needs of multiple stakeholders, and requiring a multitude of areas of knowledge to be utilised, with resources spread across space and time.

The collection of papers in this book constitutes the Proceedings of the 4th International Conference on Research into Design (ICoRD'13) held at the Indian Institute of Technology Madras in the city of Chennai, India during 7–9 January 2013. ICoRD'13 is the fourth in a series of biennial conferences held in India to bring together the international community from diverse areas of design practice, teaching and research. The goal is to share cutting edge research about design among its stakeholders; aid the ongoing process of developing a collective vision through emerging research challenges and questions; and provide a platform for interaction, collaboration and development of the community in order for it to address the challenges and realise the collective vision. The conference is intended for all stakeholders of design, and in particular for its practitioners, researchers, teachers and students.

Out of the 201 abstracts submitted to ICoRD'13, 175 were selected for full paper submission. One hundred and thirty-two full papers were submitted, which were reviewed by experts from the ICoRD'13 International Programme Committee comprising 163 members from 127 institutions or organisations from 32 countries spanning five continents. Finally, 114 full papers, authored by over 200 researchers from 91 institutions and organisations from 23 countries spanning five continents, have been selected for presentation at the conference and for publication as chapters in this book. ICoRD has steadily grown over the last three editions, from a humble beginning in 2006 with 30 papers and 60 participants, through 75 papers and 100 participants in ICoRD'09, and 100 papers and 150 participants in ICoRD'11. This is also the first time that ICoRD has taken place outside Bangalore, with the Indian Institute of Technology Madras and Indian Institute of Science Bangalore jointly sharing the responsibility for its organisation.

The chapters in this book together cover all three major areas of products and processes: functionality, form and human factors. The spectrum of topics range from those focusing on early stages such as creativity and synthesis, through those that are primarily considered in specific stages of the product life cycle, such as safety, reliability or manufacturability, to those that are relevant across the whole product life cycle, such as collaboration, communication, design management, knowledge management, cost, environment and product life cycle management. Issues of delivery of research into design, in terms of its two major arms: design education and practice, are both highlighted in the chapters in this book. Foundational topics such as the nature of design theory and research methodology are also major areas of focus. It is particularly encouraging to see in the chapters the variety of areas of application of research into design—aerospace, healthcare, automotive and white goods sectors are but a few of those explored. The theme of this year's conference is Global Product Development. The large number of chapters that impinge on this theme reflects the importance of this theme within design research.

On behalf of the Patron, Steering Committee, Advisory Committee, Local Organising Committee and Co-Chairs, we thank all the authors, reviewers, institutions and organisations that participated in the conference and the Conference Programme Committee for their support in organising ICoRD'13 and putting this book together. We are thankful to the Design Society and Design Research Society for their kind endorsement of ICoRD'13. We thank the Indian Institute of Technology Madras and the Indian Institute of Science, Bangalore for their support of this event. We also wish to place on record and acknowledge the enormous support provided by Mr. Ranjan B. S. C., Ms. Kumari M. C. and Ms. Chaitra of IISc in managing the review process, and in preparation of the conference programme and this book, and the group of student-volunteers of Indian Institute of Technology Madras led by Swostik, Suraj and Sahaj in the organisation and running of the conference. Finally, we thank Springer India for its support in the publication of this book.

Amaresh Chakrabarti
Raghu V. Prakash

Contents

Part I Design Theory and Research Methodology

How I Became a Design Researcher 3
Gabriela Goldschmidt

Why do Motifs Occur in Engineering Systems? 15
A. S. Shaja and K. Sudhakar

Thinking About Design Thinking: A Comparative Study of Design and Business Texts 29
Marnina Herrmann and Gabriela Goldschmidt

Advancing Design Research: A "Big-D" Design Perspective 41
Christopher L. Magee, Kristin L. Wood, Daniel D. Frey and Diana Moreno

Proposal of Quality Function Deployment Based on Multispace Design Modeland its Application 61
Takeo Kato and Yoshiyuki Matsuoka

Exploring a Multi-Meeting Engineering Design Project 73
John S. Gero, Jiang Hao and Sonia Da Silva Vieira

Integrating Different Functional Modeling Perspectives 85
Boris Eisenbart, Ahmed Qureshi, Kilian Gericke and Luciënne Blessing

Part II Design Creativity, Synthesis, Evaluation and Optimization

Information Entropy in the Design Process 101
Petter Krus

Mitigation of Design Fixation in Engineering Idea Generation: A Study on the Role of Defixation Instructions 113
Vimal Viswanathan and Julie Linsey

Multidisciplinary Design Optimization of Transport Class Aircraft . . 125
Rahul Ramanna, Manoj Kumar, K. Sudhakar and Kota Harinarayana

Using Design-Relevant Effects and Principles to Enhance Information Scope in Idea Generation 137
Zhihua Wang and Peter R. N. Childs

Determining Relative Quality for the Study of Creative Design Output 151
Chris M. Snider, Steve J. Culley and Elies A. Dekoninck

Development of Cognitive Products via Interpretation of System Boundaries 163
Torsten Metzler, Iestyn Jowers, Andreas Kain and Udo Lindemann

A Design Inquiry into the Role of Analogy in Form Exploration: An Exploratory Study 175
Sharmila Sinha and B. K. Chakravarthy

Supporting the Decision Process of Engineering Changes Through the Computational Process Synthesis 187
Florian Behncke, Stefan Mauler, Udo Lindemann, Sama Mbang, Manuel Holstein and Hansjörg Kalmbach

Concept Generation Through Morphological and Options Matrices 199
Dani George, Rahul Renu and Gregory Mocko

Understanding Internal Analogies in Engineering Design: Observations from a Protocol Study 211
V. Srinivasan, Amaresh Chakrabarti and Udo Lindemann

Craftsmen Versus Designers: The Difference of In-Depth Cognitive Levels at the Early Stage of Idea Generation 223
Deny W. Junaidy, Yukari Nagai and Muhammad Ihsan

Part III Design Aesthetics, Semiotics, Semantics

A Comparative Study of Traditional Indian Jewellery Style of *Kundan* with European Master Jewellers, a Treatise on Form and Structure 237
Parag K. Vyas and V. P. Bapat

A Structure for Classification and Comparative Study of Jewellery Forms 249
Parag K. Vyas and V. P. Bapat

Product Design and the Indian Consumer: Role of Visual Aesthetics in the Decision Making Process 261
Naren Sridhar and Mark O'Brien

Effective Logo Design 271
Sonam Oswal, Roohshad Mistry and Bhagyesh Deshmukh

Effect of Historical Narrative Based Approach in Designing Secondary School Science Content on Students' Memory Recall Performance in a School in Mumbai 283
Sachin Datt and Ravi Poovaiah

The Home as an Experience: Studies in the Design of a Developer-Built Apartment Residence 293
P. K. Neelakantan

Meta-Design Catalogs for Cognitive Products 303
Torsten Metzler, Michael Mosch and Udo Lindemann

Extracting Product Characters Which Communicate Eco-Efficiency: Application of Product Semantics to Design Intrinsic Features of Eco-Efficient Home Appliances 317
Shujoy Chakraborty

Indian Aesthetics in Automotive Form 331
Chirayu S. Shinde

Understanding Emotions and Related Appraisal Pattern 347
Soumava Mandal and Amitoj Singh

Part IV Human Factors in Design

Force JND for Right Index Finger Using Contra Lateral Force Matching Paradigm 365
M. S. Raghu Prasad, Sunny Purswani and M. Manivannan

Modeling of Human Hand Force Based Tasks Using Fitts's Law . . . 377
M. S. Raghu Prasad, Sunny Purswani and M. Manivannan

Self-Serving Well-Being: Designing Interactions for Desirable Social Outcomes 387
Soumitra Bhat

Do We Really Need Traditional Usability Lab for UX Practice? 399
Anshuman Sharma

Muscle Computer Interface: A Review 411
Anirban Chowdhury, Rithvik Ramadas and Sougata Karmakar

Preliminary Analysis of Low-Cost Motion Capture Techniques to Support Virtual Ergonomics 423
Giorgio Colombo, Daniele Regazzoni, Caterina Rizzi and Giordano De Vecchi

A User-Centered Design Methodology Supported by Configurable and Parametric Mixed Prototypes for the Evaluation of Interaction 435
Monica Bordegoni and Umberto Cugini

Study of Postural Variation, Muscle Activity and Preferences of Monitor Placement in VDT Work 447
Rajendra Patsute, Swati Pal Biswas, Nirdosh Rana and Gaur Ray

Relation-Based Posture Modeling for DHMs 463
Sarath Reddi and Dibakar Sen

How do People View Abstract Art: An Eye Movement Study to Assess Information Processing and Viewing Strategy 477
Susmita Sharma Y. and B. K. Chakravarthy

Part V Eco-Design, Sustainable Manufacturing, Design for Sustainability

Sustainability and Research into Interactions 491
Suman Devadula and Amaresh Chakrabarti

Residential Buildings Use-Phase Memory for Better Consumption Monitoring of Users and Design Improvement 505
Lucile Picon, Bernard Yannou and Stéphanie Minel

Developing Sustainable Products: An Interdisciplinary Challenge . . . 517
Kai Lindow, Robert Woll and Rainer Stark

Life Cycle Assessment of Sustainable Products Leveraging Low Carbon, Energy Efficiency and Renewable Energy Options 529
S. S. Krishnan, P. Shyam Sunder, V. Venkatesh and N. Balasubramanian

Inverse Reliability Analysis for Possibility Distribution of Design Variables 543
A. S. Balu and B. N. Rao

Analyzing Conflicts Between Product Assembly and Disassembly for Achieving Sustainability 557
S. Harivardhini and Amaresh Chakrabarti

Conceptual Platform to View Environmental Performance of Product and Its Usage in Co-Design 569
Srinivas Kota, Daniel Brissaud and Peggy Zwolinski

Design of Product Service Systems at the Base of The Pyramid 581
Santosh Jagtap and Andreas Larsson

Re-Assignment of E-Waste Exploring New Livelihood from Waste Management 593
P. Vivek Anand, Jayanta Chatterjee and Satyaki Roy

Conflicts in the Idea of 'Assisted Self-Help' in Housing for the Indian Rural Poor 605
Ameya Athavankar, Sharmishtha Banerjee, B. K. Chakravarthy and Uday Athavankar

A Method to Design a Value Chain from Scratch 617
Romain Farel and Bernard Yannou

Part VI Design Collaboration and Communication

Developing a Multi-Agent Model to Study the Social Formation of Design Practice . . . 631
Vishal Singh and John S. Gero

Improving Common Model Understanding Within Collaborative Engineering Design Research Projects . . . 643
Andreas Kohn, Julia Reif, Thomas Wolfenstetter, Konstantin Kernschmidt, Suparna Goswami, Helmut Krcmar, Felix Brodbeck, Birgit Vogel-Heuser, Udo Lindemann and Maik Maurer

Issues in Sketch Based Collaborative Conceptual Design . . . 655
Prasad S. Onkar and Dibakar Sen

Strategies for Mutual Learning Between Academia and Industry . . . 667
Margareta Norell Bergendahl and Sofia Ritzén

Participatory Design for Surgical Innovation in the Developing World . . . 679
Florin Gheorghe and H. F. Machiel Van der Loos

Co-Web: A Tool for Collaborative Web Searching for Pre-Teens and Teens . . . 691
Arnab Chakravarty and Samiksha Kothari

Part VII Design Management, Knowledge Management and Product Life Cycle Management

Modeling and Analyzing Systems in Application . . . 707
Maik Maurer and Sebastian Maisenbacher

A Categorization of Innovation Funnels of Companies as a Way to Better Make Conscious Agility and Permeability of Innovation Processes . . . 721
Gwenola Bertoluci, Bernard Yannou, Danielle Attias and Emilie Vallet

A Methodology for Assessing Leanness in NPD Process . . . 735
B. A. Patil, M. S. Kulkarni and P. V. M. Rao

PREMAP: Exploring the Design and Materials Space for Gears . . . 745
Nagesh Kulkarni, Pramod R. Zagade, B. P. Gautham, Jitesh H. Panchal, Janet K. Allen and Farrokh Mistree

PREMAP: Exploring the Design Space for Continuous Casting of Steel 759
Prabhash Kumar, Sharad Goyal, Amarendra K. Singh, Janet K. Allen, Jitesh H. Panchal and Farrokh Mistree

Requirements for Computer-Aided Product-Service Systems Modeling and Simulation 773
Gokula Vasantha, Romana Hussain, Rajkumar Roy and Jonathan Corney

Designers' Perception on Information Processes 785
Gokula Annamalai Vasantha and Amaresh Chakrabarti

Assessing the Performance of Product Development Processes in a Multi-Project Environment in SME 797
Katharina G. M. Kirner and Udo Lindemann

Information in Lean Product Development: Assessment of Value and Waste 809
Katharina G. M. Kirner, Ghadir I. Siyam, Udo Lindemann, David C. Wynn and P. John Clarkson

A Method to Understand and Improve Your Engineering Processes Using Value Stream Mapping 821
Mikael Ström, Göran Gustafsson, Ingrid Fritzell and Gustav Göransson

Lifecycle Challenges in Long Life and Regulated Industry Products 833
S. A. Srinivasa Moorthy

Idea Management: The Importance of Ideas to Design Business Success 845
Camille Chinneck and Simon Bolton

The Role of Experimental Design Approach in Decision Gates During New Product Development 859
Gajanan P. Kulkarni, Mary Mathew and S. Saleem Ahmed

Design Professionals Involved in Design Management: Roles and Interactions in Different Scenarios: A Systematic Review 873
Cláudia Souza Libânio and Fernando Gonçalves Amaral

Design Professional Activity Analysis in Design Management: A Case Study in the Brazilian Metallurgical Market 885
Cláudia de Souza Libânio, Giana Carli Lorenzini, Camila Rucks and Fernando Gonçalves Amaral

Analysis of Management and Employee Involvement During the Introduction of Lean Development 897
Katharina Helten and Udo Lindemann

ICT for Design and Manufacturing: A Strategic Vision for Technology Maturity Assessment 913
Mourad Messaadia, Hadrien Szigeti, Magali Bosch-Mauchand, Matthieu Bricogne, Benoît Eynard and Anirban Majumdar

Part VIII Enabling Technologies and Tools (Computer Aided Conceptual Design, Virtual Reality, Haptics, etc.)

Approaches in Conceptual Shape Generation: Clay and CAD Modeling Compared 927
Tjamme Wiegers and Joris S. M. Vergeest

Optimization of the Force Feedback of a Dishwasher Door Putting the Human in the Design Loop 939
Guilherme Phillips Furtado, Francesco Ferrise, Serena Graziosi and Monica Bordegoni

Cellular Building Envelopes 951
Yasha Jacob Grobman

Development and Characterization of Foam Filled Tubular Sections for Automotive Applications 965
Raghu V. Prakash and K. Ram Babu

The Current State of Open Source Hardware: The Need for an Open Source Development Platform 977
André Hansen and Thomas J. Howard

Part IX Applications in Practice (Automotive, Aerospace, Biomedical-Devices, MEMS, etc.)

Drowsiness Detection System for Pilots 991
Gurpreet Singh and M. Manivannan

Discussion About Goal Oriented Requirement Elicitation Process into V Model 1005
Göknur Sirin, Bernard Yannou, Eric Coatanéa and Eric Landel

Prediction of Shock Load due to Stopper Hitting During Steering in an Articulated Earth Moving Equipment 1015
A. Gomathinayagam, B. Raghuvarman, S. Babu and K. Mohamed Rasik Habeeb

A Simple Portable Cable Way for Agricultural Resource Collection 1023
Shankar Krishnapillai and T. N. Sivasubramanian

Bio Inspired Motion Dynamics: Designing Efficient Mission Adaptive Aero Structures 1031
Tony Thomas

External Barriers to User-Centred Development of Bespoke Medical Devices in the UK 1039
Ariana Mihoc and Andrew Walters

Autonomous Movement of Kinetic Cladding Components in Building Facades 1051
Yasha Jacob Grobman and Tatyana Pankratov Yekutiel

Design, Development and Analysis of Press Tool for Hook Hood Lock Auxiliary Catch 1063
Chithajalu Kiran Sagar, B. W. Shivraj and H. N. Narasimha Murthy

Design of a Support Structure: Mechanism for Automated Tracking of 1 kWe Solar PV Power System 1077
Pravimal Abhishek, A. S. Sekhar and K. S. Reddy

Automated Brain Monitoring Using GSM Module 1089
M. K. Madhan Kumar

Part X Design Training and Education

Mapping Design Curriculum in Schools of Design and Schools of Engineering: Where do the Twains Meet? 1105
Peer M. Sathikh

A National Academic-Industrial Research Program with an Integrated Graduate Research School 1117
Göran Gustafsson and Lars Frenning

Future Proof: A New Educational Model to Last? 1129
Mark O'Brien

Talking Architecture: Language and Its Roles in the Architectural Design Process 1139
Yonni Avidan and Gabriela Goldschmidt

Cross-Disciplinary Approaches: Indications of a Student Design Project 1151
Helena Hashemi Farzaneh, Maria Katharina Kaiser, Torsten Metzler and Udo Lindemann

Reflecting on the Future of Design Education in 21st Century India: Towards a Paradigm Shift in Design Foundation 1165
Indrani de Parker

Design of Next Generation Products by Novice Designers Using Function Based Design Interpretation 1177
Sangarappillai Sivaloganathan, Aisha Abdulrahman, Shaikha Al Dousari, Abeer Al Shamsi and Aysha Al Ameri

Changing Landscapes in Interactive Media Design Education 1189
Umut Burcu Tasa and Simge Esin Orhun

System Design for Community Healthcare Workers Using ICT 1201
Vishwajit Mishra and Pradeep Yammiyavar

Developing Young Thinkers: An Exploratory Experimental Study Aimed to Investigate Design Thinking and Performance in Children 1215
Anisha Malhotra and Ravi Poovaiah

Part XI Posters

Learning from Nature for Global Product Development 1231
Axel Thallemer and Martin Danzer

Design2go. How, Yes, No? 1243
Nikola Vukašinović and Jože Duhovnik

Integrating the Kansei Engineering into the Design Golden Loop Development Process . . . 1253
Vanja Čok, Metoda DodiČ Fikfak and Jože Duhovnik

Design and Development: The Made in BRIC Challenge . . . 1265
Luciana Pereira

Stylistic Analysis of Space in Indian Folk Painting . . . 1277
Shatarupa Thakurta Roy and Amarendra Kumar Das

Classifying Shop Signs: Open Card Sorting of Bengaluru Shop Signs (India) . . . 1287
Nanki Nath and Ravi Poovaiah

PREMΛP: A Platform for the Realization of Engineered Materials and Products . . . 1301
B. P. Gautham, Amarendra K. Singh, Smita S. Ghaisas, Sreedhar S. Reddy and Farrokh Mistree

PREMΛP: Knowledge Driven Design of Materials and Engineering Process . . . 1315
Manoj Bhat, Sapan Shah, Prasenjit Das, Prabash Kumar, Nagesh Kulkarni, Smita S. Ghaisas and Sreedhar S. Reddy

Bridging the Gap: From Open Innovation to an Open Product-Life-Cycle by Using Open-X Methodologies . . . 1331
Matthias R. Gürtler, Andreas Kain and Udo Lindemann

Researching Creativity Within Design Students at University of Botswana . . . 1345
Chinandu Mwendapole and Zoran Markovic

Role of Traditional Wisdom in Design Education for Global Product Development . . . 1357
Ar Geetanjali S. Patil and Ar Suruchi A. Ranadive

Color Consideration for Waiting Areas in Hospitals . . . 1369
Parisa Zraati

Hybrid ANP: QFD—ZOGP Approach for Styling Aspects Determination of an Automotive Component . . . 1381
K. Jayakrishna, S. Vinodh and D. Senthil Kumar

Kalpana: A Dome Based Learning Installation for Indian Schools 1391
Ishneet Grover

Design and Development of Hypothermia Prevention Jacket for Military Purpose 1403
S. Mohamed Yacin, Sanchit Chirania and Yashwanth Nandakumar

Decoding Design: A Study of Aesthetic Preferences 1413
Geetika Kambli

Earthenware Water Filter: A Double Edged Sustainable Design Concept for India 1421
M. Aravind Shanmuga Sundaram and Bishakh Bhattacharya

Designer's Capability to Design and its Impact on User's Capabilities 1433
Pramod Ratnakar Khadilkar and Monto Mani

Author Index 1445

Organizing Committee

Patron

Ramamurthi, Bhaskar, Director, Indian Institute of Technology Madras, Chennai, India

Chairs

Prakash, Raghu, Indian Institute of Technology Madras, Chennai, India
Chakrabarti, Amaresh, Indian Institute of Science, India

Co-Chairs

Blessing, Lucienne, University of Luxembourg, Luxembourg
Cugini, Umberto, Politecnico di Milano, Italy
Culley, Steve, University of Bath, UK
McAloone, Tim, Technical University of Denmark, Denmark
Ray, Gaur H., Indian Institute of Technology Bombay, India
Taura, Toshiharu, Kobe University, Japan

Steering Committee

Athavankar, Uday, Indian Institute of Technology Bombay, India
Gero, John, George Mason University, USA
Gurumoorthy, B., Indian Institute of Science, India
Harinarayana, Kota, National Aeronautical Laboratories, India (Chair)
Lindemann, Udo, Technical University of Munich, Germany

Advisory Committee

Arunachalam, V. S., Center for Study of Science, Technology and Policy, India
Das, Anjan, Confederation of Indian Industry, India
Dhande, Sanjay G., Indian Institute of Technology Kanpur, India
Forster, Richard, Airbus Industrie, Toulouse, France
Gnanamoorthy, R., IIIT D&M, Kancheepuram, India
Horvath, Imre, Delft University of Technology, The Netherlands
Jaura, Arun, Eaton India Engineering Center, Pune, India
Jhunjhunwala, Ashok, Indian Institute of Technology Madras, Chennai, India
Leifer, Larry, Stanford University, USA
Pathy, Jayshree, CII National Committee on Design, New Delhi, India
Mitra, Arabinda, International Division, Department of Science and Technology, India
Mohanram, P. J., Indian Machine Tool Manufacturers Association, India
Mruthyunjaya, T. S., Chairman Emeritus, CPDM, Indian Institute of Science, India
Nair, P. S., ISRO Satellite Centre, Indian Space Research Organisation, India
Pitroda, Sam, National Innovation Council, India
Saxena, Raman, USID Foundation, India
Subrahmanyam, P. S., Aeronautical Development Agency, India
Sumantran, V., Hinduja Automotive, UK
Lt. Gen. Sundaram, V. J., National Design and Research Forum, India

International Programme Committee

Albers, Albert, Karlsruhe Institute of Technology, Germany
Allen, Janet K., University of Oklahoma, USA
Anderl, Reiner, Technical University of Darmstadt, Germany
Arai, Eiji, Osaka University, Japan
Aurisicchio, Marco, Imperial College London, UK
Badke-Schaub, Petra, Delft University of Technology, The Netherlands
Bernard, Alain, Ecole Centrale, Nantes, France
Bhattacharya, Bishakh, Indian Institute of Technology Kanpur, India
Blanco, Eric, Institut Polytechnique de Grenoble, France
Bohemia, Erik, Northumbria University, UK
Boks, Casper, Norwegian University of Science and Technology, Norway
Bolton, Simon, Cranfield University, UK
Bonnardel, Nathalie, University of Provence, France
Bordegoni, Monica, Politecnico di Milano, Italy
Borg, Jonathan C., University of Malta, Malta
Braha, Dan, University of Massachusetts, USA
Brazier, Frances, Delft University of Technology, The Netherlands
Brissaud, Daniel, Institut Polytechnique de Grenoble, France
Bruder, Ralph, TU Darmstadt, Germany
Burvill, Colin, University of Melbourne, Australia

Keinonen, Turkka, University of Art and Design Helsinki, Finland
Kim, Jongdeok, Hongik University, Korea
Kota, Srinivas, Institut Polytechnique de Grenoble, France
Krishnan, S. S., Center for Study of Science, Technology and Policy (CSTEP), India
Kumar, Kris L., University of Botswana, Botswana
Larsson, Tobias C., Blekinge Institute of Technology, Sweden
Lee, Soon-Jong, Seoul National University, Korea
Leifer, Larry, Stanford University, USA
Lewis, Kemper, The State University of New York, Buffalo, USA
Lin, Rung-Tai, National Taiwan University of Arts, Taiwan
Linsey, Julie, Texas A&M University, USA
Lloyd, Peter, Open University, UK
MacGregor, Steven P., University of Girona, Spain
Macia, Joaquim Lloveras, Polytechnic University of Catalunya, Spain
McMahon, Chris, University of Bristol, UK
Magee, Christopher, Massachusetts Institute of Technology, USA
Malmqvist, Johan, Chalmers University of Technology, Sweden
Mani, Monto, Indian Institute of Science, India
Manivannan, M., Indian Institute of Technology Madras, India
Marjanovic, Dorian, University of Zagreb, Croatia
Matsuoka, Yoshiyuki, Keio University, Japan
Matthew, Mary, Indian Institute of Science, India
Mckay, Alison, University of Leeds, UK
Meerkamm, Harald, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
Ming, Henry X. G., Shanghai Jiao Tong University, China
Mistree, Farrokh, University of Oklahoma, USA
Montagna, Francesca, Politecnico di Torino, Italy
Mulet, Elena, Universitat Jaume I, Spain
Mullineux, Glen, University of Bath, UK
Murakami, Tamotsu, University of Tokyo, Japan
Nagai, Yukari, Japan Advanced Institute of Science and Technology, Japan
Papalambros, Panos, University of Michigan, USA
Petrie, Helen, University of York, UK
Poovaiah, Ravi, Indian Institute of Technology Bombay, India
Popovic, Vesna, Queensland University of Technology, Australia
Prasad, Sathya M., Ashok Leyland, India
Radhakrishnan, P., PSG Institute of Advanced Studies, India
Rahimifard, Shahin, Loughborough University, UK
Rao, N. V. C., Indian Institute of Science, India
Rao, P. V. M., Indian Institute of Technology Delhi, India
Ravi, B., Indian Institute of Technology Bombay, India
Riitahuhta, Asko, Tampere University of Technology, Finland
Rodgers, P., Northumbria University, UK

Rohmer, Serge, Universite de Technologiede Troyes, France
Roozenburg, Norbert, Delft University of Technology, The Netherlands
Rosen, David W., Georgia Institute of Technology, USA
Roy, Rajkumar, Cranfield University, UK
Roy, Satyaki, Indian Institute of Technology Kanpur, India
Saha, Subir Kumar, Indian Institute of Technology Delhi, India
Salustri, Filippo A., Ryerson University Canada
Sarkar, Prabir, Indian Institute of Technology Ropar, India
Sato, Keichi, Illinois Institute of Technology, USA
Seliger, Guenther, Technical University of Berlin, Germany
Sen, Dibakar, Indian Institute of Science, India
Shah, Jami, Arizona State University, USA
Shimomura, Yoshiki, Tokyo Metropolitan University, Japan
Shu, Li, University of Toronto, Canada
Sikdar, Subhas, Environmental Protection Agency, USA
Singh, Mandeep, School of Planning and Architecture New Delhi, India
Singh, Vishal, Aalto University, Finland
Sotamaa, Yrjo, University of Art and Design Helsinki, Finland
Srinivasan, V., Technical University of Munich, Germany
Srinivasan, Vijay, National Institute of Standards and Technology, USA
Sriram, Ram, National Institute of Standards and Technology, USA
Storga, Mario, University of Zagreb, Croatia
Subrahmanian, Eswaran, Carnegie Mellon University, USA
Sudarsan, Rachuri, National Institute of Standards and Technology, USA
Sudhakar, K., Indian Institute of Technology Bombay, India
Thallemer, Axel, Universitaetfürindustrielle und kuenstlerische Gestaltung, Austria
Thompson, Mary Kathryn, Technical University of Denmark, Denmark
Tiwari, Ashutosh, Cranfield University, UK
Tomiyama, Tetsuo, Delft University of Technology, The Netherlands
Torlind, Peter, Lulea University of Technology, Sweden
Tripathy, Anshuman, Indian Institute of Management Bangalore, India
Tseng, Mitchell, The Hong Kong University of Science & Technology, China
Umeda, Yasushi, Osaka University, Japan
Vancza, Jozsef, MTA SZTAKI, Hungary
Vaneker, Tom, Univeristy of Twente, The Netherlands
Vasa, Nilesh, Indian Institute of Technology Madras, India
Verma, Alok K., Old Dominion University, USA
Vermass, Pieter, Delft University of Technology, The Netherlands
Vidal, Rosario, UniversitatJaume I, Spain
Vidwans, Vinod, FLAME School of Communication, India
Vijaykumar, A. V. Gokula, University of Strathclyde, UK
Voort, M. C. van der, University of Twente, The Netherlands
Wiegers, Tjamme, Delft University of Technology, The Netherlands
Yammiyavar, Pradeep, Indian Institute of Technology Guwahati, India
Yannou, Bernard, Ecole Centrale Paris, France

Zavbi, Roman, University of Ljubljana, Slovenia
Zeiler, Wim, Technical University Eindhoven, The Netherlands
Zwolinski, Peggy, Institut Polytechnique de Grenoble, France

Local Organising Committee

Swaminathan, Narasimhan, Indian Institute of Technology Madras, India
Siva Prasad, N., Indian Institute of Technology Madras, India
Krishnapillai, Shankar, Indian Institute of Technology Madras, India
Seshadri Sekhar, A., Indian Institute of Technology Madras, India
Balasubramaniam, Krishnan, Indian Institute of Technology Madras, India
Varghese, Susy, Indian Institute of Technology Madras, India
Ganesh, L. S., Indian Institute of Technology Madras, India
Ramkumar, Indian Institute of Technology Madras, India
Srinivasan, Sujatha, Indian Institute of Technology Madras, India
Sivaprakasam, Mohan Sankar, Indian Institute of Technology Madras, India

Student Organising Committee

Das, Swostik, Indian Institute of Technology Madras, India
Gullapalli, Suraj, Indian Institute of Technology Madras, India
Anand, Sahaj Parikh, Indian Institute of Technology Madras, India
Dhinakaran, S., Indian Institute of Technology Madras, India
Arun Kumar, S., Indian Institute of Technology Madras, India
Sarkar, Biplab, Indian Institute of Science, India
Devadula, Suman, Indian Institute of Science, India
Kumari, M. C., Indian Institute of Science, India
Madhusudanan, N., Indian Institute of Science, India
Ranjan, B. S. C., Indian Institute of Science, India
Uchil, Praveen T., Indian Institute of Science, India

Organised By

Indian Institute of Technology Madras, Chennai, and Indian Institute of Science, Bangalore, India

Endorsed By

The Design Society and The Design Research Society

Part I
Design Theory and Research Methodology

How I Became a Design Researcher

Gabriela Goldschmidt

Abstract No one trajectory leads to becoming a design researcher. This paper is an interim overview of one case of a designer who became a design researcher. Through concerns derived from experience as a designer and a design teacher, and learning from observations of children designing, some fundamental questions were formulated under the common theme of design cognition. Two major lines of research were undertaken over the years: first, modeling and measuring design reasoning. This is done with linkography, which is a system for the notation and analysis of design activities based on protocols. With linkography light can be shed on the structure of the design process and its quality, especially its creativity. Second, visual thinking in design and primarily the generation of sketches and the use of visual stimuli are investigated. Experimental work confirms the importance of visual thinking in designing.

Keywords Cognition · Creativity · Linkography · Sketching · Visual thinking

1 Introduction

When I was an architecture student, in three different schools, I was absolutely certain that my future is in architectural design. I saw practice as the only career I would ever want to follow. Once out of school I first worked in established firms, later in my own small independent practice. Little by little I realized something was missing. Practice was exciting but also very tiring and frustrating, and work

G. Goldschmidt (✉)
Technion-Israel Institute of Technology, Haifa 32000, Israel
e-mail: gabig@technion.ac.il

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_1,

posed too many practical difficulties and too few intellectual challenges. I started teaching architectural design part time and found it rewarding, in that students dealt with hard core issues that forced me to struggle with those same dilemmas myself. My frustrations as a designer and observations of students' progress and difficulties started raising fundamental questions: how do we actually think when we design? How do we learn to design? What does it mean to be a 'good' designer and why isn't every designer's performance excellent? How and what does experience contribute? What is visual about our thinking in design, and why is that important, if it is? Questions of this nature occupied my mind but I was not sure how to go about answering them until I decided one day, quite intuitively, to look at children designing. Much to my surprise I discovered that children could design, and some of what they do does not seem to differ greatly from what my students or I do when we design. This was when I started talking to psychologists and soon I made two discoveries: First, I learned that cognitive psychology deals with some of the questions I was interested in, though it does not focus on designing. Second, I found there were a handful of others in the design world who were interested in the same questions and who had already started researching them. It was then that I turned into a design researcher; first in parallel to my design activities and later in their stead, although I continued to teach design for a long time thereafter. Certain insights regarding design thinking and its research have matured over the years and this paper presents them and traces the trajectory that led to them—a personal journey toward design research, which has become more than a career: it is a love and a passion.

2 Experiences as a Designer

Ever since I was a student design was not something that came easily to me. Every new project, at school and later in practice, required a fairly long and sometimes tortuous search until a good enough idea crystalized. Even though the final result was usually satisfactory, I envied those of my peers who were visibly more relaxed and easy-going about developing their design ideas. I wanted to be like them but did not know what would make that possible. Things got better with time and I concluded that having accumulated experience helped. But I still did not know what about that experience was responsible for a more direct path to a good solution. Have I become a better thinker? How so? Or was it just a matter of self-confidence? And then there were design reviews. How was it that for the most part reviewers agreed on what constitutes a good project and what was a less successful project, even when reasons were not elaborated?

When I started working with my own clients I had to convey design ideas to them. Things that now seemed obvious to me turned out to be far from obvious to them and sometimes I failed to gain their understanding of why something was important. Why couldn't I reach out to them? How could one ensure seeing design issues eye to eye with someone else, whether a professional or a layperson?

Once again this boiled down to design thinking, to what we know, to the nature of expertise and the contribution of experience to it. It also posed questions about creativity, communication, and what I was much later able to label as the nature of one's *design space*, and shared *mental models*. But these terms—and their significance—were not part of my terminology and my agenda until many years later. In the meantime I just continued to struggle and tried my best to connect with clients; some would call it: educating the client.

3 Experiences as a Design Teacher

When I started teaching architectural design studios I was a practitioner with a few years of experience in reputable international architectural firms. I was enthusiastic and wanted all of my students to produce wonderful work. As it were, some did but others did not do as well. I would spend hours on end with weaker students with the hope of assisting them; I tried all strategies, such as citing examples and precedents, modeling and discussing alternatives with them, eliciting thumb rules and conventions, and more. Sometimes it helped, sometimes it did not. I invented exercises that were geared at seeing the task from a different perspective: starting the design from sections as opposed to plans, starting from a whole to be divided into components, as opposed to starting with components to be assembled into a whole (or vice versa); continuing a project started by somebody else; developing a story that the design would illustrate; and more. Again, this was helpful, but not always and not as much as I had hoped it would be.

I wanted to know why some students 'get it' and others do not, although their starting point was apparently the same. Why some students needed only a subtle hint and could then leap forward on their own, whereas others were unable to develop ideas even when they were shown explicit solutions. Why some students were able to use feedback to make incremental progress from week to week and others were unable to incorporate feedback and started anew after every feedback session ('crit'). These were burning questions and they arose with students of different standing, from complete novices, i.e. first year students, to nearly professionals, that is fifth year students. I started realizing that what had weighed on me as a practitioner and what bothered me as a teacher were questions of the same kind, but I still did not know how to begin to explore them.

4 Learning from Children's Designs

One day I played with a young child who had spent the morning in a swimming pool, or rather a toddler's pool, as she did not yet know how to swim. This was an extraordinary experience which she enjoyed a lot, as she came from a small new settlement were there was no swimming pool. That afternoon she played with building blocks and a few other items and announced she was going to build a 'model' of her settlement. The settlement had a ring-road around which there were two rows of houses; the back row was served by pedestrian access paths, leading from the road to each second-row house. These paths were favorite play areas for young children. Other than single-family houses and a small number of community facilities, the settlement had semi-underground bomb-shelters scattered among the houses; their sloped roofs touched the ground and children used them as slides.

The child's model consisted of houses and a row of wooden blocks—"the path", leading to a circle of wooden blocks, "a swimming pool". Nearby there were a few bigger wooden blocks designated as "shelters". A few small plastic human figurines were scattered about, "children". I realized that the child was using her knowledge of the familiar home environment—houses, paths, shelters, to which she added a desired feature—a swimming pool, a newly acquired concept that she considered appropriate and desirable as an addition to the existing environment. It dawned on me that what this child was doing was not essentially different from what we designers do. Don't we introduce new features to old and existing ones to produce new syntheses?

With this insight in mind I conducted a workshop with older children (aged 9–10), who were given a big crate full of materials and were reminded of a children's story they all knew and loved, Pippi Longstocking. In the story Pippi and two friends run away from home, with a horse and a monkey, and have various adventures as runaways. Since they have no home now, the children's task in the workshop was to design a house for them, which they did by building models from the materials in our magic crate (cardboard sheets and rolls, wooden blocks and round pieces, wire, paper, and so on, plus glue, tape, scissors etc.). The workshop took place at school and the children were so enthusiastic that the principal decided to cancel the remaining classes for the day to allow them to complete their projects. They worked alone or in groups of two or three, and got adult help only with technicalities like cutting a piece to their specifications with a sharp cutting knife. At the end of the day they were interviewed about their projects wherein they were able to explain their acts and their choices [1]. Amazingly enough all children completed the task. It was again apparent that they used knowledge about the concept of 'house', which they were familiar with of course, and synthesised it with knowledge about Pippi's personality that was available to them because they knew the story. They were able to translate personality traits into design features (for example: Pippi is very strong and playful so she can enter the house by jumping from a seesaw and grabbing a rope hanging from the window). The main lesson from the workshop was that different children construed the task differently; the main focus was either on 'house' or on 'Pippi', leading to different design priorities.

The same workshop was repeated with first and fourth year architecture students, with far less interesting results. The first year students were held up by the fact that they were not given a 'program' and were not told at which scale they should work. Some fourth year students thought this was not a serious enough exercise. In addition to confirming the ability to use knowledge that is not design-specific, we learned about design education and pedagogy, on which we shall not dwell here.

5 Questions that Beg Answers

Having had the experiences described above in both the professional arena and the educational studio, it became clear that there are some persistent mega-questions regarding the process of designing that were wide open and invited exploration. Some of them were outlined above, and in addition the contribution of visual thinking to design, at least in some fields (e.g., architecture, industrial design, graphic design, mechanical engineering), became intriguing. Rudolf Arnheim's seminal *Visual thinking* [2] was a major influence that in addition to shedding light on visual thinking also served as an introduction to Gestalt psychology. With hindsight, the main questions I was able to formulate ran approximately as follows:

- How are different knowledge items synthesised into a design solution?
- How do we reason on the fly about issues, knowledge and acts related to a design entity that is in the process of being generated?
- How do we construe ill-defined design problems, and turn them into solvable problems? Why are there individual differences in this process?
- How are design skills acquired? What is teachable and learnable about such skills?
- How can we characterize creative designing? Can we measure creativity?
- What is the role of visuals in designing? This question may be divided into two:
- On the one hand, there is the 'consumption' of external visuals which act as inspirational agents. What mechanisms are involved in being 'inspired'?
- On the other hand there are self-generated sketches. Why do designers sketch?

When the accumulated questions gained enough coherence it became obvious that they are all of a kind; in fact they can be grouped under the heading of design cognition. This was a new concept that required some clarification.

6 Design Cognition

I had already written a few papers on the process of designing [3–5] drawing primarily on my own experiences when I felt ready to become a 'real' researcher. I realized that to succeed, I needed to belong to a research community, but which community? I was not yet aware of other designers who were interested in questions similar to the ones that intrigued me, but I found that psychologists were in fact quite interested in discussing the questions I asked. First, through the children's design study, these were developmental psychologists; through them I met other psychologists who were more interested in certain cognitive issues, in particular creativity. I started to educate myself in the field of cognitive psychology and in parallel I came across writings by designers that echoed my interests; I was delighted to find out that indeed a community of design thinking researchers was coming into being and within this community there were some prominent design thinking students like Nigel Cross, Bryan Lawson, Omer Akin, John Gero and others, whose pioneering work was of great value e.g., [6–9]. Schön [10], in essence not really a design researcher, was of great influence in that community. I eagerly joined those forerunners and before soon many more young researchers joined in: a community of design thinking researchers, interested mostly in design cognition, became an established fact.

I put together a course for graduate students called Cognitive Aspects of Architectural Design, which was taught for many years during which it continually changed and grew. This led to students knocking on the door, wanting to work on theses and dissertations in the area of design thinking. It was time to learn how to conduct empirical research and exposure to cognitive psychology paved the way to experimental work. Protocol analysis became the major methodology for our work, and it continues to serve us well to this very day. Two main and complimentary research directions emerged: modeling and measuring design reasoning, and visual thinking in design.

7 Modeling and Measuring Design Reasoning

When I first discovered protocol analysis I tried to apply it as prescribed [11, 12] to protocols we have generated. I failed to find coding schemes of categories that could reveal anything of value or interest and thought that there must be another way to use protocols of on-line design session recordings to derive information that would lead to new insights regarding the design process. My interest in cognition led to the wish to find out not only what designers were thinking about, which coding protocols aptly reveals, but also how they think, that is, how do they form ideas and concepts. This prompted the notion that what we should be looking at is links among units of verbalization, into which protocols are parsed. These units, also called segments, can be anything from a few words to long stretches of verbalization. If the thinking scale one is interested in is cognitive, the units should perforce be rather short, in the order of approximately one sentence. I decided to borrow the term *move* from chess, and here it means a step, an act, an operation, that transforms the design situation somewhat relative to the state in which it was prior to that move. The protocol is now transformed to a numbered, sequential list of design moves. These moves represent the universe in which the designer acts during the vignette that is captured in the protocol.

Design theories tell us that the crucial outcome of the preliminary design process is synthesis. A synthesis is manifest in a partial or complete design proposal that reflects the best possible balance among considered options, given requirements and goals, analysis of the givens and the situation (constraints, opportunities), the designers' knowledge and experience, and their values and personal propensities. A synthesis cannot be arrived at 'in toto' in one go: a synthesis, that is, a candidate solution, is constructed step by step in a search process that is typical of ill-structured/ill-defined problem solving, of which design is a paramount example. At the cognitive scale we equate the search steps with design moves. To arrive at a synthesis design moves must be integrated in a network such that the ensuing solution would be sure to take into account all relevant aspects of the situation and the problem. My suggestion was that this process is captured in a network of links among design moves, based on contents and arbitrated by common sense, using disciplinary knowledge. Once this understanding was reached, the task became clear: we need a system of notation and analysis of links among design moves.

Such a system was developed in the framework of *linkography*, which consists of the theory behind the relevance of links among design moves and the technical method of notating and analyzing such links e.g., [13, 14]. The linkograph is where a link is notated, if one exists, between every pair of moves in the sequence, if one exists. For n moves, the number of possible links is $n*(n-1)/2$. For each pair of moves, consecutive or far apart, we ask: is there a link between these two moves? The answer is yes, or no; if positive—a link is notated in the linkograph. There are two types of links: backlinks and forelinks.

Backlinks: Starting with move 2, we ask about a possible link with each of the preceding moves; therefore such links are designated as backlinks.

Forelinks: If move 2 links back to move 1, then we may say, with hindsight, that move 1 links forward to move 2. This is a virtual link of course as at the time move 1 is generated we cannot know whether or not it will link to move 2 (and subsequent moves). However, we are interested in forelinks because they are indicative of steps that future design activities refer back to.

Critical Moves: Not all design moves are of the same magnitude; some are more significant than others in terms of developing the final outcome. We call the most important moves critical moves (CM) and distinguish between CMs due to a large number of backlinks (<CM) and CMs due to a large number of forelinks (CM>). For each investigation we determine a threshold that indicates the minimum number of links necessary to qualify a move as critical. If, for example, the number is 5 links, the threshold of 5 is indicated (CM^5). Figure 1 depicts a linkograph of a short design vignette (20 moves).

We carried out a large number of linkographic studies and other researchers joined us in using linkography, primarily in order to investigate the structure of design reasoning e.g., [15–18]. The linkograph shows clearly where moves are concentrated and where they are sparse and far between. In as far as a linkograph displays fairly autonomous chunks of interlinked moves, with few links to neighboring chunks, we may refer to such chunks as micro-phases and the initial and last moves of a chunk are of particular interest, especially if they are critical moves (as they often are). In a way, looking at critical moves—their positioning in the sequence of moves and their contents—gives us a very good overview of the

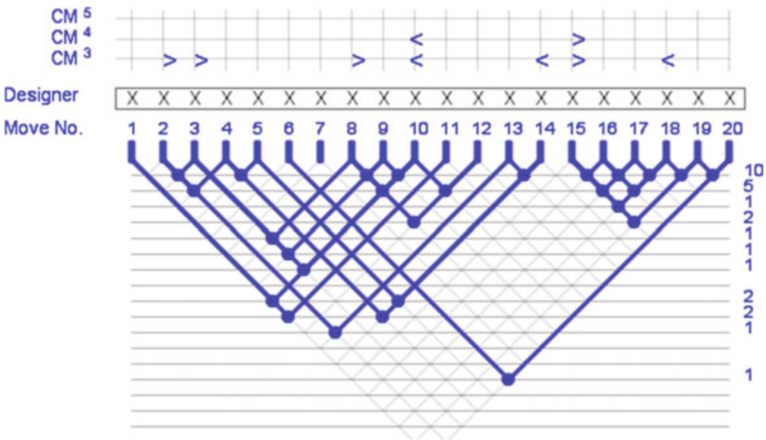


Fig. 1 Linkograph. <CMs and CMs> are indicated at thresholds of 3 and 4 links

design process is question. I propose that moves with more forelinks are roughly reflective of divergent thinking: new ideas come up in them, which further moves refer back to. Similarly, moves with primarily backlinks represent convergent thinking: they test, evaluate, confirm or question preceding moves in which a new proposal had been put forth. If we accept this notion, then the proportion and interplay among critical moves tell us something about the creativity of the process under scrutiny. Needless to say, we are not talking here about creativity of the kind that changes the world; instead, we detect acts of small-scale, quotidian creativity (that Boden [19] calls P-Creativity), which are typically marked by shifts between divergent and convergent thinking e.g., [20–22].

Linkographic studies have been able to establish a correlation between independent creativity assessments and the proportion of critical moves, especially CMs>, in a variety of settings. They also taught us a lot about problem framing and problem solving reasoning which is noticeable in the structure of the linkograph. This served as a basis for comparisons between novices and advanced students, which taught us something about learning and the role of experience. Other linkographic studies looked at communication patterns in the design studio, topic shifts in design, the dynamics of team work, and much more. Linkography was also used to look at phenomena at non-cognitive scales such as prolonged design periods and other problem-solving processes.

8 Visual Thinking

Architects and other designers are in the habit of making rough, free-hand sketches. This habit continues since industrially produced paper became available in Europe in the last quarter of the 15th century, and it persists today despite the digital revolution. The sketches we are talking about are not after-the-fact renderings but quick freehand drawings made on the fly during the search in the preliminary conceptual phase of the design process. Sketches serve a number of purposes [23]: prescription, communication, and thinking. In the framework of design cognition it is the latter we are interested in. In the hands of fluent sketchers, sketching has many cognitive advantages: it off-loads memory; is rapid and therefore requires minimal cognitive resources, stop rules are flexible, it is only minimally rule-bound, it is reversible and transformable at any stage, it is tolerant of incompletion, inaccuracy and lack of scale, it provides stimuli and cues, and finally, it supports feedback loops between external and internal representation (visual imagery).

Feedback loops are of particular interest, as they establish the 'cooperative' dynamics between imagery which we know is a valuable cognitive capacity in creative work, and what is being laid down on paper. Thus sketching does not merely record mental activity, it is part and parcel of it [24]. In fact designers discover things in their own sketches [15], sometimes much more so than anticipated. Since the early 1990s a host of studies have shown that sketching is a high impact design strategy.

Our sketching studies led to a wider interest in the mode in which designers exploit visual stimuli while developing design solutions. One of the conclusions was that images in stimuli may serve as bases for analogy, unconsciously or consciously, especially when one is explicitly instructed to use analogical thinking [25]. Like visual imagery, analogy is a helpful cognitive strategy in creative endeavors, and in both cases sketching aids the relevant cognitive operations. Of course, stimuli may also cause designers to fixate on them, thus barring them from developing original solutions. This is more likely to happen when the stimulus is an actual example of a solution to the problem in hand. Generally we were able to show that visual stimuli, with or without suggestions of analogies, are beneficial in the design process.

I propose that visual thinking is so important in designing because when the final outcome is a physical entity that needs to be considered in terms of form and function, a good synthesis can be achieved only if in the process of reasoning about candidate partial and whole solutions the designer shifts back and forth between embodiment and rationale, such that all design aspects are covered in a final well-integrated design outcome [26]. Visual thinking helps represent and assess embodiments, and therefore it is invaluable, whether sketches are hand-drawn or simulations are created digitally.

9 What Next?

Two important hallmarks of design cognition have been established in our studies: the power of interlinking moves, and the need to shift between embodiment and rationale. These traits of design cognition may not be unique to designing, but they are particularly important in this activity that deals with form and function, and that must bring about a well synthesised artifact. Important as these findings are, they are not enough; there is more to design thinking, and we must discover additional fundamental characteristics of such thinking if we are to build tools to effectively impact them. The design research community is invited to partake in this valuable, exciting and rewarding project.

References

1. Goldschmidt G (1994) Development in architectural designing. In: Franklin MB, Kaplan B (eds) Development and the arts: critical aspects. NJ Lawrence Erlbaum Associates, Hillsdale, pp 79–112
2. Arnheim R (1983) Design thinking. University of California Press, Berkeley
3. Goldschmidt G (1983) Doing design, making architecture. J Architect Educ 37(1):8–13
4. Goldschmidt G (1988) Interpretation: its role in architectural designing. Des Stud 9(4):235–245
5. Goldschmidt G (1989) Problem representation versus domain of solution in architectural design teaching. J Architect Plann Res 6(3):204–215
6. Cross N (1984) Developments in design methodology. Wiley, Chichester
7. Lawson B (1980/2005) How designers think: the design process demystified. Butterworth/Architectural Press, Oxford
8. Akin Ö (1978) How do architects design. In: Latombe JC (ed) Artificial intelligence and pattern recognition in computer aided design. IFIP. North Holland Publishing, Amsterdam, pp 65–104
9. Gero JS, Maher ML (1990) Theoretical requirements for creative design by analogy. In: Fitzhorn P (ed) Proceedings of the 1st international workshop on formal methods in engineering design, manufacturing and assembly, Colorado State University, Fort Collins, pp 19–27
10. Schön DA (1983) The reflective practitioner. Basic Books, New York
11. Ericsson KA, Simon HA (1984/1993) Protocol analysis: verbal reports as data. MIT Press, Cambridge, MA
12. van Someren MW, Barnard YF, Sandberg JA (1994) The think aloud method: a practical guide to modeling cognitive processes. Academic, London
13. Goldschmidt G (1990) Linkography: assessing design productivity. In: Trappl R (ed) Proceedings of the 10th European meeting on cybernetics and systems research. World Scientific, Singapore, pp 291–298
14. Goldschmidt G (Forthcoming) Linkography: unfolding the design process. MIT Press, Cambridge, MA
15. Suwa M, Tversky B (1997) What do architects and students perceive in their design sketches? A protocol analysis. Des Stud 18(4):385–403
16. Kan JWT, Gero JS (2008) Acquiring information from linkography in protocol studies of designing. Des Stud 29(4):315–337
17. Kvan T, Gao S (2006) A comparative study of problem framing in multiple settings. In: Gero JS (ed) Design computing and cognition'06. Springer, Dordrecht, pp 245–263
18. van der Lugt R (2003) Relating the quality of the idea generation process to the quality of the resulting design ideas. In: Folkeson A, Gralén K, Norell N, Sellgren U (eds) Proceedings of 14th international conference on engineering design, Design Society, Stockholm (CD: no page numbers)
19. Boden MA (1994) What is creativity? In: Boden MA (ed) Dimensions of creativity. MIT Press, Cambridge, pp 75–117

20. Plucker JA, Renzulli JS (1999) Psychometric approaches to the study of human creativity. In: Sternberg R (ed) Handbook of creativity. Cambridge University Press, Cambridge, pp 35–61
21. Gabora L (2010) Revenge of the 'neurds': characterizing creative thought in terms of the structure and dynamics of memory. Creativity Res J 22(1):1–13
22. Dong A (2007) The enactment f design through language. Des Stud 28(1):5–21
23. Ferguson ES (1992) Engineering and the mind's eye. MIT Press, Cambridge
24. Goldschmidt G (1991) The dialectics of sketching. Creativity Res J 4(2):123–143
25. Casakin H, Goldschmidt G (1999) Expertise and the use of analogy and visual displays: implications for design education. Des Stud 20(2):153–175
26. Goldschmidt G (2012) A micro view of design reasoning: two-way shifts between embodiment and rationale. In: Carroll JM (ed) Creativity and rationale in design: enhancing human experience by design. Springer, London, pp 41–55

Why do Motifs Occur in Engineering Systems?

A. S. Shaja and K. Sudhakar

Abstract Recent years have witnessed new research interest in the study of complex systems architectures, in domains like biological systems, social networks etc. These developments have opened up possibility of investigating architectures of complex engineering systems on similar lines. Architecture of a system can be abstracted as a graph, wherein the nodes/vertices correspond to components and edges correspond to interconnections between them. Graphs representing system architecture have revealed motifs or patterns. Motifs are recurring patterns of 3-noded (or 4, 5 etc.) sub-graphs of the graph. Complex biological and social networks have shown the presence of some triad motifs far in excess (or short) of their expected values in random networks. Some of these over(under) represented motifs have explained the basic functionality of systems, e.g. in sensory transcription networks of biology overrepresented motifs are shown to perform signal processing tasks. This suggests purposeful, selective retention of these motifs in the studied biological systems. Engineering systems also display over(under) represented motifs. Unlike biological and social networks, engineering systems are designed by humans and offer opportunity for investigation based on known design rules. We show that over(under) represented motifs in engineering systems are not purposefully retained/avoided to perform functions but are a natural consequence of design by decomposition. We also show that biological and social networks also display signs of synthesis by decomposition. This opens up interesting opportunity to investigate these systems through their observed decomposition.

A. S. Shaja (✉) · K. Sudhakar
Department of Aerospace Engineering IIT Bombay, Powai, Mumbai 400076, India
e-mail: aerocomputer@gmail.com

K. Sudhakar
e-mail: sudhakar@aero.iitb.ac.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_2, © Springer India 2013

Keywords Motifs · Engineering systems · Synthesis by decomposition

1 Introduction

This section gives an introduction to the field of our research and an overview of insights proposed in this paper.

1.1 Complex Systems Architecture

Recent years have witnessed a growing interest in the study of complex systems architectures, in domains like biological systems and social networks [1]. Unifying principles have emerged [2]. Literature has commented on the hesitation of researchers in complex engineering systems, to look at their problems, in the light of emerging ideas in complex systems in general. "Engineering should be at the centre of these developments, and contribute to the development of new theory and tools" [3]; "Engineers seem a little bit indifferent as if engineering is at the edge of the science of complexity" [4].

Architecture is the fundamental structure of components of a system—the roles they play, and how they are related to each other and to their environment [5]. A layman definition of complexity refers to interconnected/interwoven components. Complexity of a system scales with the number of components, number of interactions, complexities of the components and complexities of interactions [6]. Complex engineering systems are synthesized from a large number of components coupled to each other, giving them a physical architecture. Architecture of a system (from any domain—say engineering, biology, sociology) can be abstracted as a network/graph, where the nodes/vertices correspond to components in the system and edges correspond to interconnection between them.

1.2 Literature Survey

In biology, over-represented motifs have led to interesting insights in the areas of protein–protein interaction prediction [7, 8]. For instance, in sensory transcription (protein–protein interaction) networks of biology the over-represented motif has been theoretically and experimentally shown to perform signal-processing tasks. This has led to the belief that over-represented motifs are simple building blocks of complex networks and can help understand the basic functionality of a system [7]. Importance of ideas related to motifs has recently become research interest in other domains.

Incremental ideas related to motifs have also been proposed in recent literature. Paulino et al. [9] proposed a different type of motif named 'chain of motifs' (that is, sequence of connected nodes with degree 2). They divided chains into subdivisions named cords, rings etc. depending on the type of their extremities (e.g. open or connected). The main difference between these chain motifs and the motifs by Milo et al. [7] is that the former may involve a large number of vertices and edges. They calculated the statistics of chain of motifs for few biological networks and reported the appearance of chain motifs in these networks [9].

Milo et al. [10] proposed an approach to study similarity in the structure of networks based on the Motif Significance Profile (MSP) of their graphs. These profiles are seen to be highly correlated across systems of the same family (i.e., MSPs for all systems of same type are highly correlated, e.g. Sensory transcription network of *E. coli* and Yeast of Biology family are highly correlated). Due to the distinct motif signature indicated by systems, motif significance profile signatures have also been proposed as a classifier for systems [11]. In this paper, we proceed to investigate motifs and possible reasons for its occurrence in engineering systems [12].

1.3 New Insights

Unlike biological and social networks, engineering systems are designed by humans and offer opportunity for investigation based on known design rules. We show that over(under) represented motifs in engineering systems are not purposefully retained/avoided to perform functions but are a natural consequence of design by decomposition. We also show that biological and social networks also display signs of synthesis by decomposition.

2 Theoretical Background About Motifs

"Motifs are recurring sub-graphs of interactions from which the networks are built" [7]. If a graph/network representing a system has N nodes there are NC3 3-node 'triads' in it. Some of these triads need not be connected and the rest that are connected are sub-graphs of the graph. Each 3-node sub-graph will correspond to one of 13 possible motifs (Fig. 1).

Each of the ${}^{N}C_3$ triplets, if a sub-graph, will assume the pattern of one of the 13 motifs and one can count the occurrence of each motif in a graph and define a vector, of size 13 $n = \{n_i,\ i = 1 \text{ to } 13\}$. In a network, the count for a particular motif may be high, which by itself is not considered important. It is possible that such high count for that motif is unavoidable for a network synthesized using the N nodes that preserve the degree distribution of the real network. To investigate this, randomized networks are created [7] using same N nodes, i.e., the number of nodes and their degree distribution is preserved. A large number of randomized networks (i = 1 to m) will define a vector of means, $\mu = \{\mu_i,\ i = 1 \text{ to } 13\}$ and a vector of standard deviations of motif counts, $\sigma = \{\sigma_i,\ i = 1 \text{ to } 13\}$. For the real network one can check the motif significance profile (MSP) of all the 13 motifs by a vector $Z = \{Z_i,\ i = 1 \text{ to } 13\}$

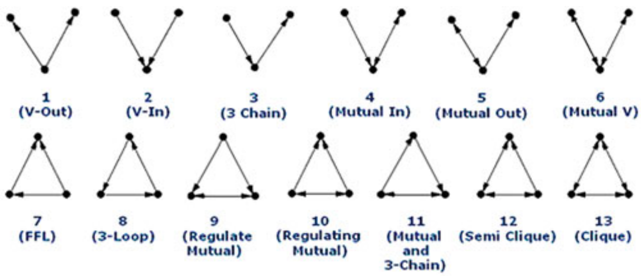


Fig. 1 All 13 patterns (motifs) for 3 node sub-graphs. The numbers are motif-ids and within brackets are nomenclature

$$[Z = (n_i - \mu_i)/\sigma_i \quad \text{for } i = 1 \text{ to } 13] \tag{1}$$

In simple words, Motif Significance Profile (MSP) is the vector (of size 13 for 3-node motifs) of the extent of over(under)-representation of all 13 motifs in a system. For a normally distributed random number, $-3 \leq Z_i \leq 3$ implies a rare occurrence (beyond $\pm 3\sigma$ limit). Any motif with its $Z_i > 2$ is considered an over-represented motif and any motif with its $Z_i < -2$ is an under-represented motif [7].

Milo et al. [10] argue that Z is influenced by the size of the network and propose normalisation of Z to make it largely independent of network size. Thus, the normalised significance profile vector, W is defined as $W = \{W_i, i = 1 \text{ to } 13\}$ where $W_i = Z_i/|Z|$.

3 Motifs in Engineering Systems

This section gives an introduction to the field of our research and an overview of insights proposed in this paper.

3.1 Details of Systems

We have gathered architecture data for more than 100 diverse engineering systems ranging from mechanical, software and electronic circuits. In this paper we consider 38 arbitrarily chosen systems from literature and study their architectures. Systems considered range from aircraft engine [13], softwares [14], electronic circuits [15, 16], robot [17], refrigerator [18], bacteria *E. coli* [19], yeast *S. cerevisiae* [19], language networks [19]. These 38 systems are of vastly different sizes (ranging from minimum 16 components to maximum 23,843 components). We extracted architecture data from these datasets by developing some tools for parsing/filtering from the raw data. Table 1 briefly identifies each of the 38 systems for the data.

Table 1 38 systems considered for study

S.no	System name	Nodes	S.no	System name	Nodes
1	Digital fractional multiplier (s208)	122	20	Traffic control system (s400)	186
2	Digital fractional multiplier (s420)	252	21	PLD (s820)	312
3	Digital fractional multiplier (s838)	512	22	Traffic control system (s382)	182
4	*E.coli*	423	23	ALU (74181)	87
5	Yeast	688	24	PLD (s832)	310
6	Apword	1,096	25	ECAT (c499)	243
7	Linux	5,420	26	ALU (c880)	443
8	Mysql	1501	27	ALU (c7552)	3,718
9	Vtk	778	28	PLD (s641)	433
10	Xmms	1,097	29	ECAT (c1908)	913
11	Traffic control system (s444)	205	30	ALU (c3540)	1,719
12	PLD (s713)	447	31	Traffic control system (s562)	217
13	ALU (c2670)	1,350	32	Aircraft Engine	54
14	ECAT (c1355)	1,355	33	Refrigerator	16
15	Forward logic chips (s9234)	5,844	34	Robot	28
16	Forward logic chips (s13207)	8,651	35	English	7,724
17	Forward logic chips (s15850)	10,383	36	French	9,424
18	Forward logic chips (s38417)	23,843	37	Japanese	3,177
19	Forward logic chips (s38584)	20,717	38	Spanish	12,642

In electronic circuits, nodes represent component gates and edges represent the flow of digital signals between gates. In case of software systems, nodes represent classes and edges represent directed collaboration relationships between classes. In mechanical systems, nodes represent physical components and edges represent exchange of energy, material or signal between components. In case of biological systems, nodes represent genes and edges represent direct transcription interactions. In case of languages, each word in a passage is a node and each edge represents word adjacency in the passage.

3.2 Motif Experiment and Results

We create 1,000 random networks for each considered system using same N nodes, i.e. number of nodes and their degree distribution is preserved (we have proposed a method named 'switching method' for doing this. The details of this method along with its comparison with existing method from literature are archived in our website [20]). We estimate the μ and σ of motifs of these random networks based on 1,000 random networks. For 10 arbitrarily chosen systems we create 10,000 and then 1,00,000 random networks to confirm that μ and σ of motifs counts based on 1,000 random cases are converged values. The further observations and analysis made in this paper is based on 1,000 random networks for each system.

For each real network we compute the significance of each of the 13 motifs of 3-noded sub-graphs, $Zi = (ni - \mu i)/\sigma i$ for i = 1 to 13. For example, the digital fractional multiplier s838 has n = [860, 1100, 0, 401, 0, 0, 0, 0, 40, 0, 0, 0, 0], μ = [856.9, 1213.7, 0, 397.9, 3.1, 0, 0, 0, 1.1, 0, 0, 0, 0], σ = [1.8, 3.6, 0, 1.8, 1.8, 0, 0, 0, 1, 0, 0, 0, 0] and therefore Z = [1.72, −31.89, 0, 1.72, −1.72, 0, 0, 0, 37.1, 0, 0, 0, 0]. One shall note the under-representation of motif id 2 and the over-representation of motif id 9 in the above example. We found all the systems that we studied had some or the other motif over-represented or under-represented. Z vectors are in fact computed for 3-noded, 4-noded and 5-noded sub-graphs. The results of 3-noded are available at [21] and the results of 4-noded, 5-noded are available at our website [20]. (It may be noted that the size of Z vector for 4-noded is 199 and for 5-noded is 9,364). Further study in this paper is restricted to 3-noded sub-graphs only.

3.3 What Causes Over(Under)-Represented Motifs?

All systems studied, including engineering systems, display over(under)-represented motifs; i.e., counts of some motifs in the real system are far in excess or short of their expected counts (beyond $+3\sigma$) in random graphs created using the same nodes. Such motif counts represent highly improbable events. In naturally evolving biological or social systems such motif presence can be attributed to deliberate retention to create useful functionality. But engineering systems are designed and the design process does not address functionality through motifs. So, why do over(under)-represented motifs appear in engineering systems?

4 What Causes Over-Represented Motifs

Engineering systems are designed by humans and offer opportunity for investigation based on known design rules. All engineering systems display over (under) represented motifs and they are rare events as per accepted interpretations. If designers of engineering systems explicitly retain/avoid motifs for the purpose of meeting system design requirements or system design objective, the rarity would have got explained. But we know these motifs are not retained/avoided by designers for any specific purpose. This prompts us to look for an interpretation that renders the motifs counts in a system as probable events. Thus we look for design rules that are responsible for the motifs counts in engineering systems. The motif counts when viewed without regard to those design rules will appear as rare events, but when viewed with regard to those design rules will appear as probable events. Artzy-Randrup et al. [20, 23] have argued that motifs can arise by various mechanisms other than evolutionary selection for function and highlighted for the first time that a rule in synthesis can influence motif counts in a system. They showed that a rule like "the probability of preferential connection to other nodes falling off with the physical distance between nodes" can explain the over-represented motif in neural-connectivity map of a nematode *Caenorhabditis elegans*. But that design rule was unable to reproduce the full motif significance profiles [7].

One major design rule in complex engineering systems is 'design by decomposition' that is invoked to conquer complexity. System is decomposed into sub-systems (and recursively so for very complex systems) such that nodes within each sub-system are densely inter-connected and nodes from across sub-systems are sparsely inter-connected. We investigate impact of design by decomposition on motif counts in engineering systems. Consider an arbitrarily chosen engineering system—digital fractional multiplier s832 [16]. It has N = 512 nodes with each node having specific in-degree and out-degree and has a motif count vector of n, i.e. $n = n_i$, i = 1 to 13 is the count of 13 motifs in s832. We first study expected motif counts, of random graphs synthesized monolithically, i.e. without decomposition, from these 512 nodes. This is referred to as single cluster configuration and designated by c = 1. Large number of such randomized graphs are created by inter-connecting all node pairs such that the degree distribution of nodes and the count of 2 node sub-graphs as in the real network are retained in the random graphs. A vector of means of motif counts, $\mu_1 = \mu_{1,i}$ where i = 1 to 13 and a vector of standard deviations, $\sigma_1 = \sigma_{1,i}$ where i = 1 to 13 are defined. Here the subscript 1 of μ and σ refers to c = 1. The motif significance profile (MSP) vector [10] which we have defined in Sect. 2 as, $Z_1 = (n-\mu_1)/\sigma_1$ is computed. Some elements of Z_1 have values outside of ±3 (From the picture (1) of Fig. 2 it can be seen that $Z_{1,2} < -3$ is under-represented and $Z_{1,9} > +3$ is over-represented). With regard to these over(under) represented motifs we can take a stand that a rare event is being witnessed. But such a stand becomes not justifiable when similar rare events are witnessed for all systems. So we take the alternate stand, that the event witnessed does not belong to configuration c = 1 and proceed to investigate other configurations.

We then create two cluster configurations out of same 512 nodes to represent two sub-systems. Each cluster has roughly N/2 = 256 nodes. We create large number of random graphs by inter-connecting edges of node pairs within a cluster with higher probability (p = 0.9) than node pairs across clusters (p = 0.1) along with preserving degree distribution of nodes and the count of 2 node sub-graphs as in the real network. Vector of means of motif count, μ_2 and vector of standard deviations, σ_2 are estimated. We now define MSP as $Z_2 = (n-\mu_2)/\sigma_2$ for this

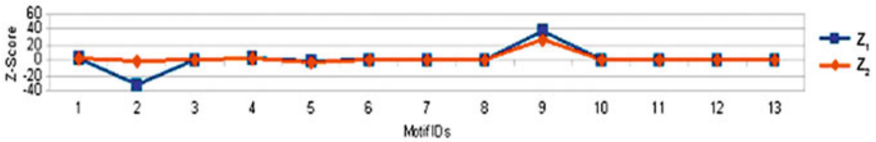


Fig. 2 MSP for Z_1 and Z_2 of digital fractional multiplier s832

c = 2 configuration. Motif significance profile vector Z_2 for clustered case (configuration c = 2) is significantly different from Z_1 (configuration c = 1). Motif id 2 ceases to be under-represented, while motif id 9 is continues to be over-represented whilst all other motif ids continue to be near zero. We similarly study cluster numbers c = 3, 4, 5, etc. and observe a clear dependence of motif significance profile vector, Z_c to clustering.

Let us assume that the real system is synthesized by the designer with k subsystems. Since k for the s832 system is not known we use the following approach: We first use Walktrap Community Detection algorithm by Pons and Latapy [23] to find the best possible sub-systems grouping for a given k, from k = 1 to k = N. In order to choose the best k out of this, we use the system modularity index proposed by Newman and Girvan [24]. The modularity index calculates how modular is a given division of a graph into subgraphs. The system modularity index for clusters k = 1 to k = N is computed and shown in Fig. 3.

When k = 1 all nodes are in one subsystem and have same probability to be connected to each other. When k = N each node is a separate cluster and has same probability to get connected to each other node. The similarity of modularity index for k = 1 and k = N is explained. Modularity index is highest for k = 38 suggesting that s832 is designed with k = 38 sub-systems. We show MSP for k = 38 as $Z_{38} = (n-\mu_{38})/\sigma_{38}$, in comparison with Z_1 in the Fig. 4. Z_{38} has no over(under)-represented motifs and hence no rare events.

We now repeat the process for aircraft engine [25] for which N = 54. The number of clusters present is discovered as k = 5 (Fig. 5).

Sosa et al. [25] have reported the number of modular sub-systems in aircraft engines as 6, which is close to what we discover here. Z_1 and Z_5 are computed for aircraft engine and compared in the Fig. 6. It can be seen that extent of over(-under)-represented motifs in Z_5 as reduced significantly compared to Z_1. We have repeated this exercise for other engineering systems to confirm the above

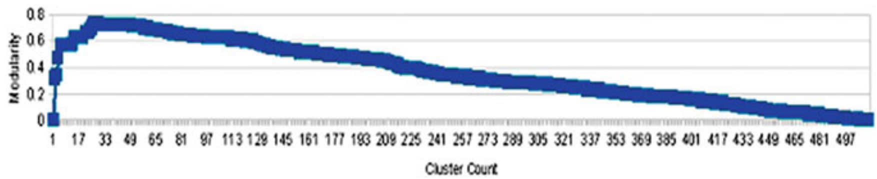


Fig. 3 System modularity index for various clusters sizes of s832

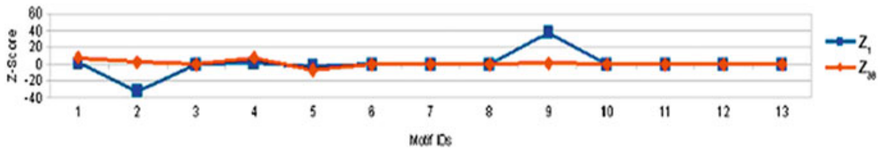


Fig. 4 MSP for Z_1 and Z_k (here k = 38) of digital fractional multiplier s832

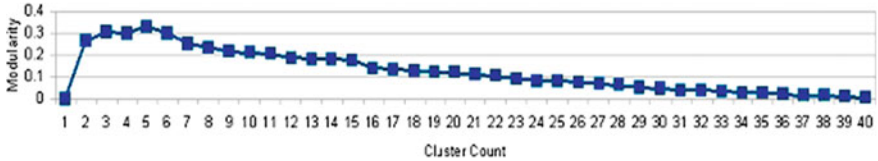


Fig. 5 System modularity index for aircraft engine [12] peaks at k = 5

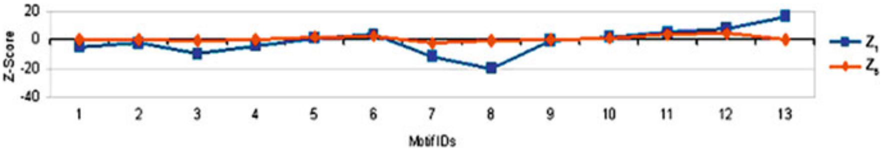


Fig. 6 MSP for Z_1 and Z_k (here k = 5) of aircraft engine

observation (the results are archived in our website [20]). We conclude that over(under) represented motifs observed are merely an outcome of comparing motif counts in a real system synthesized by decomposition to mean motif counts of random networks synthesized monolithically. Over(under) represented motifs do not show up if motif counts in the real system are compared to mean motif counts of random networks synthesized by decomposition. Randomization does not try to mimic exact nodes that go into each cluster or even exact number of nodes in each cluster, but has roughly equal number of nodes randomly picked in each cluster. But such randomization still shows remarkable likeness in motif count to real system.

5 Impact of Our Observations on Biological and Social Networks

Engineering systems are invariably designed through decompositions and it is evident that observed motif counts are a natural consequence of design by decomposition. With this backdrop of understanding for engineering system we now investigate biological systems and social networks.

We first investigate *E. coli* [19] for clustering and discover that it is not a connected graph and actually a collection of 28 sub-graphs not connected to each other. We investigate this collection of 28 sub-graphs to discover 49 subgraphs[1] (Fig. 7). We estimate Z_k for k = 28 and 49 and compare it with Z_1 (Fig. 8) and find a reduction in the extent of over(under) representation of the significant

[1] Out of the 28 sub-graphs, the big enough ones are decomposed further to discover 49 sub-graphs.

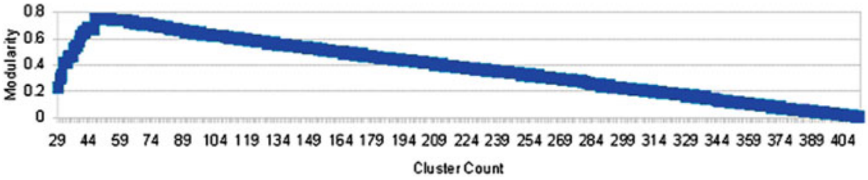


Fig. 7 System modularity index for *E. coli* [19] peaks at k = 49

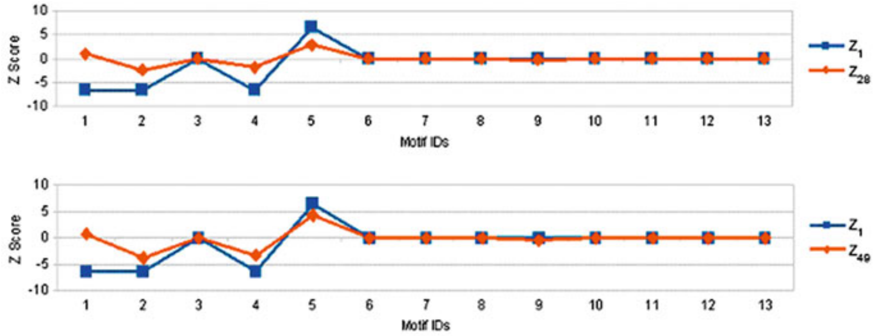


Fig. 8 MSP for Z_1 and Z_k (here k = 28, k = 49) of *E. coli*

motifs, though the reduction is not as dramatic as in engineering systems. There could be other rules apart from clustering that are present in these systems that may further reduce the extent of over(under) representation.

It is not clear why a bio-logical system must have sub-systems (clusters). Previous researchers have studied the role of over-represented motifs in a biological system. We feel it could be more revealing to investigate role of clustering. What function do clusters of specific nodes with dense interconnections perform in biological system may lead to interesting and useful findings.

We finally investigate a social network, representing games played between American (NCAA) college football teams during the year 2000. Radicchi et al. [26] have reported the number of modular teams in football system under study as 9, which is same as what we discover here k = 9 (Fig. 9). We estimated Z_9 and compared it with Z_1 (Fig. 10). It can be seen that extent of over(under)-represented motifs in Z_9 has reduced significantly (almost close to zero indicating no rare

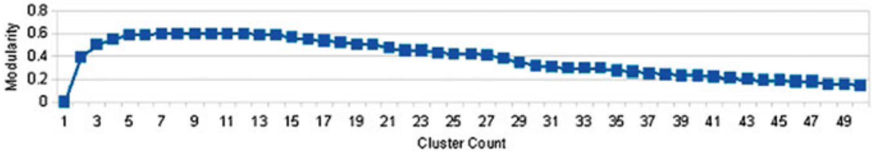


Fig. 9 System modularity index for football [20] peaks at k = 9

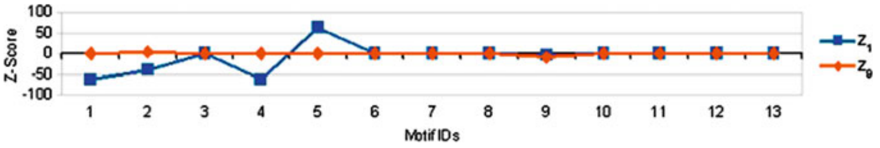


Fig. 10 MSP for Z_1 and Z_2(here k = 9) of football

events) compared to Z_1. This again implies that over(under) represented motifs observed are merely an outcome of comparing motif counts in a real system synthesized by decomposition to mean motif counts of random networks synthesized monolithically.

6 Computational Aspects

All the code that we have developed as part of this research as a software framework named CASMot. Some computational aspects about this framework are mentioned in Table 2.

Table 2 Computational aspects related to CASMot

Features	
Functionalities supported by CASMot framework	Automated scripts to convert raw domain specific data to network, discover over(under)-represented motifs, create MSP, Create CCP, perform decomposition Analysis.
Software	
Operating system	Debian Linux with kernel version 2.6
Programming language	Statistical R, Erlang, Bash shell scripting
Lines of code	48539
Main software paradigm	Functional programming using map-reduce architecture
Hardware	
CPU1	Eight core CPU 2 nos with a processing speed of 1.5 GHz
CPU2	Dual core CPU 5 nos with a processing speed of 1.5 GHz
RAM1	2 GB in the dual core machines
RAM2	16 GB in the eight core machines
Hard disc	80 GB in the dual core machines 500 GB in the eight core Machines
Computational effort	
After harnessing the computing capacity of both the hardware computational effort to run motif experiments	Computations required to generate MSPs of the 38 systems took roughly 850 h (approximately 35 days)

The reader is requested and encouraged to refer to our webpage [20] for the algorithms used for producing clustered random graphs, how to use our distributed software framework named CASMot for doing motif experiments etc.

7 Conclusion

Ideas related to complex system architectures may give insight into previously complex and poorly understood phenomena in engineering domains. Barabasi [27] argues that, "The science of networks is experiencing a boom. But despite the necessary multi-disciplinary approach to tackle the theory of complexity, scientists remain largely compartmentalised in their separate disciplines". The application of this complex system architectures theory is still in infancy and has very recently entered into study of engineering systems or their design. We have shown that over(under) represented motifs in engineering systems are not purposefully retained/avoided to perform functions but are a natural consequence of design by decomposition. We also have shown that biological and social networks also display signs of synthesis by decomposition. This is shown by considering 38 arbitrarily chosen systems ranging from—biology systems, languages, electronic circuits, software systems and mechanical engineering systems. This study has thrown some new insights about Classification of Systems from Component Characteristics.

Acknowledgments We thank Centre for Aerospace Systems Design & Engineering, IIT Bombay, India for the excellent research environment and Aeronautics Research and Development Board (ARDB), India for this project grant. We are also thankful to Mr. Mahesh for his support in plotting few graphs.

References

1. Watts DJ (2004) Six degrees: the science of a connected age. Norton and Company, New York
2. Boccaletti S, Latora V, Moreno Y, Chavez M, Hwang D (2006) Complex networks: structure and dynamics. Phys Rep 424(4):175–308. doi:10.1016/j.physrep.2005.10.009
3. Ottino JM (2004) Engineering complex systems. Nature 427:399. doi:10.1038/427399a
4. Jiang Z-Q, Zhou W-X, Bing X, Yuan W-K (2007) Process flow diagram of an ammonia plant as a complex network. AIChE J 53(2):423–428. doi:10.1002/aic.11071
5. ANSI IEEE Standard 1471. http://www.iso-architecture.org/ieee-1471/
6. Crawley E, de Weck O, Eppinger S, Magee C, Moses J, Seering W, Schindall J, Wallace D, Whitney D (2004) The influence of architecture in engineering systems. MIT Eng Syst Div (Monograph)
7. Milo R, Shen-Orr S, Itzkovitz S, Kashtan N, Chklovskii D, Alon U (2002) Network motifs: simple building blocks of complex networks. Science 298:824–827

8. Ronen M, Rosenberg R, Shraiman BI, Alon U (2002) Assigning numbers to the arrow: parameterizing a gene regulation network by using accurate expression kinetics. In: Proceedings of the national academy of sciences vol 99, no 16, pp 10555–10560
9. Villas Boas PR, Rodrigues FA, Travieso G, Da Fontoura Costa L (2008) Chain motifs: the tails and handles of complex networks. Phys Rev E—Stat, Nonlinear Soft Matter Phys 77(2):026106
10. Milo R, Itzkovitz S, Kashtan N, Levitt R, Shen-Orr S, Ayzenshtat I, Sheffer M, Alon U (2004) Superfamilies of evolved and designed networks. Science 303(5663):1538–1542
11. Ahnert SE, Fink TMA (2008) Clustering signatures classify directed networks. Phys Rev E—Stat, Nonlinear Soft Matter Phys 78(3):036112
12. Blanchard BS, Fabrycky WJ (1998) Systems engineering and analysis, 3 edn. Prentice Hall, Upper Saddle River
13. Sosa ME, Eppinger SD, Rowles CM (2003) Identifying modular and integrative systems and their impact on design team interactions. J Mech Des 125(2):240–252. doi:10.1115/1.1564074
14. Software graph data for specified software systems. http://www.tc.cornell.edu/~myers/Data/SoftwareGraphs/index.htm
15. ISCAS High level models. http://www.eecs.umich.edu/~jhayes/iscas.restore/
16. ISCAS'89 benchmark data. http://www.pld.ttu.ee/~maksim/benchmarks/iscas89/bench/
17. Farid AM, McFarlane DC (2006) An approach to the application of the design structure matrix for assessing, reconfigurability of distributed manufacturing systems. In: Proceedings of the IEEE workshop on distributed intelligent systems: collective intelligence and its applications, art no. 1633429, pp. 121–126. doi: 10.1109/DIS.2006.10
18. Pimmler TU, Eppinger SD (Sep 1994) Integration analysis of product decompositions. ASME design theory and methodology conference, Minneapolis
19. Datasets for Bacteria *E-coil*, yeast *S. cerevisiae* and language networks http://www.weizmann.ac.il/mcb/UriAlon/groupNetworksData.html
20. Artzy-Randrup Y et al Casmot: motif related tool made at centre for aerospace systems design and engineering. Indian Institute of Technology. https://www.casde.iitb.ac.in/complexsystems/motif/results
21. Shaja AS, Sudhakar K (2009) Overrepresented and underrepresented patterns in system architectures across diverse engineering systems, in 19th annual INCOSE international symposium, (Singapore)
22. Artzy Randrup Y, Fleishman SJ, Ben Tal N, Stone L (2004) Comment on network motifs: simple building blocks of complex networks and superfamilies of evolved and designed networks. Science 305(5687):1107c
23. Pons P, Latapy M (2006) Computing communities in large networks using random walks. J. Graph Algorithms Appl 10(2):191–218
24. Newman M, Girvan M (2004) Finding and evaluating community structure in networks. Phys Rev E 69:026113
25. Sosa ME, Eppinger SD, Rowles CM (2003) Identifying modular and integrative systems and their impact on design team interactions. J Mech Des 125(2):240–252
26. Radicchi F, Castellano C, Cecconi F, Loreto V, Parisi D (2004) Defining and identifying communities in networks. In: Proceedings of the national academy of sciences of the United States of America, vol 101(9), pp 2658–2663
27. Barabási A-L, Complexity Taming (2005) Taming complexity. Nat Phys 1:68–70. doi:10.1038/nphys162

Thinking About Design Thinking: A Comparative Study of Design and Business Texts

Marnina Herrmann and Gabriela Goldschmidt

Abstract In the past 10 years design thinking has become a popular buzzword in the design and business communities alike. While much has been written on the subject in both academic and popular literature no consensus has been reached as to its actual definition and nature. The following study employs a semiotic analysis in order to identify lexical patterns that can provide us with insight into many underlying principles of design thinking.

Keywords Design thinking · Language · Semiotics · Business

1 Introduction

It was in the 1960s that the stage was first set for the design thinking revolution. Individuals such as Simon [1], McKim [2], Rittel and Webber [3] first introduced the world to concepts such as design as a way of thinking and planning, systems thinking, and the solving of wicked problems. As these ideas developed throughout the second half of the last century and helped establish a practice of human-centered design, they gained popularity and began to receive the attention of other disciplines.

Today a quick Amazon search of the term reveals its sudden burst of popularity in the past few years. Unfortunately, reading the literature only reveals just how ambiguous the term actually is. There are those who define design thinking in terms

M. Herrmann (✉) · G. Goldschmidt
Israel Institute of Technology, Haifa 32000, Israel
e-mail: marnina@technion.ac.il

G. Goldschmidt
e-mail: gabig@technion.ac.il

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_3, © Springer India 2013

of its goals, others who define it in terms of process and methodology and others still who define it in terms of ideology. While there does not appear to be a consensus as to its meaning explicitly stated in any of the current literature, when one digs a little deeper into the language design thinkers use to discuss their process, certain patterns rise to the surface. A deeper understanding of these patterns is crucial in order for the design thinking discourse to move forward in a meaningful way.

Design thinking has not only gained popularity in the design world, but in the business world as well. Business leaders did not adopt a design thinking ideology or methodology overnight. Rather, it was the result of a long process that began with the acknowledgment that design had a positive impact on the bottom line, as well as the more recent shift from designer as solitary practitioner to an integral part of a collaborative business team [4]. This shift came about as a result of business leaders' realization that to stay competitive in the modern world, efficiency was no longer enough. In today's innovation-based economy consumers want more varied options and richer experiences. Design thinking assists businesses in delivering these options and experiences [5].

With businesses turning to designers with new challenges and responsibilities, designers have been given their long awaited permission to expand the reach of their own practice. To effectively do this they used design thinking as a way to expand their definition of design. In his book "Design Thinking" Lockwood, president of the Design Management Institute describes design thinking as:

> …a human-centered innovation process that emphasizes observation, collaboration, fast learning, visualization of ideas, rapid concept prototyping, and concurrent business analysis, which ultimately influences innovation and business strategy. [6, p. xi]

While none of these are new ideas, by combining these concepts and verbalizing them designers are able to more effectively communicate and exchange ideas with collaborators from the business world. It is this exchange of ideas that will help to bring design to the front and center of the business world and further propel businesses into the 21st century.

While the term design thinking had no one single definition or description of its nature it is clear from the literature that there are specific commonalities and differences in how the two communities described it. This study brings those commonalities and differences to light by examining the choice of language used by authors of design thinking texts.

2 Methodology

The study employed an in-depth literature survey, semi-structured interviews with design thinkers from various different fields, a modified semiotic analysis of design thinking texts and a comparison of the results garnered from the analysis using a two factor design—factorial analysis. The examination of both formal and informal sources of information will allow for a broader understanding of the evolution of the term design thinking. Because the study is primarily qualitative it can take on a more flexible nature. Rather than develop a hypothesis and try to prove it, the conclusions presented arose inductively through the classification and examination of the gathered data in a manner similar to grounded theory.

2.1 Semiotic Analysis

The bulk of the study consists of a modified semiotic analysis. Semiotics is a branch of linguistics that seeks to understand how signs convey meaning in context [7]. Semiotics can be applied to anything which signifies something [8] be that a word, picture, gesture, etc. Semiotic analysis uses various analytical tools to determine the meaning of signs in different contexts. Semiotic analysis enables texts of all types of media to be analyzed in the same way. For this study the primary tool used was syntagmatic analysis, which refers to the contextual relationship between two or more linguistic units.

An assortment of both business and design texts from a variety of media were collected. The inclusion criteria were that the texts were written no earlier than the year 2000 (as it was only after 2000 that the term design thinking gained its popularity in the business world), that their primary purpose was to discuss design thinking as a whole and that the term design thinking was actually used. Texts were categorized by community (business or design) and medium. The community was determined primarily according to the background of the author, but content was taken into account as well. Exact definitions for the term design thinking (when explicitly stated) were extracted from the texts. Terms that were syntagmatically related to the term design thinking were then extracted from the text and categorized according to their use as describing: goals and outcomes, process, ideology, comparable terms, qualities, and context. Not all texts contained terms that fit into all six categories. As well, some texts had words that fit into multiple categories. Each list of terms was then alphabetized and repetition of terms within the individual lists was removed. Then, all terms were combined into two lists: design and business, and the terms in each of these lists were counted and organized according to frequency of appearance.

2.2 Factorial Analysis

Following the semiotic analysis a two factor design—factorial analysis was applied. 50 terms were used that were most prominent in the semiotic analysis. Texts were then reviewed for the appearance of these 50 terms. Each term was then given a value representing the proportion X/N where X is the number of times a term appears and N is the number of texts in each category (in our case 9). This information was then graphed.

3 Results

Results were culled from an analysis of 18 texts,[1] nine design and nine business. Within each category there was two journal articles, three magazine or newspaper articles, one book, one essay and two blog posts. The number of extracted terms was not limited to a specific number and the final number of terms was somewhere in the hundreds.

3.1 Semiotic Analysis: Commonalities

Over all the design thinking process looks fairly similar within both communities. Both communities see design thinking as a repetitive (Fig. 1), collaborative (Fig. 2) and fast (Fig. 3) process. Both employ an expansive toolbox of methodologies and ways of thinking (Fig. 4) toward reaching multiple solutions.

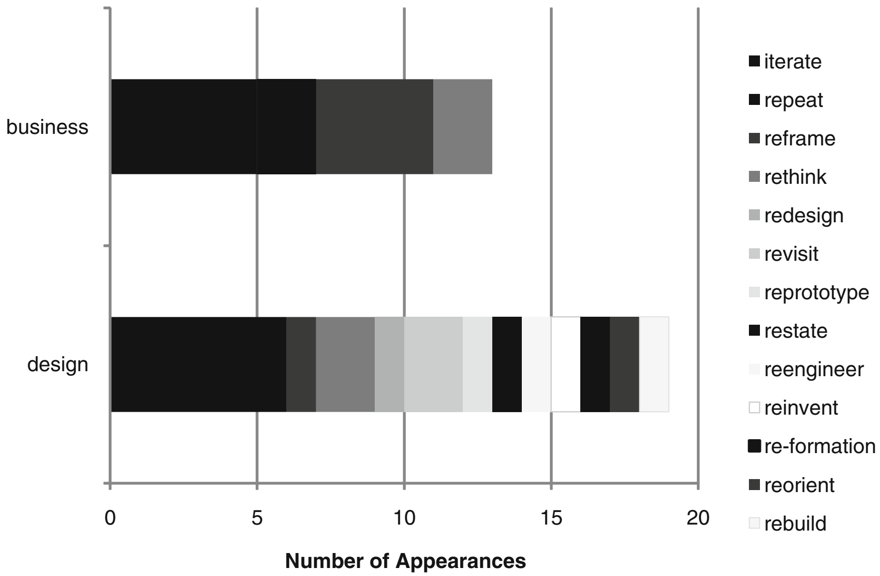


Fig. 1 Design thinking is a repetitive process

[1] Texts include but are not limited to: Leavy, “Design Thinking—a new mental model of value innovation”, Strategy and Leadership, 2010. Wylant, “Design Thinking and the Experience of Innovation”, Design Issues, 2008. Teal, “Developing a (Non-linear) Practice of Design Thinking”, The International Journal of Art and Design Education, 2010. Ward, Runcie and Morris, “Embedding innovation: design thinking for small enterprises”, Journal of Business Strategy, 2009. Brown, “Change by Design”, Harper Business, 2009. Martin, “The Design of Business”, Harvard Business School Press, 2009.

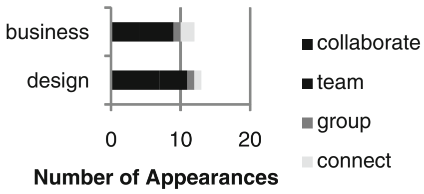


Fig. 2 Design thinking is a collaborative process

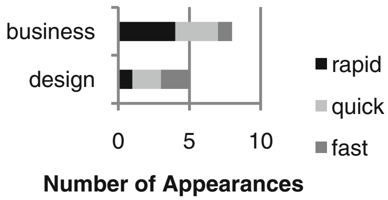


Fig. 3 Design thinking is a fast process

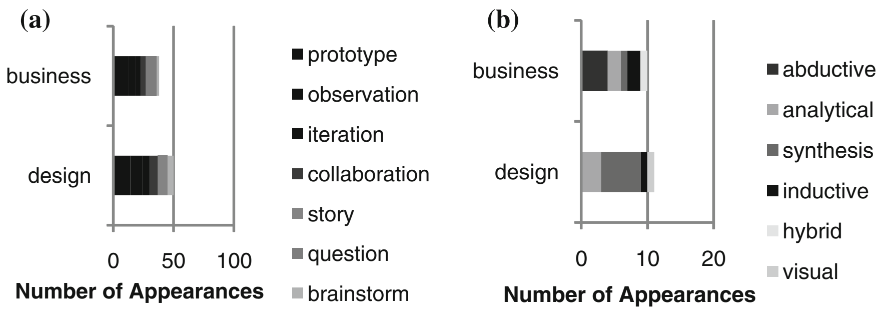


Fig. 4 Design thinking has multiple methodologies (**a**) and ways of thinking (**b**)

The similarities visible within the design thinking community not only help to bridge the gap between the design and business worlds but help give us a framework within which to identify differences as well.

3.2 Semiotic Analysis: Differences

Designers tend to look at design thinking as more of an experiential and immersive process (Figs. 5, 6 and 7) whereas business sees it as more of a knowledge based process (Fig. 8a). This difference in perspective has various practical implications. To designers, design thinking is more about what you do not know than what you do. It is a process guided by curiosity and asking questions which places a strong emphasis on decision making through experimenting and learning (Fig. 8b). The business community on the other hand favors a knowing and judging model

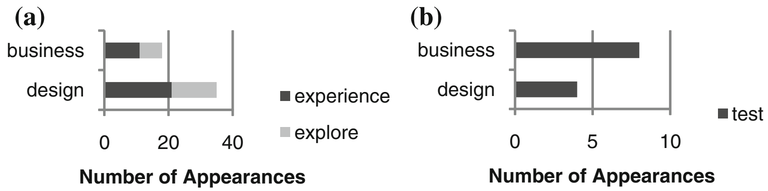


Fig. 5 Design emphasizes a more experiential process (**a**) whereas business emphasizes a process based on testing (**b**)

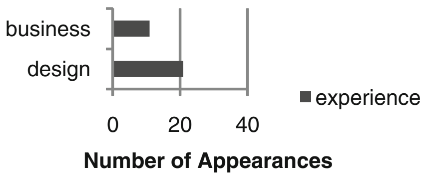


Fig. 6 Design places a stronger emphasis on experience

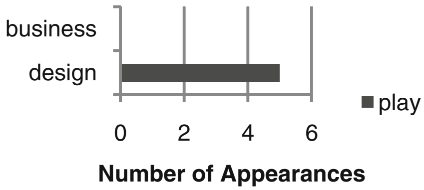


Fig. 7 Design emphasizes a playful process

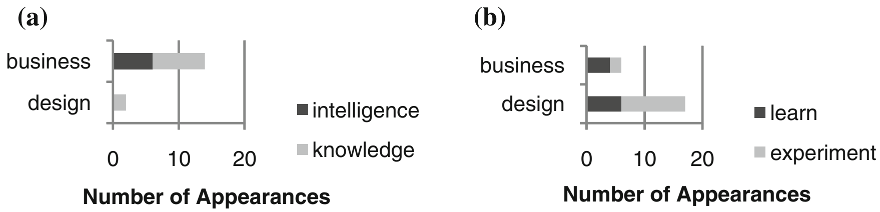


Fig. 8 Business emphasizes knowledge and intelligence (**a**) whereas design emphasizes a process based on learning and experimentation (**b**)

(Figs. 8a and 9). Design's leanings toward learning and experimentation explain its openness to failure as a learning experience and an important part of the design thinking process (Fig. 10).

An additional difference between the two communities is business's preference for verbal communication (Fig. 11a) as compared to design's focus on visual communication (Fig. 11b). This in mind, it is no surprise that the design community also puts a strong emphasis on complexity and patterns while the business

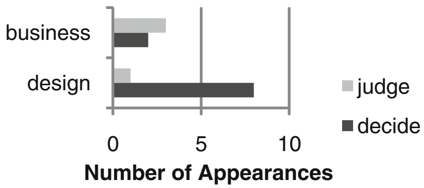


Fig. 9 Business emphasizes judging while design emphasizes deciding

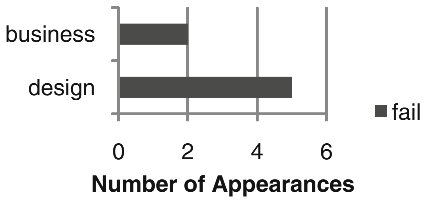


Fig. 10 Design puts a stronger emphasis on failure as part of the process

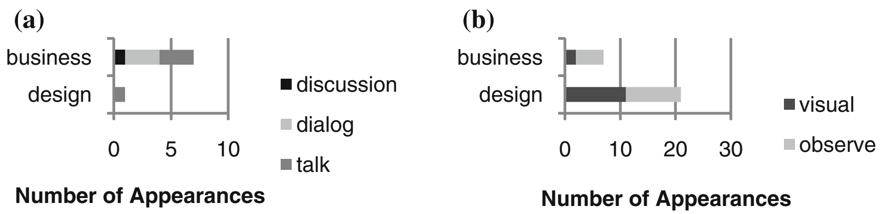
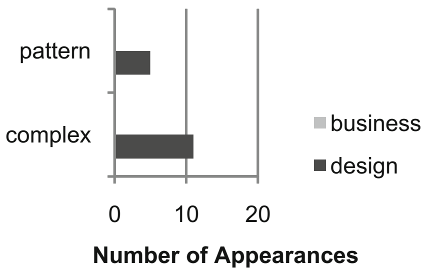


Fig. 11 Business emphasizes verbal communication (**a**) whereas design emphasizes visual communication (**b**)

Fig. 12 Design embraces the idea of complexity and patterns, business mentions neither



community does not (Fig. 12). Another significant difference is the business community's emphasis on innovation. While both communities give equal weight to creativity and imagination, the term innovation appeared much more frequently in business texts (Fig. 13).

Many of the differences highlighted above are interconnected and follow certain patterns that align with their respective communities' various ideologies and philosophies.

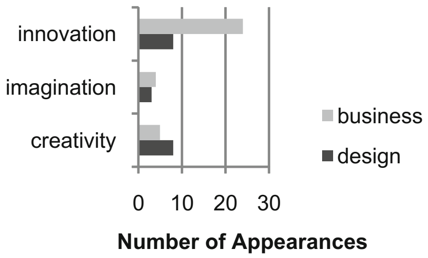


Fig. 13 Both categories put a similar emphasis on imagination and creativity but business emphasizes innovation

3.3 Factorial Analysis

For the most part the factorial analysis (Fig. 14) was not an independent data source but rather a tool used to interpret the results of the semiotic analysis. The results of the two forms of analysis were very different. This was because the factorial analysis answered a *yes* or *no* question: "was (a form of) the term present in the text at least once?" The semiotic analysis on the other hand examined the terms in relation to form and meaning. Terms could be counted multiple times in

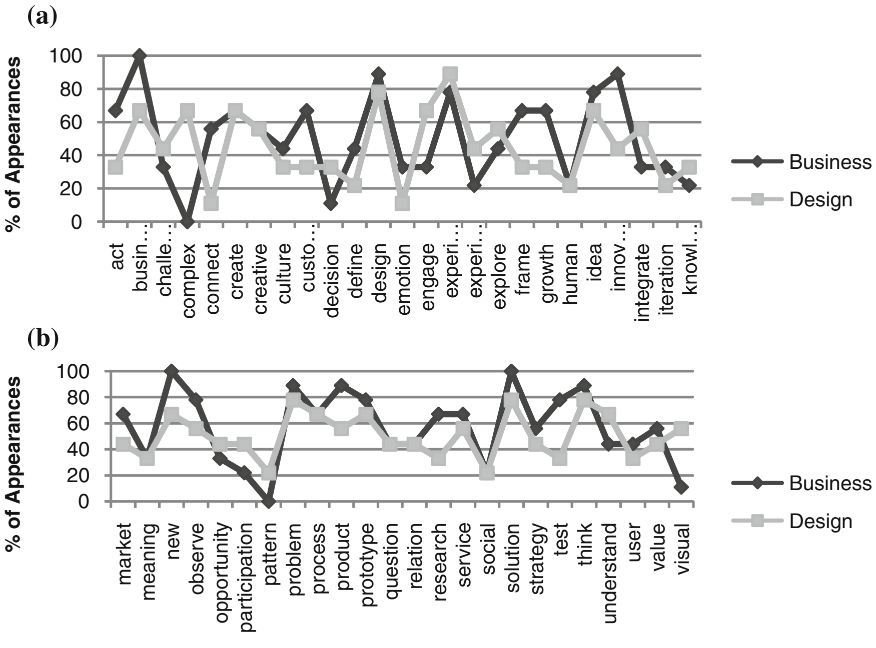


Fig. 14 **a**, **b** Factorial analysis shows the percentage of texts in which the 50 most prominent words from the semiotic analysis appeared

individual texts if they were used to describe different aspects of design thinking or if they were used in a different form (either grammatical or part of a larger term, e.g., product and product design).

It is interesting to note the prominence of the words ‘design’ and ‘business’ in both categories of texts (Fig. 14a) proving the interconnectedness of the two industries. Additionally, the factorial analysis highlights the importance of the problem solving process as part of the design thinking philosophy (Fig. 14b).

4 Discussion

Design thinking is comprised of many possible elements. Some of these elements are unique to a particular individual, studio or organization; others are consistent within a particular community (design and business being the ones examined here), a few appear to be universal. The semiotic and factorial analyses resulted in a variety of interesting findings that highlight various lexical patterns within the design thinking literature that provide us with insight into these different elements allowing us to pinpoint commonalities and differences between the two communities. These commonalities and differences are reflective of the philosophies of the individual communities as well as their relationship to one another.

4.1 Commonalities

The disciplines of design and business are undeniably interconnected. Business provides design with a platform for identifying problems and distributing the solutions, whereas design provides business with added value and a way to connect with users on an emotional level. In order to work together the two must have some common ground. Design thinking provides this common ground by acting as a vehicle for the creative process. It allows business people to be more imaginative and adventurous in their work and allows designers to implement their strategies in a more structured environment.

One of the reasons design thinking serves this purpose so well is because of its emphasis on choice. Design thinking does not force one single methodology or way of thinking on a person but rather provides a toolbox of various methodologies and ways of thinking (Fig. 4) along with a loose framework in which to implement the chosen tools.

While different communities may favor different tools (for example design favors observation whereas business favors questions) the framework enables the tools to be used in a similar manner and for similar goals. The basis for this framework is repetition (Fig. 1), collaboration (Fig. 2) and speed (Fig. 3). These three characteristics allow design thinkers from either discipline to churn out and test multiple solutions to any number of problems as quickly and inexpensively as possible.

Additionally, this framework allows for the design process to be more interactive giving people the opportunity to provide feedback and learn along the way [9].

4.2 Differences

It is when one starts to look at some of the underlying principles behind the different communities' use of design thinking that differences come out. Designers tend to view design thinking as a learning-based process (Fig. 7b) whereas the business community sees it as a knowledge-based process (Fig. 7a). This dichotomy results in designers having a much more immersive design thinking experience. For example, design texts tend to emphasize experience, exploration, experimentation, play and failure (Figs. 5a, 6, 7b, 8b and 10) and business texts emphasize a more passive approach using tools such as testing (Fig. 5b) and intelligence (Fig. 8a). This dichotomy can also be used to explain business' preference for judging (a more top-down, exclusionary action) over design's more active choice of deciding (Fig. 9).

> For designers, the process of building, prototyping and trying things is the decision making process. Instead of boiling down a problem to one large decision, designers make lots of little decisions, learning as they go. As they build and learn, something interesting happens: through the iterations, the best option often reveals itself and the other less-appropriate options fall by the wayside. [10, p. 36]

The debate between the learning-based model and knowledge-based model is most likely related to what Martin, Dean of the Rotman School of Management, refers to as the validity versus reliability debate. Designers tend to search out valid solutions. Valid solutions are solutions whose success cannot be proved at the moment, their success can only be predicted through experimentation and learning. Reliable solutions on the other hand can be proved using statistics, facts and past events. Traditionally, designers tend to search out valid solutions whereas business people tend to search out reliable ones [11]. The learning-based model arose out of the design community's search for valid solutions, whereas the knowledge-based model arose out of the business community's search for reliability.

Another difference between the two communities is the design community's emphasis on visual communication versus business' emphasis on verbal communication (Fig. 11). This could be because of design's emphasis on complexity (and in turn patterns) a theme that reoccurs in many design thinking texts but was not present in the business texts (Figs. 12 and 14). Visualizations can be used as an aid to understand complex problems and to search out patterns. Additionally, the interviews conducted revealed that many designers found verbal language to be an unclear communication method. One example is that many (even those who wrote extensively on the subject) stated in the interviews that they did not like the *term*

[2] Based on an interview with Nir in Moshav Bnei Ataroton July 18, 2011.

design thinking, a possible reason for this being that design has always been able to rely on the visual in order to communicate[2] and so verbal communication becomes less important.

Lastly, there is business' focus on innovation. While both communities put similar emphasis on creativity and imagination business places a much stronger emphasis on innovation (Fig. 13). While the two words are often used interchangeably there are differences. For example, according to Bob Hambly, creative director of Hambly and Wooly,[3] innovation is about moving forward and challenging what is out there while creativity can go in any direction (including examining the past). According to Yariv Sade of Igloo Design[4] innovation is external while creativity is internal. To be innovative one's idea or product has to be something new when compared to what is out there but to be creative one only has to do what is new for them. According to Mark Leung, associate director of Rotman Design Works[5] innovation is about doing something differently from the status quo; it is applied creativity and therefore all businesses are creative. While design texts gave the same prominence to both words, business texts favored the term innovation. This could be for two reasons. The first being that the recent fixation with innovation came about in the business world as a response to a need to adapt to the 21st century consumer experience [5] whereas in the design world innovation is less about a specific objective and more about something that just goes hand in hand with practice. Another reason for this could relate to the fact that innovation is itself seen as a buzzword, and that generally speaking business people are more comfortable with rhetoric and dialog (Fig. 11a).

5 Conclusion

Despite differences in how individuals define and describe design thinking there are definite linguistic patterns evident within the texts available from each community. These patterns can provide insight into how design thinking manifests in the real world, as well as reveal certain truths about the design and business communities. Additionally, the design thinking community as a whole does have many notable similarities when it comes to their vision of design thinking. These patterns are what will enable design thinking to become an effective communication tool among designers and business people, allowing design thinking to hold a strategic role in the future of design and business not only as individual disciplines, but as collaborative partners. This collaboration will elevate the role of designer to one that is more central in the business process as well as provide businesses with better product offerings and a more integrated business process.

---

[3] Based on an interview with Hambly on April 28, 2011 at Hambly and Wooly.

[4] Based on an interview with Sade on June 15, 2011 at the Technion.

[5] Based on an interview with Leung conducted on April 27, 2011 at Design Works.

Acknowledgments Thank you to Professor Ayala Cohen for her assistance with the factorial analysis and to all the individuals who took the time to be interviewed over the course of this study.

References

1. Simon HA (1969) The sciences of the artificial. MIT Press, Cambridge
2. McKim R (1973) Experiences in visual thinking. Brooks/Coles Publishing Co, Belmont
3. Rittel HWJ, Webber MM (1973) Dilemmas in a general theory of planning. Policy Sci 4: 155–169
4. Shedroff N (2010) An opportunity for shared strategy. Innov J 29:45–48
5. Kumar V (2009) A process for practicing design innovation. J Bus Strategy 30:91–100
6. Lockwood T (ed) (2010) Design thinking. Allworth Press, New York
7. Manning PK (1987) Semiotics and fieldwork. Qual Res Methods 7
8. Chandler D (2004) Semiotics: the basics. Routledge, New York
9. Kelley T (2001) Prototyping is the shorthand of innovation. Des Manage J 12:35–42
10. Raney C, Jacoby R (2010) Decisions by design: stop deciding and start designing. Rotman Mag 34–39
11. Martin R (2007) Design and business: why can't we be friends? J Bus Strategy 28:6–12

Advancing Design Research: A “Big-D” Design Perspective

Christopher L. Magee, Kristin L. Wood, Daniel D. Frey and Diana Moreno

Abstract Advances in design research representations and models are needed as the interfaces between disciplines in design become blurred and overlapping, and as design encompasses more and more complex systems. A conceptual framework known as “Big-D” Design, as coined by Singapore’s newest national university (the Singapore University of Technology and Design or SUTD), may provide a meaningful and useful context for advancing design research. This paper is an initial examination of the implications for scientific design research on using this particular framework. As part of the analysis, the paper proposes a simplified decomposition of the broader concept in order to explore potential variation within this framework. It is found that many research objectives are better investigated when the broader design field is studied than in a singular category or domain of design. The paper concludes by recommending aggressive attempts to (1) arrive at a coherent set of terminology and research methodologies relative to design research that extend over at least all of technologically-enabled design and

C. L. Magee (✉)
SUTD-MIT International Design Center Cambridge, MA and Singapore MIT,
77 Massachusetts Avenue, Building E38-450, Cambridge, MA 02139-4307, USA
e-mail: cmagee@mit.edu

K. L. Wood · D. Moreno
SUTD-MIT International Design Center Cambridge, MA and Singapore SUTD,
20 Dover Drive, Dover 138682, Singapore
e-mail: kristinwood@sutd.edu.sg

D. Moreno
e-mail: Diana_moreno@sutd.edu.sg

D. D. Frey
SUTD-MIT International Design Center Cambridge, MA and Singapore MIT,
77 Massachusetts Avenue, Building 3-449D, Cambridge, MA 02139-4307, USA
e-mail: danfrey@mit.edu

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD’13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_4, © Springer India 2013

(2) perform epistemological and ontological studies of the relationship of engineering science and technologically-enabled design science as there is more overlap between them than is generally recognized.

Keywords Design research · Technologically-intensive design · Heuristics · Principles · Design theory

1 Introduction

A novel concept central to future innovation economies and the fields of engineering and architecture is "Big-D Design. As created by and used as a vision for Singapore's newest national university (the Singapore University of Technology and Design or SUTD), "***Big-D Design***" *includes all technologically-intensive design, from architectural design to product design, software design, and systems design. It is design through conception, development, prototyping, manufacturing, operation, maintenance, recycling, and reuse—the full value chain. It includes an understanding and integration of the liberal arts, humanities, and social sciences.* In short, Big-D encompasses the art and science of design; for more information about the university and its concepts, see references [1, 2].

The authors are all associated with the SUTD-MIT International Design Center which is metaphorically seen as the cardiovascular system of SUTD. Our research agenda aims to extend Big-D Design science and Big D Design practice through new methods, theories, principles, heuristics, pedagogy, technologies, processes, and the development of leaders in Design. This paper explores the implications on ours and any design research agenda of taking a Big-D Design perspective. Three elements of this Design perspective and the nature of the questions they lead to about design research are:

1. All technologically-enabled design: what are the advantages and disadvantages of committing to research across this breadth of fields?
2. Full Value Chain: What are the benefits and potential pitfalls of engaging the full value chain in Design research?
3. Art and Science of Design: Does design research entail both of these? Must it?

In order to adequately address these questions, we examine prior design research and establish criteria we are using in this examination. Our criteria are twofold: the first is to continue building a cumulative research enterprise around design so that future research builds upon a reliable base and has continually more impact on Big D Design research communities, and Big D Design education. The second criterion, which we consider equally important, is to impact design practice favorably, in new and exciting ways. Research results can impact practice favorably by development of new methods, theories, guidelines, heuristics and principles that when applied directly lead to superior results for practicing engineers and teams. Design research output can also favorably impact practice through results that point to superior education methods that can involve better basic knowledge structure to support design and better exposure to methods and experiences that are effective in design practice.

The next three sections of the paper examine, in order of the questions, each of the three aspects of the Design perspective introduced here. Each section considers the potential advantages and disadvantages based upon the criteria discussed in the preceding paragraph, relying upon examination of a wide range of design research and education literature. The final section (Sect. 5) draws together the separate elements in the other sections examining interactions among the three separate aspects of Big D Design. This section also discusses the relationship of “Design Science” with “Engineering Science.” It is acknowledged that when exploring Big-D Design Science, there is much overlap with engineering science.

2 All Technologically: Enabled Design

The first aspect of Big D design is that it includes “All” technologically-enabled design; thus question 1 asks what are the advantages and disadvantages of committing to research across this breadth of fields. To address this question, it is necessary to define what is not in Big D Design following this definition and also about alternative ways to categorize the domains that are contained within Big D Design. This construct for design, although broad, does not envelope fields that are focused on aesthetics as the primary or exclusive criterion. It does not include design of visual art such as sculptures or paintings, or design of music or poetry, but does include technologically-enabled fields with a high aesthetic content such as architecture or product design. There are some fuzzy boundaries to any definition, but for our purposes debating specific cases is not important to our overall agenda. Design as used in the Big-D context is broad but does not include all activities that are legitimately called design.

In order to examine what might be gained or lost as one performs design research in the “Big D” perspective, it is useful to consider how one might establish categories included within Big D Design. Categories are desired that connect naturally with cognition and the cognitive science that pervades design as a process, methods, and science. Since “Big D” Design includes all engineering design and architecture, one approach is to think about design across all “typical” departments in an engineering school plus architecture. Such a listing is shown in the first column in Table 1. A second approach shown in the second column in Table 1 comes from a paper by Purao et al. [3] which reports on a workshop where a significant attempt was made to have presentations across a wide array of design domains. The domains listed are those describing the presentation disciplines at the workshop. We note only modest overlap between the lists in the first two columns of Table 1 but believe *both* are fully within “Big D” Design. The listing in the paper by Purao et al.—even though resulting from an attempt to encourage

Table 1 Categorizations within "Big D" design

Typical university departments	Disciplines listed in [1, 3]	Simplified categorization suggested here
Aerospace engineering architecture	Computer science	Software (algorithm and program) design
Biological engineering	Environmental design	Electromechanical-architectural artifacts and systems design
	Human computer interaction	
Chemical engineering		Socio-economic-technical systems design
	Informatics	Materials and molecular-level design
	Information sciences	
Civil engineering	Information studies	
	Information systems	
	Management science	
Computer (software) engineering and science	Production and management	
Electrical engineering	Software engineering	
Engineering mechanics		
Environmental engineering		
Industrial Engineering		
Materials engineering and science		
Mechanical engineering		
Nuclear engineering		
Systems and socio-technical engineering		

and obtain very broad design input—was organized by a MIS (Management Information Systems) group and many of the disciplines are from the area where management and engineering overlap—an area labeled systems socio-technical engineering in column 1. Interestingly, this field is one not stabilized within typical university engineering schools.

Although there is not uniformity in choices of departments or names within all universities, the listing in the first column of Table 1 is the most objectively defined partly because accrediting boards and fields of practice dictate some level of uniformity in names and content. This stability is an argument for exploring question 1 using this list. However, taxonomy criteria (and we are in fact discussing taxonomy for technologically-enabled design) more importantly express the desirability for internally homogenous categories and for the entire taxonomy to be collectively exhaustive and mutually exclusive.

In our attempt to answer question 1, we want to know if homogeneous, mutually exclusive categories are strong enough to support a set of homogeneous principles or heuristics about design. In reality, categorization attempts rarely arrive at homogeneous, mutually exclusive categories in a collectively exhaustive set, but it is our judgment that the first two columns of Table 1 fail badly enough to make further analysis using either approach potentially meaningless. Column 2 is clearly not collectively exhaustive based upon cursory analysis of design research in an engineering school within a typical university. Because specific university engineering departments engage in a broad variety of types of design and typically have overlap in each type, the organizing approach in column 1 misses badly on mutual exclusivity and internal homogeneity. Consider, for example, software engineering that is carried out in nuclear engineering, aerospace engineering, civil engineering and in other places beyond computer engineering or science in a typical engineering school. Similarly diverse placement of materials invention, systems engineering, structural engineering, fluid dynamics, and others indicate that to consider design in any one engineering field could verge on equivalence to studying it across all of "Big D" Design. Thus decomposition to categories at the university department level—while useful for other purposes—does not seem useful to analysis of design research. Perhaps a consolidation or purification of these fields can yield categories more useful to our needs.

Thus, a further attempt to develop categories within technologically-intensive design is undertaken. Technologically-intensive design is a very broad term covering many types and types of design output. To name just a few specific examples, the act and output of such design includes halogen light bulbs, a personal water purification device for developing countries, LED lighting, improved supercapacitors, nano-materials for water purification, a new soccer robot, a new military aircraft, software for controlling air flow in a large building, a new large–scale building, the Internet, and the road system in a large city. Depending upon the specifics of the typology one might think about, it might be possible to define hundreds if not thousands of technologically-intensive design domains. For example, the US patent system has more than 400 classes of patents in its highest classification category and more than 200,000 in its most granular categorization. One must recognize that each of these hundreds and even thousands of "domains" in fact has unique characteristics that might affect how design is performed. Specifying these characteristics (or especially trying to teach or carry out research in a cohesive fashion) for hundreds or even thousands of design fields is not especially feasible and certainly not very useful.

For the purpose of condensation for this paper, our reading of the design literature—particularly the references given in the next subsections, our experience with specific examples of design we have pursued, and our discussions with a variety of technologically-intensive designers, is synthesized to suggest four prototypical classes. These categories are our attempt to capture the breadth of the field, while designating classes likely to contain similar design fundamentals and methods. In other words, it is our judgment that these classes represent some of the most important differences likely to have effect in terms of advancing research fields and performing design. The third column of Table 1 gives the following names to these four classes:

- Software (algorithm and program) design;
- Electromechanical-architectural artifacts and systems design;

- Socio-economic-technical system design; and
- Materials and molecular-level design.

We now briefly discuss each of these classes in order to summarize what the literature analysis suggests is homogeneous in each category. The brief descriptions also are meant to support our contention that these four classes are to a large degree mutually exclusive. It is also clear that no simple set represents a perfect decomposition of "Big D" Design, but these four are more useful to us than any identified alternative in considering question 1. Since we are attempting to include all technologically-intensive design within the four categories, we are using the terms more broadly than may be customary for most readers.

2.1 Software Algorithms and Program Design

Software design relates to the digital and not the material world, where the output of this category of design are programs, or software systems, that accomplish many different functions and have a range of sizes (usually characterized by lines of code even as all recognize the imperfections of the metric). In cases where control software is highly integrated with physical artifacts, there exists a clear connection with our next class (electromechanical-architectural artifact and system design). For very large scale software systems where the software, hardware and the users are tightly coupled (for example, an air traffic control system), we consider such design problems to be contained in our third category (socio-economic-technical system design). Thus, the category we discuss here is for relatively pure software but the descriptions connect, interact, and apply to software subsystems in our other categories.

Software design is relatively new as a practice domain but nonetheless has received a large amount of attention academically [4–10].[1] Pressman [4] has summarized the "evolution of software design" as an ongoing process that has spanned four (and now more) decades which early on concentrated on modular programs and methods for refining software structures in a top-down manner. Later work proposed methods for translation of data flow or data structure into a design definition. In the 90s (and beyond) emphasis was on an object-oriented approach to design derivation. Software architecture and design patterns have also recently received emphasis in software design. Abstraction, complexity and re-use are also fundamental concerns in software design whereas the basic knowledge needed by designers in this category centers on discrete mathematics. Representation and possibly cognitive differences between this category of design and others have not been demonstrated but would be interesting to pursue.

[1] These references are only a modest fraction of the books in this general area.

2.2 Electromechanical-Architectural Artifacts and Systems Design

Electromechanical-architectural artifact and system design produces output that is generally the most visible and tangible of our four categories. As used in this paper, it includes almost all of what are commonly called products (e.g., automobiles, home appliances and furnishing, PCs, cell phones, cameras, etc.) and extends in scale and function beyond what is usually referred to as "products" to include boats, air conditioning systems, elevators, cranes, houses, buildings, locomotives, etc. In our definition, even quite large artifacts such as airplanes, electric power generation turbines and plants, aircraft carriers and large buildings are included in this category. When these large scale systems include a large social, economic and human-enterprise component, they can be categorized within the third category (socio-economic-technical systems).

In our definition, human-designed physical systems that process energy are also classified as electromechanical artifacts. Thus the output of this category includes much of the human-made physical world. Possibly because of the visibility and prevalence of its output, much popular and academic thinking equates this category with the totality of what is meant by technologically-intensive design. However, Design, as defined within the Big-D Design concept and at SUTD, recognizes a much broader domain of technologically-intensive design, so we do not restrict "Big D" Design to this category. Two important sub-fields in the electromechanical-architectural design field tend to, in most instances, even more narrowly define design, using the term to focus on the actual kind of design they do: those sub-fields are industrial design and architecture. These fields which are leading areas in key sub-fields of electromechanical-architectural artifacts and systems—for example, aesthetically and spatial sensitive electromechanical-architectural systems—deserve special attention.

Electromechanical-architectural artifacts and system design has—not surprisingly—resulted in a number of textbooks that are used in universities and by practitioners. References [11–25] give a small sample of the many diverse published books that treat this category of Big-D Design. Given the physical nature of these systems, consideration of space (geometry) is fundamental to electromechanical-architectural design. However, electromechanical-architectural design goes well beyond space considerations to include energy and information feedback. Due to the wide variety of designed objects, the fundamental topics of interest include function, materials, architecture and flexibility. The basic knowledge that underlies electromechanical-architectural design is centered, in part, on physics and mathematics. Practical knowledge in this domain often includes visual representation from sketching to complex 3D geometric representation systems, it also often includes knowledge of fabrication, materials and manufacturing of discrete products and it often includes deep knowledge of systems dynamics, modeling, making, and testing.

2.3 Socio-Economic-Technical System Design

Of the four categories we define for this study, historically, recognition of the concept of socio-economic-technical system design occurred latest. Although interest in large-scale technical systems with major social and economic impact has existed for a few decades [26, 27], it is only more recently that such a category was recognized as critical in the world of design and needing to be addressed from an engineering/technical perspective [28–34]. The boundary between socio-economic-technical systems with both large-scale electromechanical-architectural systems and large scale software systems is the inclusion within the design problem of complex social elements. At times, technical designers leave these social aspects to others, such as those from management or policy fields. Only if such problems are considered as part of the design do we consider the example to be in the socio-economic-technical design category. Here are two specific examples which might shed light on our use of the term: (1) Some might consider design of an air-traffic control system as only concerned with the radar sensing system and the software; (2) The design of a corporate control and improvement system such as the Toyota Production System (TPS) has been considered by some to only include the protocols, plant layouts and technical heuristics. In our use of the term socio-economic-technical design, however, these two examples also include: (1) the personnel, organizational and communication problems (pilot to controller, controller to controller, pilot to pilot, controller to supervisor etc.) and (2) the problem-solving approach, the redesigned role of management, cooperative teams and personnel incentives. It is the nature of socio-economic-technical systems [28–30] that if the complete design effort is constrained within the purely technical domain, the system will be much less effective than it would otherwise be.

Socio-economic-technical system design thus has prominently among its concerns considerations of stakeholders, decision processes, protocols, and standards. Because of their large scale and typically societal importance, architecture, flexibility, sophisticated design processes such as systems engineering and re-use are also top concerns in design of such systems. Representation of various types including process flow, as well as sophisticated programs for requirements and stakeholders are generally associated with this category of design. Of the four categories we have proposed, socio-economic-technical system designers have the most need for fundamental understanding of operations research and social science approaches and theories.

2.4 Materials and Molecular Level Design

Even though a relatively large fraction of technological progress [35–37] is due to design (invention and improvement) of materials and fabrication processes, there has been relatively little attention paid to materials design research and theory as a subject of enquiry. This lack of attention occurs despite (or perhaps because) materials and molecular level design predates even engineering and science as we know them. There have been a few papers describing the expanding knowledge that underlies particularly exciting new materials [38–40], but only Olson's contribution [40] contains significant attention to materials design in a broader sense. In many design textbooks [11–25], design *of* materials is not covered. In a few of these books [11, 14], design *with* materials is discussed including the introduction of Ashby diagrams [41] that systematize materials choice in a variety of design problems. However, choosing the best available material for a given application is ***not*** the focus of what we mean here by materials design. Instead materials design is the process of changing fundamental materials, processes, and processing parameters to create novel and useful materials. Examples of these include new nano-materials processing techniques for Li-ion batteries, vapor deposition of low band-gap semiconductors on Si for solar photovoltaic improvement, new thermoforming techniques for polymeric materials, and literally many hundreds of other specific novel useful materials and processes documented in the patent literature each year. In the solar PV field alone (about ½ of one of the 400 categories in the US patent database), there are about 75 "materials design" patents per year [42].

For consistency, we do not consider design of new materials systems such as large scale materials manufacturing systems or photovoltaic arrays to be materials design, but instead categorize these in either socio-economic-technical or electromechanical-architectural system design. Thus, our definition of materials design positions itself at the relatively small end of a dimensional scale. Perhaps most importantly, materials design always is intimately involved with processing (fabrication of the material). Olsen [40] and others [35] are clear that when materials designers undertake their creative steps, processing can come first: concurrent consideration of making and creating is not a new procedure for materials and molecular level designers. Materials are used as important elements in other artifacts and systems so materials design often aims at improving properties that are known to be important rather than directly aiming to improve an end user function. The fundamental knowledge important to materials and molecular design includes physics, biology, and chemistry at multiple scales; important practical knowledge includes deep and broad knowledge of material processing approaches and understanding of functional requirements that link to properties of various kinds.

2.5 Design Research from Narrower or Wider Perspectives

The fundamental knowledge and approaches used by the four categories of technologically-intensive designers have clear differences even in the brief discussions just presented. In addition, it seems quite reasonable to expect some cognitive processing differences even though this subject has not yet been researched. Thus, there is significant and strong rationale for conducting much design research within such domains and in even finer categories where specific methods and approaches might have value. The benefits from a narrower focus can be consideration of specific important problems (for example, flexibility—see [29, 44, 45] or very specific design methods (for example, objects that transform as part of their function—see [45]). Is there any evidence for value in research from broader perspectives? In fact, there is much work that has produced valuable output while taking a very broad view of design. Indeed, two of the most cited and most important contributors to a cumulative design research agenda are Simon [46] and Schön [47]. Both of these "founding fathers" of design research considered design quite broadly. Based upon their work, the benefits from a broad agenda are deeper insights, improved generalizability and improved capacity for differentiating fundamental from contingent aspects of design.

We also used two other approaches for input to answering the first of our questions. The first additional approach was to review 56 design papers relative to differences in "Type of Theory" from publications in different design domains. The theory typology (or taxonomy) that we followed is from Gregor [48, 49] who considers Information Systems design but argues for looking at design broadly. Table 2 shows Gregor's taxonomy and Table 3 shows the distribution of theory types as a function of papers that are predominantly in the differing design domains shown. Class IV of Gregor's taxonomy is the theory type that is most consistent with the establishment of a cumulative research agenda for design. It is important that our classification of the reviewed papers shows a significant fraction in this theory type and that those papers appear in all the different design categories. Further research will extend this analysis and seek causality connections and implications on cumulative Design theory.

Table 2 A taxonomy of theory in information systems research after Gregor [45]

Theory type	Distinguishing attributes
1. Analysis	Concerns what is. The theory does not extend beyond analysis and description. No casual relationships among phenomena are specified and no predictions are made.
2. Explanation	Concerns what is, how, why, when, and where. The theory provides explanations but does not aim to predict with any precision. There are no testable propositions.
3. Prediction	Concerns what is and what will be. The theory provides predictions and has testable propositions but does not have well-developed justificatory causal explanations.
4. Explanation and prediction	Concerns what is, how, why, when, where and what will be. Provides predictions and has both testable propositions and causal explanations
5. Design and action	Concerns what and how to do something. The theory gives explicit prescriptions (e.g., methods, techniques, principles of form and function) for constructing an systems, artifact (product), or process.

Table 3 Theory type distribution of analyzed papers (references are papers analyzed)

Theory type	Materials and molecular-level design [38–40, 50–55]	Electromechanical-architectural artifacts and systems design [43–45, 56–85]	Software (algorithms and program) design [86–92]	Socio-economic-technical systems design [28, 37, 92–96]	Total
Analyze	1	8	2	2	13
Explain	0	4	1	1	6
Predict	0	2	0	0	2
Explain, predict	6	10	2	4	24
Action, design	2	9	2	0	11

In addition to examining theory type distributions, we also briefly examined design principles that have resulted from design research. In the spirit of design science, much research and writing on design attempts to identify principles that can be used beyond single cases. In some instances, these are called heuristics or guidelines [94] and axioms [95]. In other cases [96, 97], researchers attempt to describe overall systems of interlinked principles for invention (such systems are of potential relevance here since the most novel design outputs are inventions).

Much of the work on design principles and heuristics has been carried out within a particular design context. For two examples, we consider the 180 plus heuristics given in Rechtin and Maier's book [97] and the 201 principles discussed by Davis [101]. In the former case, the principles are clearly framed in terms of design of classes of large-scale complex technical (and socio-economic-technical) systems, while in the latter case the principles are intended to guide software development. Analyzing these carefully, one can identify a number that have wider applicability but some—not surprisingly—are clearly not relevant in other domains. Specific examples from each study—two that have potentially general interest across domains (G) and one too narrow to be general (S) are:

- Rechtin and Maier (G): The first line of defense against complexity is simplicity of design;
- Rechtin and Maier (G): You can't avoid **redesign**. It's a natural part of design;
- Rechtin and Maier (S): If social cooperation is required, the **way** in which a system is **implemented** and introduced must be an **integral part** of its architecture;
- Davis (G): The design process should not suffer from "tunnel vision;"
- Davis (G): The design should be structured to degrade gently, even when aberrant data, events or operating conditions are encountered; and
- Davis (S): The design should "minimize the intellectual distance" between the software and the problem as it exists in the real world.

Similar to these examples, most principles of design are framed within a limited context and are often judged to be useful and instructive within that context.

Most research papers published—dissimilar to the textbooks just discussed—specify principles only for the intended problem and domain (examples are [42–45]). There are clear overlaps with principles between the two texts just reviewed sometimes with quite similar and sometimes dissimilar terminology (decomposition, integration, function and customer concerns are obvious ones that arise). Thus, it is worth exploring if a good starting point to examine design principles from a Big-D Design perspective already exists. As far as the authors are aware, only two attempts have been made to define general design principles and these will be considered next.

The first is the work done by Nam Suh and described in his book *The Principles of Design* [98]. The book–as opposed to the references noted in the preceding paragraphs–does not list a large number of principles or heuristics; instead it focuses on a very small number of what the book terms axioms. In fact, the two key "axioms" are the independence axiom (each functional requirement should be independent of other functional requirements) and the information axiom (among the designs that satisfy the independence axiom, the design that has the smallest information content is the best design). Suh's work in this book and other writings [67] uses these two axioms to "derive" larger numbers of theories and corollaries. On one hand, the independence concept is fairly widely applicable to thinking about designs across our full range of design domains. On the other hand—despite the terminology—the basic axioms are not as fundamental as this mathematical terminology implies. Indeed, while independence has a number of advantages, many designs that do *not* follow it are superior to alternatives that do. In this sense, it is much like the other "principles and heuristics" that have been postulated and is not in any sense truly axiomatic. The derived theories and corollaries are similar principles that can be seen as implications of the two major principles (independence and information). The strength of "axiomatic" design is that the principles apparently have wider application than others. In addition, there have been a number of conferences and workshops held on axiomatic design and some use in industry; however, at the present time this is not a fully developed set of principles for use across all Design.

The second effort that apparently attempts to develop generally applicable design principles is the work initiated by Altshuller [100, 101] in the 1940s and still actively pursued today. This work, known both by its Russian acronym (TRIZ) and by English terminology (Theory of Inventive Problem Solving or TIPS), has its empirical basis in study and classification of patents. Four different aspects of TRIZ include:

1. TRIZ identifies eight "laws" of technical systems evolution which are useful in predicting the nature of desired future design changes;
2. TRIZ identifies thousands of "effects" that are characterized as domain independent;
3. TRIZ identifies 40 design "principles" for resolving contradictions (TRIZ hypothesizes that contradictions in existing solutions are the major way to specify inventive opportunities for the future);
4. TRIZ identifies $\sim$75 "standard solutions" that deal with identified problems.

The translation of TRIZ to “Big D” Design is challenging because the TRIZ literature does not discuss the breadth of applicability and tends to not recognize what aspects of “technologically-intensive design” that it may be neglecting. Moreover, most of the examples shown in the literature are from the electromechanical-architectural design field which may be a result of the background of practitioners and supporters of TRIZ.

The TRIZ laws of evolution are largely descriptive and some may seem difficult to make operational. For example, evolutionary law number 2 (“increasing ideality”) simply says that output per resource increases over time. This is better stated by the exponential improvements seen in various output per resource as first documented by Moore [102] and now known to be much more general [103, 104]. Nonetheless, many of the design principles appear quite general and can be imagined to apply across all “Big D” Design domains. For example, principle number 13 “the other way around” suggests the powerful heuristic to examine the problem in a reverse (or with the inside out or in different temporal order or). However, many principles appear to be more limited in their application across domains (examples include #7 “Nesting”, #8 “counterweight”, #18 “Mechanical vibration”, #28 “Replacement of a mechanical system”, #29 “pneumatic or hydraulic construction”, #32 “Changing the Color”, #35 “transformation of the chemical or physical states of an object”, #37 “Thermal expansion”). Although these apparent limitations may relate to terminology and translation from the theory’s source language, research and advancement of TRIZ are needed to understand this system’s application for all technologically-intensive design.

Recognizing exceptions such as the relatively general #13, neither the TRIZ principles nor the solutions appear to have direct application to software or socio-technical design—perhaps because of the scarcity of such solutions in the patent database that underlies the approach. It is also not clear how well the approach covers materials design despite its prevalence in the patent database. The principles with clear materials content are about materials change or substitution, not about inventing new materials (as examples, #30 “Flexible membranes or thin films” and #31 “Use of porous materials”). Thus, despite some uptake in practice and ongoing documented work [105], TRIZ is also not a fully developed set of Big-D Design principles.

Overall, based upon this preliminary analysis, it appears that sets of broadly applicable design principles are potentially derivable which gives tentative support for a positive answer to question 1. However, the current general approaches do not seem adequate. From the commonality seen in the lists examined, one infers that by some work an overall listing might be developed giving principles in an organized framework but doing this (or even proving its value) will require significant additional work.

3 The Full Value Chain

Question 2 in the first section asks: What are the benefits and potential harm of engaging the full value chain in design research? There are clear practice benefits from considering the full value chain in design as the extensive practice-oriented work done on concurrent engineering signals. There are also clear educational benefits both from a leadership education and understanding design in context viewpoint. Thus, from a university such as SUTD, there is great value in defining design as broadly across the value chain as it does. However, from a research perspective, there may be only a few research objectives that benefit from the wider lens—design for sustainability, value, manufacturability [106, 107] and other DFX areas are examples. Since the full value chain differs in the categories we consider (software does not have physical facilities or tools, materials processing is mostly continuous vs. the discrete product or system manufacturing in the other categories, the nature of customers, clients and stakeholders are different), Design for manufacturability research naturally occurs in narrower domains than ***all*** technologically-intensive Design. Based on these examples, care must be taken in understanding how to develop and engage in design research from the broader Big-D context in regard to the value chain.

4 Art and Science of Design

The question of interest in this section is whether design research must involve both the art and science of design. Our criteria for assessing design research state that such research must impact practice in order to be of value. Since the practice of design is essentially about creating something that has not previously existed, an irreducible element of art is involved in the practice of all technologically-intensive design. This conclusion combined with our criterion for research value and the fact that research is the process for developing new science dictates that all design research includes both the art and science of design.

While almost no-one would disagree with design practice having at least some artistic aspect, there are some [10] who object to a Science of Design (thereby implicitly or explicitly arguing that design research is not viable). This position seems indefensible given the progress that has been made in design research. In our study of design principles (Sect. 2), we find some principles that apply quite widely (modularity or independence of function) and much opportunity exists to explore others. Moreover, there is much more understanding of the importance of expertise [108] than there was when the cumulative design research agenda was initiated almost 50 years ago. Similarly, the importance of analogical transfer in design has been much more strongly established [109, 110] including some work [111] that points towards the best "knowledge structure" for enabling this process.

5 Concluding Remarks

Although we have chosen to discuss the three elements of “Big-D” Design separately (1-all domains of technologically-intensive design, 2-full value chain and 3-art/science combination), there are clear and important interactions among these dimensions. One example of the interconnectedness of these elements is that when research is performed that combines the art and science of design, valuable work has been done that examines design in essentially all domains [46, 47] as well as by looking at more specific problems within a domain [43–45]. A second example of the interactions among the elements is that when research is carried out on the full design value chain, more practical (or art content) is introduced as well as more scientific content [106]. A third example—among many that can be noted—is that as mentioned in Sect. 3, the full value chain has very different content in the different domains that we have described.

Our consideration of the impact of taking a “Big-D” perspective in design research has in all cases shown potential value for broader viewpoints while clearly avoiding any requirement to do so. A 2008 paper by Kuechler and Vaishnavi [93], that argues for broadening the scope of Information Systems Design Research (ISDR), criticizes ISDR for missing important contributions from the “designerly way of knowing” schools [112] and that the ISDR literature contains little in citations to design work outside ISDR. This is not apparently so in all design research domains, but a tendency to fragment might be working to overcome the early start by Simon and others in a broader way. In addition, there are valuable results in the literature that come from considering design beyond technologically-intensive domains. In regard to combining art (practice) and science (research), we have already argued that this is a natural outcome of carrying out research with one objective being to impact the practice of design favorably. However, we do not believe that all design research must involve designing something new as this would amount to the methodological straight-jacket (elimination of valuable research projects) noted by Purao et al. [3]. Research on the art of design can uncover theory that is at least partly scientific, but this can be accomplished by a variety of methods beyond designing something new—for example by systematic study of much design output (empirical studies) [43, 113, 114] or by systematizing observed designer methods [59, 81].

Arguing as we have for a broader (technologically—enabled) perspective for much design research introduces two issues that can limit the value of the work. The first issue is one articulated well in Purao et al. [3] after participating in presentations and extensive discussion among the fields of design shown in the second column of Table 1; one participant said:

> The lack of a common language constitutes a danger to the nascent design sciences. The danger is that our joint efforts will dissolve into incoherence, as exemplified by the myth of the ill-fated Tower of Babel.

Analyzing a wide variety of literature from across design research domains reinforces this point. As one example, many in software design consider design only the creative core of the process so design as used by them does not include specifying, coding or testing; whereas in most electromechanical-architectural design literature, design includes specifying and testing and often manufacturing. Multiplying this example by the many other words that are used quite differently shows that the Tower of Babel danger is real and present (even within domains there is surprising variety in terminology). Thus, one necessary step in pursuing a broader and effective design research agenda is a serious attempt to arrive at a more coherent terminology.

A second major issue in pursuing a research agenda across all technologically-intensive design is the epistemological relationship of such design research to "Engineering Science"—the reigning academic standard in engineering schools worldwide. There is extensive discussion in the design science literature about the epistemological relationship of design to natural science, and there is significant discussion of its relationship to the social sciences. However, there is almost none discussing the relationship of engineering science with technologically-intensive design science. This silence is almost surely related to the fact that the epistemological basis of engineering science has not been considered very deeply. In fact, the arguably best and perhaps only serious consideration of engineering science—Vincenti's 1990 book "What Engineers Know and How They Know it" [114]—does not use the term engineering science despite discussing knowledge that most engineering scientists would consider appropriate to the term. Most interestingly, the major conclusion by Vincenti appears to be that the difference in the science that engineers do compared with natural science, is that "[engineering] science" is fundamentally oriented to make the findings of natural science useful in *design*. Thus, one can probably consider "engineering science" and "design science" intertwined and one possibly a sub-set of the other. An aggressive attempt to clarify this relationship would have great value in setting an agenda for pursuing design research—particularly over the broad spectrum of "all technologically-enabled design."

As a conclusion to this paper, it is clear that we have only examined a small fraction of the issues and foundations needed to create a Big-D perspective of Design research. At the core of our analysis is an understanding of technologically-intensive design as categories, as the study, identification, formalism, and use of design principles and heuristics, as the full value chain, and inclusive of art and science. While the supporting literature of this paper generally supports this view, significantly more analysis is needed on this literature, in addition to integration with design research methodologies and other segments of the design research literature, including [115–124] and beyond.

Acknowledgments The authors thank Professor Robert W. Weisberg for many helpful comments on an earlier and partial draft. This work is supported by the SUTD-MIT International Design Center.

References

1. Wood KL, Rajesh Elara M, Kaijima S, Dritsas S, Frey D, White, CK, Crawford RH, Moreno D, Pey K-L (2012) A symphony of designiettes—exploring the boundaries of design thinking in engineering education. ASEE annual conference, San Antonio
2. Magee CL, Leong PK, Jin C, Luo J, Frey DD (2012) Beyond R&D: what design adds to a modern research university. Int J Eng Educ 28:397–406
3. Purao S, Baldwin CY, Hevner A, Storey V, Pries-Heje J, Smith B (2008) The sciences of design: observations on an emerging field. Commun Assoc Inf Syst 3
4. Pressman RS (2001) Software engineering : a practitioners approach, 5th edn
5. Somerville I (2011) Software engineering, 9th edn
6. McConnell S (2004) Code complete: a practical handbook of software construction
7. Pilone D (2008) Head first software development
8. Braude EJ (2010) Software engineering: modern approaches
9. van Vliet H (2008) Software engineering: principles and practice
10. Brooks FP (2010) The design of design: essays from a computer scientist
11. Dym CL, Little P (2009) Engineering design: a project-based introduction, 3rd edn
12. Ulrich KT, Eppinger ST (1995) Product design and development
13. Otto KN, Wood KL (2001) Product design: techniques in reverse engineering and new product development. Prentice-Hall, Englewood Cliffs
14. Dieter GE, Schmidt LC (2008) Engineering design
15. Anderson J (2010) Basics architecture: architecture design
16. Legendre GL (2011) Mathematics of space: architectural design
17. Norman DA (2002) The design of everyday things
18. Lidwell W (2010) Universal principles of design, revised and updated: 125 ways to enhance usability, influence perception, increase appeal, make better design decisions, and teach through design
19. Cross N (2008) Engineering design methods: strategies for product design, 4th edn. Wiley, Chichester
20. Ullman D (2009) The mechanical design process, 4th edn. McGraw-Hill, New York
21. Venturi R (1966) Complexity and contradiction in architecture. The Museum of Modern Art
22. Thackara J (2005) In the bubble: designing in a complex world. MIT Press, Cambridge
23. Brawne M (1992) From idea to building: issues in architecture. Butterworth Architecture
24. Addis W (2007) Building: 3,000 years of design engineering and construction. Phaidon, London
25. McDonough W, Braungart M (2002) Cradle to cradle: remaking the way we make things. North Point Press, New York
26. Hughes TP (1983) Networks of power: electrification in western society, 1880–1930
27. Hughes TP (1998) Rescuing prometheus
28. Maier MW (1999) Architecting principles for systems-of-systems. Syst Eng
29. de Neufville RA, Scholtes S (2011) Flexibility in engineering design
30. de Weck OL, Roos D, Magee CL (2011) Engineering systems, meeting human needs in a complex technological world (Chap. 6)
31. Simchi-Levi DS (2010) Operations rules: defining value through flexible operation
32. Hopp WJ, Spearman ML (2007) Factory physics, 3rd edn
33. Boland R, Callopy F (2004) Managing as designing
34. Boland R, Callopy F, Lyytinen K, Yoo Y (2008) Managing as designing: lesssons for organization leaders from the design practice of frank gehry. Desig Issues 24(1):10–25
35. National Research Council study (1989) Materials science and engineering for the 1990s: maintaining competitiveness in the age of materials. In: Chaudhari P, Flemings MC (eds) National Academy Press, ISBN: 0-309-57374-2
36. Magee CL (2010) The role of materials innovation in overall technological development. JOM
37. Magee CL (2012) Toward quantification of the role of materials innovation in overall technological development. Complexity, 18:10–25

38. Langer R, Tirrell DA (2004) Designing materials for biology and medicine. Nature 428:487–491
39. Ortiz C, Boyce MC (2008) Bio-inspired structural materials. Science 319:1053–1054
40. Olsen GB (2000) Designing a new material world. Science 288:993–998
41. Ashby MF (1999) Materials selection in mechanical design, 2nd edn
42. Benson CL, Magee CL (2012) A framework for analyzing the underlying inventions that drive technical improvements in a specific technological field. Eng Manage Res 1:2–15
43. Keese DA, Tilstra AH, Seepersad CC, Wood KL (2007) Empirically-derived principles for designing products with flexibility for future evolution. ASME international design technical conferences
44. Tilstra AH, Backlund PB, Seepersad CC, Wood KL (2008) Industrial case studies in product flexibility for future evolution: an application and evaluation of design guidelines. ASME international design technical conferences DETC2008-49370, ASME
45. Weaver J, Wood KL, Crawford RL, Jensen D (2010) Transformation design theory: a meta-analogical framework. J Comput Inf Sci Eng 10:013012-1–013012-11
46. Simon HA (1996) The sciences of the artificial, 3rd edn. MIT Press, Cambridge
47. Schön DA (1983) The reflective practitioner: how professionals think in action. Basic Books, New York
48. Gregor S (2006) The nature of theory in information systems. MIS Q 30:611–642
49. Gregor S, Jones D (2007) The anatomy of a design theory. J Assoc Inf Syst 5:313–335
50. Mooney DJ, Baldwin DF, Suh NP, Vacanti JP, Langer R (1996) Novel approach to fabricate porous sponges of poly(D, L-Lactic-co-glycolic acid) without the use of organic solvents. Biomaterials 17:1417–1422
51. Bruet BF, Song J, Boyce MC, Ortiz C (2008) Materials design principles of ancient fish armor. Nat Mater 7:748–756
52. Suresh S (2001) Graded materials for resistance contact deformation and damage. Science 292:2447–2451
53. Gao H, Ji B, Jager IL, Arzt E, Fratzl P (2003) Materials become insensitive to flaws at nanoscale: lessons from nature. Proc Nat Acad Sci (US) 100:5597–5600
54. Kuehmann CJ, Olsen GB (2011) ICME: success stories and cultural barriers. In: Arnold S, Wong T (eds) Integrated computational materials engineering, ASM
55. Han L, Grodzinsky AJ, Ortiz C (2011) Nanomechanics of the cartilage extracellular matrix. Annu Rev Mater Res 41:133–168
56. Gunther J, Ehrlenspeil J (1999) Comparing designers from practice and designers with systematic design education. Des Stud 20:439–451
57. Paramasivam V, Senthil V (2009) Analysis and evaluation of product design through design aspects using digraph and matrix approach. Int J Interact Des Manuf 3:13–33
58. Sorenson CG, Jorgenson RN, Maagaard J, Bertelsen KK, Dalgaard L, Norremark M (2010) Conceptual and user-centric design guidelines for a plant nursing robot. Biosyst Eng 105:119–129
59. Yilmaz S, Seiffert CM (2011) Creativity through design heuristics: a case study of expert product design. Des Stud 32:384–415
60. Wu JC, Shih MH, Lin YY, Shen YC (2005) Design guidelines for tuned liquid column damper for structures responding to wind. Eng Struct 27:1893–1905
61. Galle P (1996) Design rationalization and the logic of design. Des Stud 17:253–275
62. Joseph S (1996) Design systems and paradigms. Des Stud 17:227–239
63. Berends J, Reymen I, Stultiens RGL, Peutz M (2011) External designers in product design processes of small manufacturing firms. Des Stud 32:86–108
64. Dorst K, Veermas PE (2005) John Gero's function-structure-behavior model of designing: a critical analysis. Res Eng Des 16:17–26
65. Magee CL, Thornton PH (1978) Design considerations in energy absorption by structural collapse. Soc Automot Eng Trans SAE 780434
66. Matthews PC, Blessing LTM, Wallace KM (2002) The introduction of a design heuristics extraction method. Adv Eng Inform 16:3–19

67. Suh NP (1998) Axiomatic system design. Res Eng Des 10:189–209
68. Wood KL, Jensen D, Singh V (2009) Innovations in design through transformation: a fundamental study of tRaNsFoRmAtIoN principles. ASME J Mech Des 131:8
69. Frey DD, Herder PM, Wjnia Y, Subrahmaniam E, Katsikopoulos K, Clausing DP (2009) The pugh controlled convergence method: model-based evaluation and implications for design theory. Res Eng Des 20:41–58
70. Frey DD, Herder PM, Wjnia Y, Subrahmaniam E, Katsikopoulos K, de Neufville RA, Clausing DP (2010) Reply: the role of mathematical theory and empirical evidence. Res Eng Des 21:341–344
71. Hirtz J, McAdams DA, Sykman S, Wood KL (2002) A functional basis for engineering design: reconciling and evolving previous efforts. NIST technical note 1447
72. Stone RB, Wood KL, Crawford RH (2000) A heuristic method for identifying modules for product architectures. Des Stud 21:5–31
73. Rajan PKP, van Wie M, Campbell MI, Wood KL, Otto KN (2005) An empirical foundation for product flexibility. Des Stud
74. Hey J, Linsey J, Agogino AM, Wood KL (2008) Analogies and metaphors in creative design. Int J Eng Educ 24:283–294
75. Qureshi A, Murphy JT, Kuchinsky B, Seepersad CC, Wood KL, Jensen DD (2006) DETC 2006-99583
76. Weaver JM, Kuhr R, Wang D, Crawford RH, Wood KL, Jensen D, Linsey JD (2009) Increasing innovation in multi-function systems: evaluation and experimentation of two ideation methods for design. DETC 2009-86526
77. Rajan PKP, van Wie M, Campbell MI, Otto KN, Wood KL (2003) Design for flexibility—measures and guidelines. ICED03
78. Moe RE, Jensen DD, Wood KL (2004) Prototype partitioning based upon requirement flexibility. DETC 2004-57221
79. Weaver J, Wood KL, Jensen D (2008) Transformation facilitators: a quantitative analysis of reconfigurable products and their characteristics. DETC2008-49891
80. Singh V, Skiles SM, Krager JE, Wood KL, Jensen D, Sierokowski R (2009) Innovations in design through transformation: a fundamental study of transformation principles. J Mech Des 131:081010-1–081010-18
81. Chrysikou EG, Weisberg RW (2005) Following the wrong footsteps: fixation effects of pictorial examples in a design problem-solving task. J Exp Psychol: Learn Mem Cogn 31:1134–1148
82. Weisberg RW (2009) On 'out-of-the-box' thinking in creativity. In: Wood K, Markman A (eds) Tools for innovation, pp 23–47
83. Rowe PG (1987) Design thinking
84. Luo J, Olechowski AO, Magee CL (2012) Technologically-based design as a strategy for sustained economic growth. Technovation, to appear
85. Magee CL, Frey DD (2006) Experimentation in engineering design: linking a student design exercise to new results from cognitive psychology. Int J Eng Educ 22(3):85–103
86. Gill GR, Hevner AR (2010) A fitness-utility model for design science research
87. MacCormack AD (2001) Product development practices that work: how internet companies build software. Sloan Manag Rev 42:75–84
88. Kim H (2010) Effective organization of design guidelines reflecting designer's design strategies. In J Indus Erg 40:669–688
89. Hevner AR, Ram S, March ST, Park J (2004) Design science in information systems research. MIS Q 28:75–105
90. MacCormack AD, Rusnak R, Baldwin CA (2006) Exploring the structure of complex software designs: an empirical study of open-source and proprietary code. Manag Sci 52:1015–1030
91. Venables JR (2010) Design research post Hevner et al: criteria, standards, guidelines and expectations. In: DESRIST proceedings
92. Shaw M, Garlan D (1996) Software architecture: an emerging discipline

93. Kuechler W, Vaishnavi V (2008) The emergence of design research in information systems in North America. J Des Res 7:1–16
94. Poole S, Simon M (2007) Technological trends, product design and the environment. Des Stud 18:237–248
95. Jarvinen P (2007) On reviewing of results in design research. In: ECIS, Proceedings of the fifteenth European conference on information systems, pp 1388–1397
96. Indulska M, Recker JC (2008) Design science in IS research : a literature analysis. In: 4th biennial ANU workshop on information systems foundations, 2–3 Oct 2008
97. Rechtin E, Maier MW (2009) The art of system architecting, 3rd edn
98. Suh NP (1990) Principles of design
99. Altshuller G (1984) Creativity as an exact science
100. Sickafus E (1997) Unified structured inventive thinking: how to invent
101. Davis AM (1995) 201 principles of software development
102. Moore GE (1965) Cramming more components onto integrated circuits. Electron Mag 8:38
103. Koh H, Magee CL (2006) A functional approach for studying technological progress: application to information technology. Technol Forecast Soc Chang 73:1061–1083
104. Koh H, Magee CL (2008) A functional approach for studying technological progress: extension to energy technology. Technol Forecast Soc Chang 75:735–758
105. The TRIZ Journal is published regularly, see http://www.triz-journal.com/
106. Boothroyd G (2005) Assembly automation and product design, 2nd edn
107. Boothroyd G, Dewhurst P, Knight W (2002) Product design for manufacture and assembly, 2nd edn
108. Weisberg RW (2006) Creativity: understanding innovation in problem solving, science, invention, and the arts. Wiley, New York
109. Christensen CB, Schunn CD (2007) The relationship of analogical distance to analogical function and pre-inventive structure: the case of engineering design. Mem Cogn 35:29–38
110. Markman AB, Wood KL, Linsey JS, Murphy JT, Laux J (2009) Supporting innovation by promoting analogical reasoning. In: Markman AB, Wood KL (eds) Tools for innovation. Oxford University Press, New York, pp 85–103
111. Linsey JS, Wood KL, Markman AB (2008) Modality and representation in analogy. Artif Intell Eng Des Anal Manuf 22:85–100
112. Cross N (1984) Developments in design methodology
113. Baldwin CY, Clark KB (2006) Between 'knowledge' and 'the economy': notes on the scientific study of designs. In: Kahin B, Foray D (eds) Advancing knowledge and the knowledge economy. MIT Press, Cambridge
114. Vincenti W (1990) What engineers know and how they know it: analytical studies from aeronautical history
115. Friedman K (2003) Theory construction in design research: criteria: approaches, and methods. Des Stud 24:507–522
116. Collins A, Josepjh D, Bielaczyc K (2004) Design research: theoretical and methodological issues. J Learn Sci 13(1):15–42
117. Horvath I (2004) A treatise on order in engineering design research. Res Eng Des 15:155–181
118. Eder WE (2011) Engineering design science and theory of technical systems: legacy of vladimir hubka. J Eng Des 22(5):361–385
119. Ball P (2001) Life's lessons in design. Nature 409:413–416
120. Dorst K (2008) Design research: a revolution-waiting-to-happen. Des Stud 29:4–11
121. Galle P (2008) Candidate worldviews for design theory. Des Stud 29:267–303
122. Farrell R, Hooker C (2012) The Simon-Kroes model of technical artifacts and the distinction between science and design. Des Stud 33:480–495
123. Reich Y (2010) The redesign of research in engineering design. Res Eng Des 21:65–68
124. Andreasen MM (2011) 45 years with design methodology. J Eng Des 22(5):293–332

Proposal of Quality Function Deployment Based on Multispace Design Model and its Application

Takeo Kato and Yoshiyuki Matsuoka

Abstract Due to the specialization and professionalization of the design work, sharing the product information between the product development members has been important in the product development process. Quality Function Deployment is one of the effective methods that enables the development members to share the information of the product using the quality matrices that describes the relationship between design elements needed to be considered. This paper improves the quality matrices by introducing the multispace design model and the Interpretive structural modeling. The proposed quality matrices are applied to a disc brake design problem, and their applicability is confirmed.

Keywords Design methodology · QFD · ISM · DSM

1 Introduction

Functions and mechanisms of products have been diversified and complicated recently. Therefore, design work has been specialized and professionalized [1]. In the situation, the members of the product development should share the product information, including the concept and knowledge. However, the information tends to be left in their mind (i.e. not to be transmitted to others), and this causes quality

T. Kato (✉)
Department of Mechanical Engineering, Tokai University, Hiratsuka, Japan
e-mail: t.kato@tokai-u.jp

Y. Matsuoka
Department of Mechanical Engineering, Keio University, Yokohama, Japan
e-mail: matsuoka@mech.keio.ac.jp

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_5, © Springer India 2013

issues. Quality Function Deployment (QFD) is one of the effective methods to solve these problems and used in many company throughout the world [2]. QFD is suitable for the members to share the information using the quality matrices as shown in Fig. 1 [3]. Quality matrices are composed by the deployment charts including allied design elements needed to be considered in the design process and the relationship matrices which represent the relationship between design elements in different deployment charts. Using the quality matrices, design elements of customer demands can be translated into that of engineering tasks (engineering characteristics, product's function, parts and etc.). This enables the product development members (product planners, designers, manufacturing staff and etc.) to share the product's information and assist to implement the ideal product design free of the quality issues. However, the quality matrices have some problems as follows:

1. Applying to a whole new product development is difficult because they are assumed to be applied to the design for improving existing product [3];
2. Sharing the product's information between the development members is counteracted because the quality matrices are different depend on the design process. For example, the relationship matrix between engineering characteristics and parts is only used by the engineering designers or manufacturing staff in the detail design process [4];
3. The circumstance of the developing product is not clarified in the detail design process (i.e., the design elements meeting the circumstance cannot be extracted);
4. The relationship between design elements in the same deployment chart cannot be identified because the relationship matrices represent only the relationship between design elements in different deployment chart. However, the relationship of design elements in the deployment chart of engineering characteristics is considered in some conventional study [5].

This study proposes new QFD including both the Multispace design model (MDM) and the Interpretive Structural Modeling (ISM) method to overcome the above problems. Section 2 describes a brief description of the MDM and the

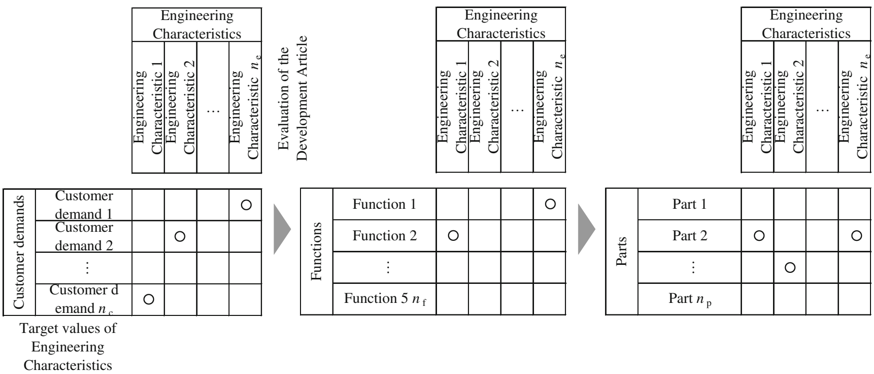


Fig. 1 Conceptual diagram of quality matrices used in QFD

introduction of the MDM into the QFD. Section 3 describes the overview of the ISM method and the introduction of the ISM into the QFD. Section 4 illustrates an application of the proposed QFD to a disc brake, while Sect. 5 provides conclusions and the future research direction.

2 Introduction of MDM into QFD

The MDM aims to comprehensively deal with design and is comprised of the thinking space and knowledge space (Fig. 2) [6]. The thinking space includes a reasoning model for four types of spaces and inter-spaces: value space, meaning space, state space, and attribute space. These space are defined as follows:

1. The value space is a set of the value elements. The value elements are psychological elements relating to values that the user thinks about products. For example, functional value, social value, and so forth;
2. The meaning space is a set of the meaning elements. The meaning elements are psychological elements relating to meanings that the user thinks about products. For example, function, image, and so forth;
3. The state space is a set of supposed circumstance and the state elements. The circumstance is physical environment for which products are used. For example, time, external force, users physique and so forth. The state elements

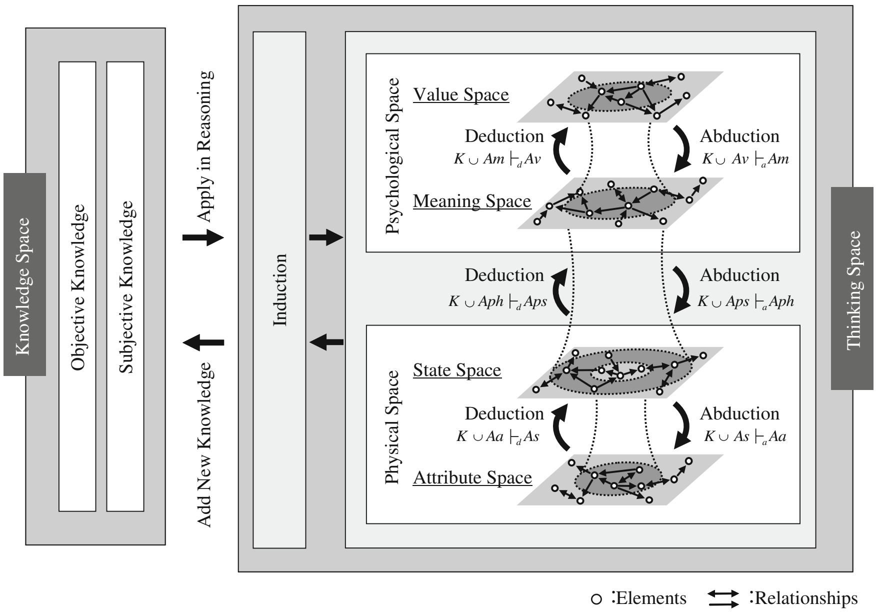


Fig. 2 Conceptual diagram of multispace design model

are physical quantity generated when products are in the circumstance. For example, stress, acceleration produced when an external force acts on products and so forth;

4. The attribute space is a set of the attribute elements. The attribute elements are geometrical and physical property of the products. For example, dimension and material like being shown in the technical drawing and so forth.

Value space and meaning space composes the psychological space, whereas state space and attribute space composes the physical space. Knowledge space is comprised of objective knowledge and subjective knowledge. The objective knowledge holds generalities such as theories and methodologies, including physical laws in natural science, social sciences, and humanities. In contrast, the subjective knowledge contains specialties that depend on individual contexts. The knowledge space is the basis for identifying intra-space and inter-space models in the thinking space.

One of the features of the MDM is to describe whole design process (from the early to late process). As a feature of design process, in the early process of design, the designers focus both on the psychological and physical design elements, and search design solution candidates by considering the relationship between the elements through trial and error (bidirectional design). On the other hand, in the late process of design, the designers derive a unique design solution by optimizing both psychological and physical design elements systematically (unidirectional design). The features of both design processes can be properly described by the four space of the MDM (value, meaning, state, and attribute space). Conventional QFD seems to assume the late design process because of its procedure in which the designers deploy the design elements from the customer demands (psychological design element) to the product's parts (physical design element) systematically as shown in Fig. 1. This causes the difficulty of applying QFD to a whole new product development, which needs the bidirectional design in the early process of design, described in Sect. 1. Therefore, to overcome the problem, the concept of the MDM (four space) is introduced into the QFD. Specifically, the four space deployment charts and three relationship matrices are put into the quality matrices in order to bidirectional design in the early process of design (Fig. 3). The quality matrices can also be used in the late process of design. This means that the common quality matrices can be used throughout the whole process of design. Hence, this also overcome the problem regarding the sharing of the product's information between the development members described in Sect. 1.

Another feature of the MDM is a clear definition of the product circumstance. The MDM describes that the function of the product is generated not only based on the product physical characteristics but also on the circumstance of the product. Unless the circumstance is adequately considered or clarified, the following problems have a potential to emerge:

1. The variance of the circumstance worsens the product's objective characteristic;
2. In the redesign (improvement design) after the development, the product information during the development cannot be utilized.

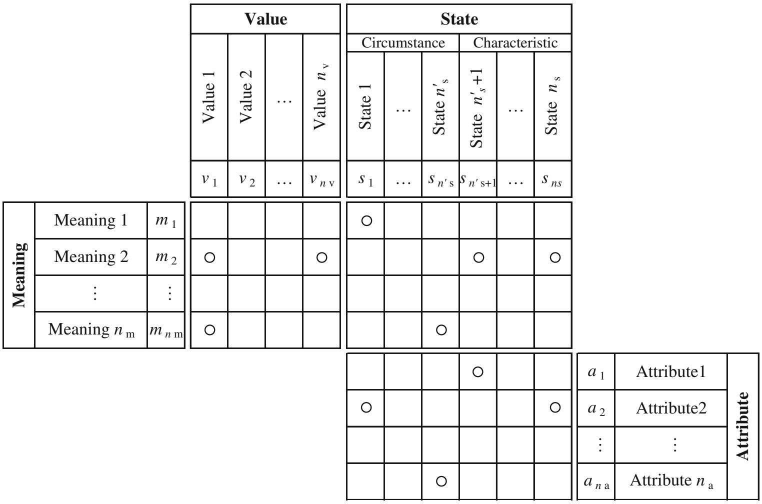


Fig. 3 Proposed QFD include the concept of multispace design model

Therefore, the MDM divides the physical elements into state elements affected to the circumstance and attribute elements and clearly categorizes the circumstance elements in the state space. In the conventional QFD, the information about the circumstance does not tend to be carried to the engineering designers or manufacturing staff in the late process of design because the circumstance descriptions are in the customer demands or product's function in most cases. This study creates a category of the circumstance in the state deployment chart based on the concept of the MDM (Fig. 3) and clarifies the design elements of the current circumstance to overcome the problem as mentioned in Sect. 1.

3 Introduction of ISM into QFD

The ISM method is one of the design methods to visually express the complex relationship between design elements by using matrix operation [7, 8]. In the ISM method, the direct affective matrix **X** (Fig. 4a), which expresses the relationship between design elements, is firstly constructed as following equation:

$$X = \begin{pmatrix} X_{11} & \cdots & X_{1j} & \cdots & X_{1n} \\ \vdots & & & & \\ X_{i1} & & \ddots & & \vdots \\ \vdots & & & & \\ X_{n1} & & \cdots & & X_{nn} \end{pmatrix}, \qquad (1)$$

where, n is the number of design elements and X_{ij} are calculated as:

$$X_{ij}\begin{cases} 1 & \textit{if ith element relates to jth element} \\ 0 & \textit{else} \end{cases} \quad \begin{pmatrix} i = 1, 2, \ldots, n \\ j = 1, 2, \ldots, n \end{pmatrix}. \tag{2}$$

Secondly, the reachable matrix $\mathbf{M}_{\mathrm{R}}$ (Fig. 4b) is derived using the matrix $\mathbf{M} = \mathbf{X} + \mathbf{I}$, where $\mathbf{I}$ is a unit matrix, as shown in the following equation:

$$M_R = M^r \qquad \left(M^r = M^{r-1}\right) \tag{3}$$

Finally, the reachable matrix MR is transformed into the skeleton matrix M (Fig. 4c) and the structural model (Fig. 4d) is constructed based on the relationship in the matrix. Where, the skeleton matrix can represent the relationship of the reachable matrix using minimum relationships [8]. This paper omits the detail calculation of the skeleton matrix.

This study introduces the correlation matrix to each of the four space deployment charts in order to overcome the problem of unclear relationship between them described in Sect. 1. The correlation matrix is described as Fig. 5. In the matrices, the unidirectional relations (i.e. element "A" causes "B" but "B" does not causes "A") are described as arrows, whereas, the bidirectional relations (i.e. element "A" causes "B" and "B" also causes "A") are described as "○". In Fig. 5, design element 1 (d_1) affects both d2 and dn and is affected by d_2. Additionally, this study introduces the ISM method to figure out the relationships between design elements in each deployment chart. This paper describes an introduction of the ISM method to

(a)

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
x_1	0	0	0	0	1	0	1	0
x_2	0	0	1	0	1	0	0	0
x_3	0	1	0	0	0	1	0	1
x_4	0	0	0	0	1	0	1	0
x_5	0	1	1	0	0	0	0	0
x_6	0	0	0	0	0	0	0	0
x_7	0	0	1	0	0	0	0	0
x_8	0	0	0	0	0	1	0	0

(b)

	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8
x_1	1	1	1	0	1	1	1	1
x_2	0	1	1	0	1	1	0	1
x_3	0	1	1	0	1	1	0	1
x_4	0	1	1	1	1	1	1	1
x_5	0	1	1	0	1	1	0	1
x_6	0	0	0	0	0	1	0	0
x_7	0	1	1	0	1	1	1	1
x_8	0	0	0	0	0	1	0	1

(c)

	x_6	x_8	x_2'	x_7	x_4	x_1
x_6	0	0	0	0	0	0
x_8	1	0	0	0	0	0
x_2'	0	1	0	0	0	0
x_7	0	0	1	0	0	0
x_4	0	0	0	1	0	0
x_1	0	0	0	1	0	0

(Note) $x_2' \ni \{x_2, x_3, x_5\}$

(d)

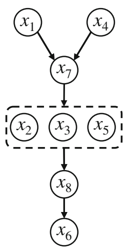


Fig. 4 Conceptual diagram of ISM

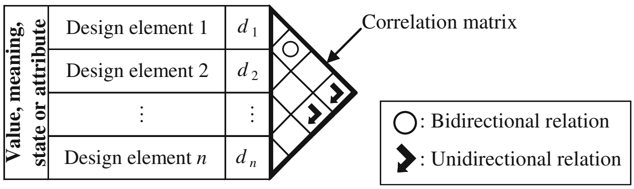


Fig. 5 Correlation matrix

the attribute (product's parts) design elements, whose relationships are complicated due to the greatest element number, in order to construct the parts design procedure. The procedure is constructed by not only their relationships but also the state (engineering characteristic) elements relationships. For example, the parts elements, which are not related to each other but related to the same engineering characteristics, assumed to have relationship and should be designed concurrently. In this study, the sum of both direct affective matrices **X** derived from the attribute correlation matrix (Eq. 1) and **X**′ derived from the engineering state correlation matrix are used to construct the parts design procedure.

$$X + X' \quad \left(X' = \begin{pmatrix} X'_{11} & \cdots & X'_{1j} & \cdots & X'_{1n_p} \\ \vdots & & & & \\ X'_{i1} & & \ddots & & \vdots \\ \vdots & & & & \\ X'_{n_p1} & & \cdots & & X'_{n_pn_p} \end{pmatrix} \right), \tag{4}$$

where n_a is the number of the attribute elements, and X'_{ij} are calculated as:

$$X'_{ij} \begin{cases} 1 & \text{if both } a_i \text{ and } a_j \text{ relate to } s_k \\ 1 & \text{if } s_k \text{ (relating } a_i\text{) relates to } s_j \text{ (relating } s_j\text{)} \\ 0 & \text{else} \end{cases} \quad \begin{pmatrix} i = 1, 2, \ldots, n_a, \\ j = 1, 2, \ldots, n_a, \\ k = 1, 2, \ldots, n_a, \\ l = 1, 2, \ldots, n_a \end{pmatrix}, \tag{5}$$

where a_i is ith attribute element and s_k is kth state element.

4 Procedure of proposed QFD

The proposed quality matrices including the deployment charts of the four space and their correlation matrices are shown in Fig. 6. The procedure of the proposed quality matrices is as follows. First, the design elements (including value, meaning, state, and attribute elements) are extracted (Step 1 in Fig. 6). Second, the relationship matrices between them are developed (Step 2). Third, the correlation

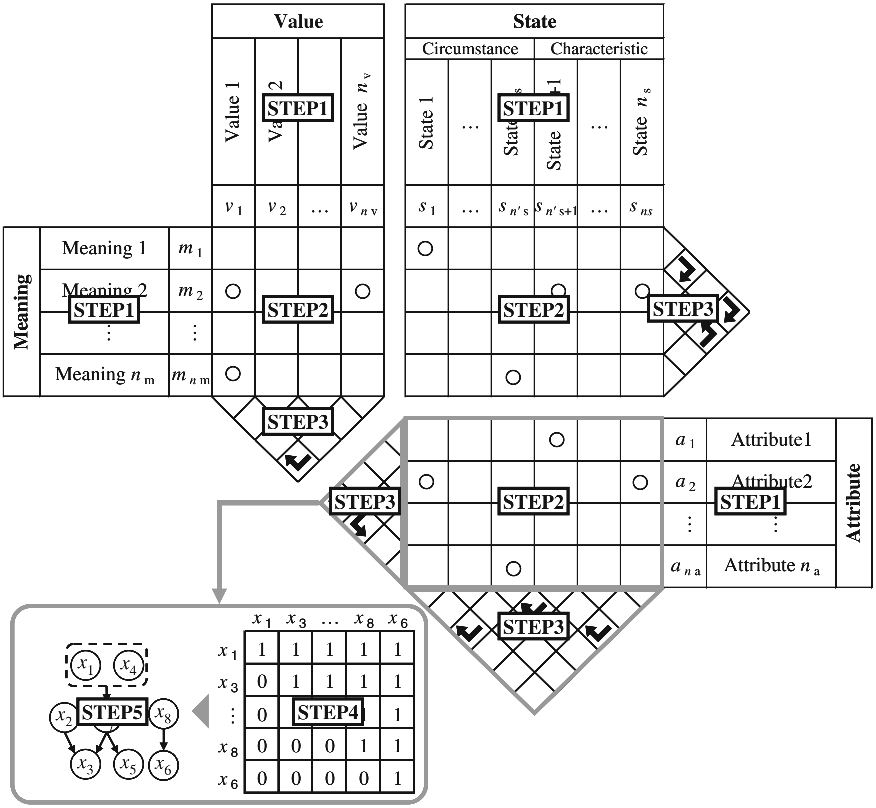


Fig. 6 Procedure of proposed QFD

matrices of each space is constructed (Step 3). Where, Step 1–3 are repeated until the product development members are satisfied. Fourth, the state and attribute correlation matrices are transformed into the direct affective matrices using Eqs. 1 and 5 (Step 4). Where, the value and meaning correlation matrices can be transformed if the members need. Finally, the structural models of them are constructed by the ISM method using the direct affective matrices (Step 5). Based on the structural models, the designers can proceed the parts (attribute) design without design change which is caused by the inadequate design procedure.

5 Illustrative Example

The proposed quality matrices were applied to a design problem of a disc brake to confirm their effectiveness. The common disc brakes generate brake torque by pushing the disc rotor (armature) to the brake pad (friction material) due to the spring force. Figure 7 shows a conceptual diagram of the disc brakes. In this figure, the coil springs located between the coil case and armature push the armature to the brake pad when braking. Whereas, when releasing the brake, the armature is attracted to the coil case by electromagnetic force. To sense that the brake is braking or released, the brake switch is installed on the coil case and flipped by the striker bolt set on the armature. In the disc brake design, the designers should consider a lot of design elements (e.g., the spring characteristics related to the brake torque, the coil characteristics to specify the electromagnetic force, the armature stroke which concerns both drive noise and brake switch characteristics) to realize the ideal brake characteristic (e.g., high brake torque, low drive noise, no brake switch glitch). However, there are trade-off relationship between the characteristics. Hence, there is a high possibilities that design change caused by inadequate design process is occurred.

Figures 8 describe the proposed quality matrices and structural model of the disc brake. These figures shows the followings:

1. The quality matrices composed by the four space deployment charts can describe both the design elements considered in the early process of design (e.g. safety and comfort) and that in the late process (e.g. brake torque and coil material). This enables designers to implement bidirectional design for a whole new product development. Additionally, the matrices can be used through the whole design process, and therefore promote the sharing of the product's information between the development members.
2. The structural model of the attribute elements simply describes the relationship between them and contributes the construction of the ideal product design process free of the design change. Additionally, the structural model of the state elements describe the circumstance elements, and the designers can easily extract and manage the elements related to the circumstance in redesign (improvement design).

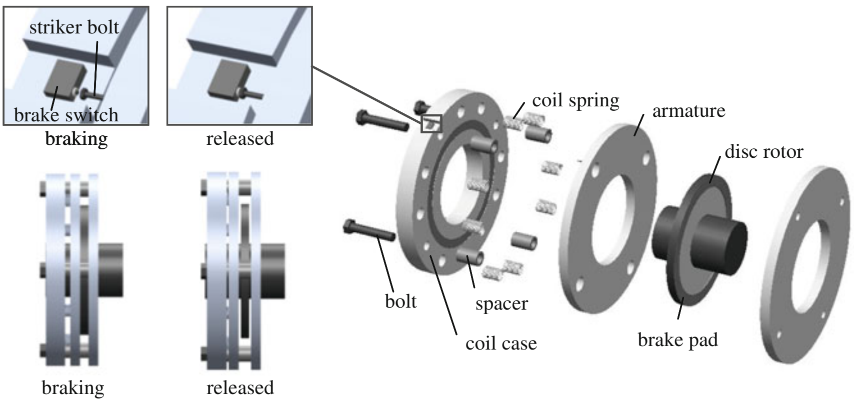


Fig. 7 Conceptual diagram of disc brake

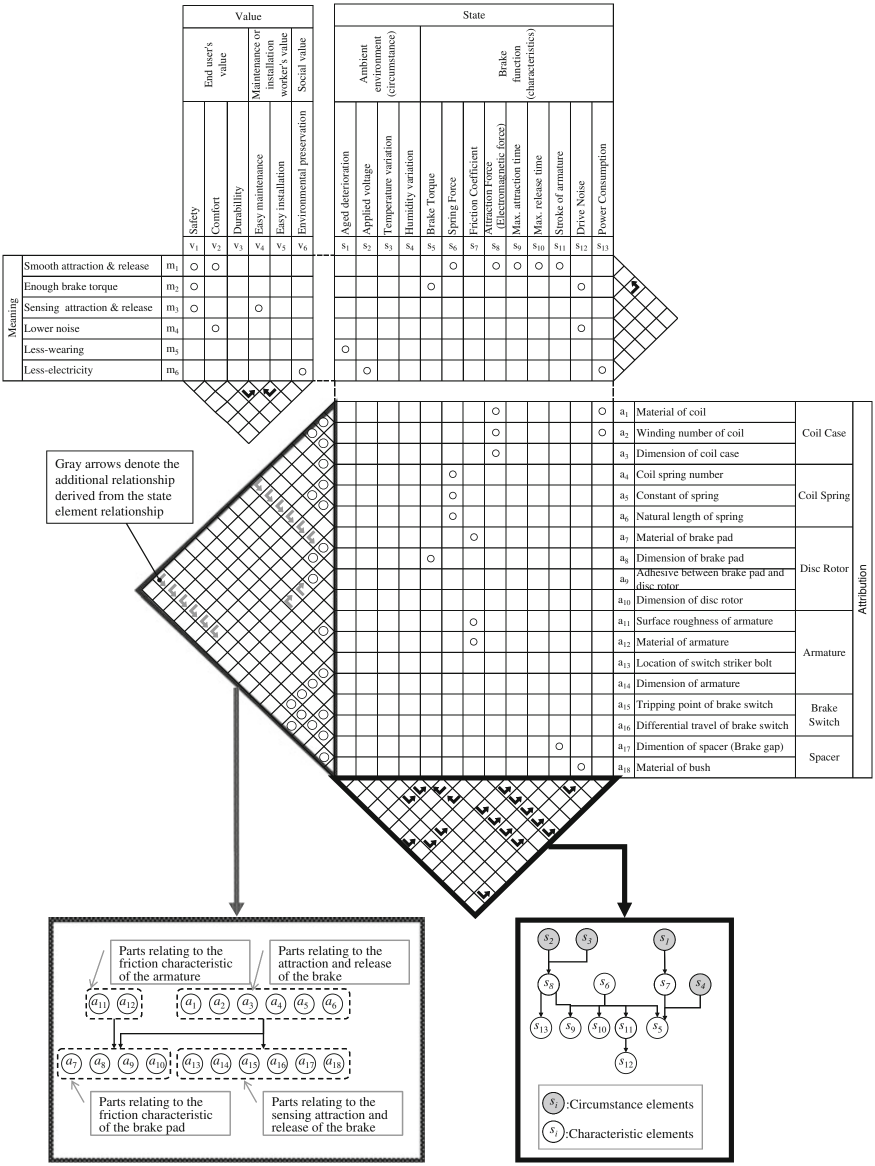


Fig. 8 Quality matrices of disc brake

6 Conclusion

This study introduced the Multispace Design Model and Interpretive Structural Modeling into the Quality Function Deployment (QFD). This introduction was expected to have the following effects:

1. Promoting the bidirectional design which enables the QFD to be applied to the whole new product development;
2. Increase the sharing information of the product between the development members;
3. Easier extracting and managing the elements related to the circumstance of the design object;
4. Assisting the construction of the ideal product design process free of the design change.

Additionally, the proposed QFD was applied to a design problem of the disc brake, and its applicability was confirmed. Future work should implement the followings:

1. Application of both the proposed and the conventional QFD to the same product development in order to confirm the effectiveness of the proposed one;
2. Many design application, including novel design, redesign, and improvement design, in order to confirm the versatility;
3. Designer survey on user friendliness.

Acknowledgments This work was supported by the Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research (C) (23611037).

References

1. Matsuoka Y (2010) Design science. Maruzen
2. Poel IVD (2007) Methodological problems in QFD and directions for future development. Res Eng Design 18:21–36
3. Akao Y (1990) Quality function deployment. Integrating customer requirements into product design. Productivity Press, Boca Raton
4. Akao Y (1989) Result of Questionnaire for application status on quality deployment—report of quality deployment research section. Qual J JSQC 19(1):35–44
5. Bode J, Fung RYK (1998) Cost engineering with quality function deployment. Comput Ind Eng 35:587–590
6. Matsuoka Y (2010) Multispace design model as framework for design science towards integration of design. In: Proceedings of international conference on design engineering and science 2010 (ICDES2010), Tokyo
7. Olsen SA (1982) Group planning and problem-solving methods in engineering. Wiley, London
8. Warfield JN (1976) Societal systems: planning, policy and complexity. Wiley, London

Exploring a Multi-Meeting Engineering Design Project

John S. Gero, Jiang Hao and Sonia da Silva Vieira

Abstract This paper reports a case study of a multi-meeting engineering design project lasting 5 months, unlike most design studies that focus on a single meeting. The project involved an engineering consultancy for the design of a robot controller. The design team consisted of engineers with different backgrounds. Eight sequential design meetings were studied using protocol analysis. The video recordings of these meetings were transcribed and then segmented and coded using an ontologically-based coding scheme. The analysis of these meetings focused on differences in the distributions of design issues and syntactic design processes between adjacent meetings. Statistically significant differences between some adjacent meetings were observed, which implies changes in design behavior between those meetings.

Keywords Multi-meeting project · Protocol analysis · FBS ontology

J. S. Gero (✉)
Krasnow Institute for Advanced Study, George Mason University, Fairfax, USA
e-mail: john@johngero.com

J. S. Gero
University of North Carolina, Charlotte, USA

J. Hao
Division of Industrial Design, National University of Singapore, Kent Ridge, Singapore
e-mail: didjh@nus.edu.sg

S. da Silva Vieira
IDMEC, Faculty of Engineering, University of Porto, Porto, Portugal
e-mail: sonia.vieira@fe.up.pt

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_6,

1 Introduction

The overwhelming majority of studies into engineering design, whether they are conducted in the laboratory or in the office, are of single design sessions or meetings. There are a few studies of engineering design that involve two meetings (e.g., [1]). In practice most design projects are spread out over time and involve the design team in multiple meetings. It is important to study such multi-meeting projects both to determine differences in design behavior between multi-meeting and single meeting design projects and differences in design behavior between several meetings of one project. This paper reports on the results of comparing adjacent meetings of a case study of a multi-meeting engineering design project.

Design meetings are considered as a sampling technique for investigating a lengthy design projects [1]. In the field of design cognition research, protocol analysis has been identified as the dominant methodology, aiming to explore cognitive processes underlying designers' behaviors [2–4]. This is a resource intensive methodology with a high ratio of analysis time to observation time; the observed design activities were usually of a limited duration, ranging from a few minutes to 1 or 2 h [5]. It is thus inappropriate to directly apply the existing methods focusing on the observation scale of minutes or hours on a lengthy project lasting a few weeks or months. Some adoptions were made by reducing the resolution of observation, e.g., omitting the minute-by-minute details, to track a longer design project [6–8]. This kind of approach fails to capture the transient cognitive events and interactions/transitions between thoughts.

This paper uses eight sequential meetings to represent an engineering robotic controller design project lasting 5 months. The remainder of the paper commences by describing the engineering design project and providing an overview of the eight meetings that made up the design sessions of the project with a qualitative description of the activities in each meeting. This is followed by an outline of the protocol analysis method used to produce the base data, which is in the form of a sequence of design issues and design processes for each of the eight meetings. These design issues and design processes are derived from an analysis of the transcriptions of the meeting videos using the Function-Behavior-Structure (FBS) ontologically-based segmentation and coding approach. The sequences of design issues and design processes are then analyzed as statistical distributions and comparisons between adjacent meetings are made.

2 An Engineering Design Project

In this engineering design case study, eight sequential meetings took place during a period of 5 months for the design of a robot controller. This project was the subject of a research project developed in collaboration with a design team of engineers with different backgrounds in mechatronics, namely: software/hardware,

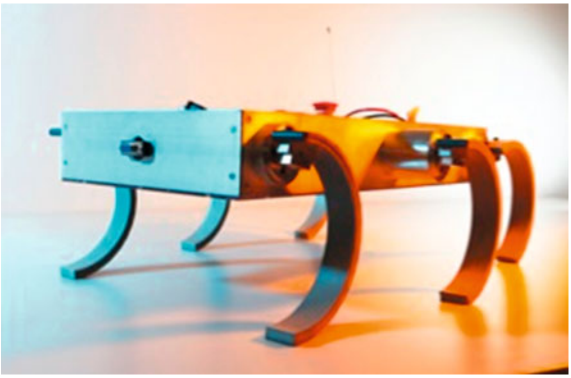


Fig. 1 Prototype of the robot hexapod

control, aerospace and electronics engineering. The design was based on a previous similar robotic controller, nevertheless the team faced several unexpected situations and challenges. The robot prototype is illustrated in Fig. 1.

Table 1 provides an overview of the meetings, their lengths, topics, team members' attendance and qualitative division of the eight meetings into two fundamental stages. Each of these meetings lasted approximately 1 h. In the first month, three meetings were dedicated to analyzing and clarifying specifications and production planning. In the second month a fourth meeting initiated the testing and detailing tasks that lasted until the end of the observation period. The three meetings in the last 2 months focused more on evaluations of problems, detailing and testing. Issues of specification analysis, connection systems, power supply, costs, and identification and analysis of problems were mostly discussed in these meetings.

3 Ontologically-Based Protocol Analysis

Each these eight meetings was videotaped, the utterances in them were transcribed and the transcriptions were then converted into a sequence of design issues using a principled coding scheme developed from the Function-Behavior-Structure (FBS) ontology [9, 10]. The FBS ontology models designing by three classes of ontological variables: function, behavior, and structure. The function (F) of a designed object is defined as its teleology, the behavior (B) of that object is either derived (Bs) or expected (Be) from the structure, where structure (S) represents the components of an object and their compositional relationships. These ontological classes are augmented by requirements (R) that come from outside the designer and description (D) that is the document of any aspect of designing, Fig. 2.

The FBS ontologically-based coding scheme consists of these six codes, each represents a particular aspect of design cognition. Application of this coding scheme can segment and encode the meeting videos (i.e., design conversations and gestures, etc.) into a sequence of design issues denoted with semantic symbol, i.e.,

Table 1 Overview of meetings during the design of a robot control

Month	1st			2nd	3rd	4th		5th
Meeting	1	2	3	4	5	6	7	8
Duration	1 h 06 min	1 h 03 min	1 h 08 min	52 min	34 min	52 min	1 h 01 min	58 min
Topic	Detailed discussion about the specifications and solutions	Planning, outsourcing and power supply	Discussion about the internal communication of the robot	Assembly of sub-parts, connections, testing and details	Discussion of software, defining tests and connections	Identification of problems, connections and detail	Complete assembly, Identification of problems, detailing and testing	Identification of problems, detailing and testing
Stage	Clarifying specifications, production planning				Concept generation, evaluations of problems, detailing and testing			
Team member: Leading researcher	√	√	√	√	√	√	√	√
Electronics Engineer	√	√	√	√	√	√	√	√
Software Engineer	√	√	√		√	√	√	√
Technician	√	√		√	√	√	√	√

LR: Leading Researcher, **EE**: Electronics Engineer, **SE**: Software Engineer, **TC**: Technician

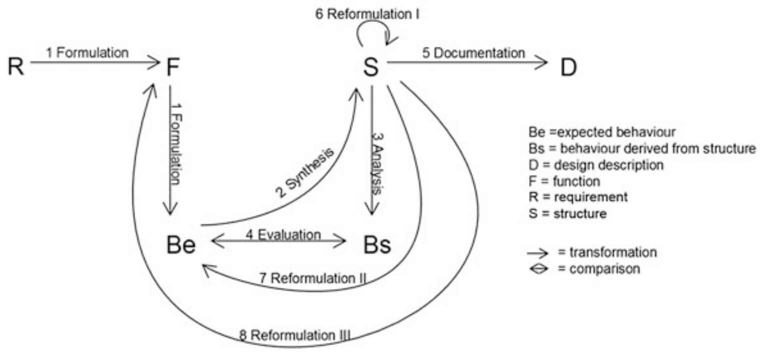


Fig. 2 The FBS ontology (after [10])

the FBS codes. The transitions between adjacent design issues were then defined as eight types of syntactic design processes, as numbered in Fig. 2 [9, 10].

The transformed data of these eight design meetings, namely eight sets of design issues and syntactic design processes, became the foundational data for subsequent analyses. Design cognition is multifaceted. Design issues and syntactic design processes measure two orthogonal dimensions of design cognition, respectively responding to the content-oriented and process-oriented analyses of design cognition.

4 Method of Analysis

Each design meeting's frequency distributions of design issues and syntactic design processes summarize the overall characteristics of the design cognition manifested in that meeting. The cognitive differences between two meetings can be examined by Pearson's Chi square test for independence. When a statistical significance is identified ($p < 0.05$), Cramer's V coefficient is calculated as the effect size to describe the relative strength of the difference between two meetings' issue/process distributions. The possible value of Cramer's V varies from 0 to 1. This study used the value of 0.15 as the threshold to indicate a substantive difference [11, 12].

The cross tabulations (here referred to as cross tabs) are then used as a *post hoc* test to further investigate which specific design issue(s) or syntactic process(es) contributes to the overall cognitive differences between two meetings. Adjusted residuals in a cross tab provide an estimation of the differences between observed and expected values (by assuming the distributions under comparisons are identical to each other). The design issues/processes with a high absolute value of adjusted residuals (≥ 2) indicate that designers are more engaged in those aspects of design cognition in the meeting corresponding to the positive cells, than the other one.

5 Results

5.1 Coding Results

This paper presents preliminary coding results carried out by a single coder. The frequencies of design issues and syntactic design processes were normalized by converting them into percentages; this eliminates the different lengths of the design meetings and the subsequent different number of segments in each meeting. The design issues and syntactic design processes for all the eight design meetings are aggregated and are plotted in Fig. 3 along with the standard deviations. The means for the eight sessions shown in Fig. 3 provide an overall indication of the design cognition of the entire design activity while the standard deviations provide an indication of the variability across the meetings.

The distributions of design issues, Fig. 3(a), indicate that, in each meeting, the majority of design issues were structure and behavior from structure. These two solution-related issues represented about 85 % of total issues. The requirement issues, i.e., input from outside of the design teams, on the other hand, were negligible in this project, only occupying 0.23 % of the total issues. The requirement issue was thus excluded in the following Chi square analysis of design issue distributions.

The most frequent syntactic design processes, shown in Fig. 3(b), were associated with reasoning about the solution space, namely the processes of reformulation I (M = 35.59, SD = 9.91), analysis (M = 32.59, SD = 4.96) and evaluation (M = 16.65, SD = 9.54). Three problem-related processes, i.e., formulation, reformulation II (of expected behaviors) and reformulation III (of

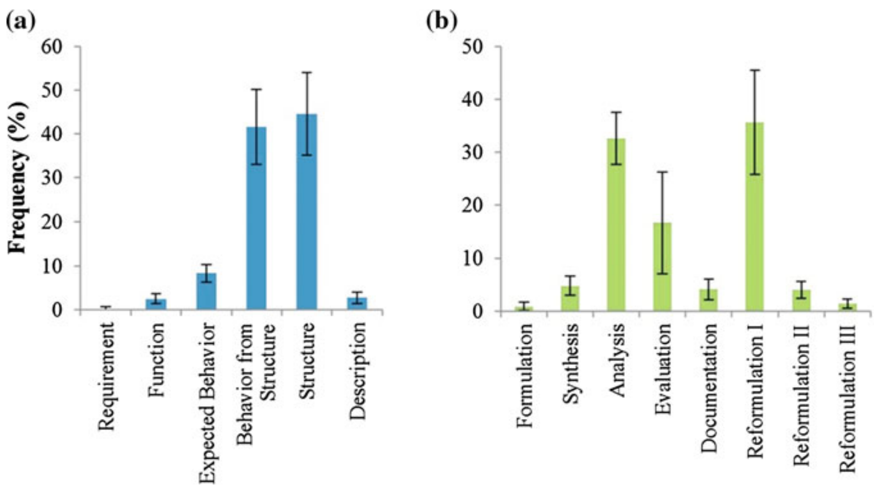


Fig. 3 Frequency distribution of (**a**) design issues and (**b**) syntactic design processes

functions), consumed less cognitive effort; each was less than 5 % of the total processes. They were thus combined as a single category in the Chi square analysis of syntactic process distributions.

5.2 Cognitive Shifts Between Two Adjacent Meetings

The analysis of cognitive progress during the 5 month observation was undertaken by comparing the cognitive changes between two adjacent meetings. The Chi square test results are summarized in Table 2. Two significant cognitive shifts were identified in adjacent meetings: from Meeting 3 to Meeting 4; and from Meeting 6 to Meeting 7.

5.2.1 Cognitive Transition Between Meetings 3 and 4

The comparisons of specific design issues and syntactic design processes between Meetings 3 and 4 are presented in two cross tabs, Table 3. Meeting 3 was more engaged in the generative aspect of design cognition, indicated by significantly higher percentages of structure issue and the syntactic design process of reformulation of structure (reformulation I). Meeting 4 then shifted to behavioral aspect of design cognition, indicated by higher percentages of expected behavior and behavior from structure issues, as well as the syntactic design process of evaluation.

Table 2 Comparisons of issue/process distributions of adjacent meetings

Comparison	Distr. of issue/process	*df*	Chi square statistics	*p* value	Cramer's V
Meeting 1 vs 2	Issue	4	5.162	0.271	0.092
	Process	5	5.835	0.323	0.123
Meeting 2 vs 3	Issue	4	12.902	0.012*	0.134
	Process	5	5.704	0.336	0.112
Meeting 3 vs 4	Issue	4	19.712	0.001**	0.169
	Process	5	27.161	0.000***	0.263
Meeting 4 vs 5	Issue	4	7.631	0.106	0.124
	Process	5	11.739	0.039*	0.207
Meeting 5 vs 6	Issue	4	1.907	0.753	0.065
	Process	5	0.973	0.965	0.060
Meeting 6 vs 7	Issue	4	20.423	0.000***	0.173
	Process	5	30.06	0.000***	0.282
Meeting 7 vs 8	Issue	4	9.522	0.049*	0.113
	Process	5	12.429	0.029*	0.187

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 3 Comparison between meetings 3 and 4, significant differences are highlighted in bold

(a) Comparison of the design issue distributions

Design issue	Meeting Number	3	4
Function	Count	17	10
	% within the meeting	5.0	2.8
	Adjusted residual	1.5	−1.5
Expected behavior	Count	25	46
	% within the meeting	7.4	13.1
	Adjusted residual	−2.5	**2.5**
Behavior from structure	Count	123	163
	% within the meeting	36.5	46.4
	Adjusted residual	−2.6	**2.6**
Structure	Count	166	124
	% within the meeting	49.3	35.3
	Adjusted residual	**3.7**	−3.7
Design description	Count	6	8
	% within the meeting	1.8	2.3
	Adjusted residual	−0.5	0.5
Total	Count	337	351
	% within the meeting	100.0	100.0

(b) Comparison of the syntactic process distributions

Syntactic design process	Meeting#	3	4
(Re-)formulation of function and expected behavior	Count	17	10
	% within the meeting	8.5	5.2
	Adjusted residual	1.3	−1.3
Synthesis	Count	9	12
	% within the meeting	4.5	6.3
	Adjusted residual	−0.8	0.8
Analysis	Count	61	55
	% within the meeting	30.3	28.6
	Adjusted residual	0.4	−0.4
Evaluation	Count	21	56
	% within the meeting	10.4	29.2
	Adjusted residual	−4.7	**4.7**
Documentation	Count	6	7
	% within the meeting	3.0	3.6
	Adjusted residual	−0.4	0.4
Reformulation I (of structure)	Count	87	52
	% within the meeting	43.3	27.1
	Adjusted residual	**3.4**	−3.4
Total	Count	201	192
	% within the meeting	100.0	100.0

Table 4 Comparison between meetings 6 and 7, significant differences are highlighted in bold

(a) comparison of the design issue distributions

Design issue	Meeting#	6	7
Function	Count	6	9
	% within the meeting	2.0	2.4
	Adjusted residual	−0.3	0.3
Expected behavior	Count	23	31
	% within the meeting	7.7	8.1
	Adjusted residual	−0.2	0.2
Behavior from structure	Count	111	202
	% within the meeting	37.0	53.0
	Adjusted residual	−4.2	**4.2**
Structure	Count	155	134
	% within the meeting	51.7	35.2
	Adjusted residual	**4.3**	−4.3
Design description	Count	5	5
	% within the meeting	1.7	1.3
	Adjusted residual	0.4	−0.4
Total	Count	300	381
	% within the meeting	100.0	100.0

(b) Comparison of the syntactic process distributions

Syntactic design process	Meeting#	6	7
(Re-)formulation of function and expected behavior	Count	11	6
	% within the meeting	5.8	3.2
	Adjusted residual	1.2	−1.2
Synthesis	Count	8	5
	% within the meeting	4.2	2.6
	Adjusted residual	0.8	−0.8
Analysis	Count	58	83
	% within the meeting	30.7	43.9
	Adjusted residual	−2.7	**2.7**
Evaluation	Count	25	51
	% within the meeting	13.2	27.0
	Adjusted residual	−3.3	**3.3**
Documentation	Count	5	4
	% within the meeting	2.6	2.1
	Adjusted residual	0.3	−0.3
Reformulation I (of structure)	Count	82	40
	% within the meeting	43.4	21.2
	Adjusted residual	**4.6**	−4.6
Total	Count	189	189
	% Within the meeting	100.0	100.0

5.2.2 Cognitive Transition Between Meetings 6 and 7

The cognitive shift between Meetings 6 and 7 is articulated in Table 4. Resembling the previous cognitive change between Meetings 3 and 4, the latter meeting shifted from an emphasis on generative aspect of design cognition (indicated by higher percentages of structure issue and the process of reformulation I) to engage more in the evaluative aspect of design cognition (indicated by higher percentages of behavior from structure issue and the processes of analysis and evaluation).

6 Discussion

The engineers in this design project had previous experience in designing robot controllers. Many robotic components, such as the microcontroller, and battery were continuously discussed from the first meeting on. This may explain the descriptive statistics result that solution-related design issues and solution-related syntactic design processes constituted the majority of design reasoning in all the eight meetings. The two significant cognitive changes identified in this case study were shifting from a relative focus on the solution generation to an increased focus on the analysis and evaluation of the proposed solutions.

The quantitative comparisons were then triangulated with qualitative assessments of the individual meetings. Meeting 3 focused on the discussion of structure components introduced in Meeting 1. Similar to Meeting 7, Meeting 3 did not continue the topics raised in Meeting 2. The control aspects of the robot are introduced in the next meeting. Meeting 4 seemed to be a “bridge meeting,” discussing some design considerations more in depth, attempting to make connections to other considerations. This may explain that, in this meeting, the cognitive effort spent on reasoning about structure decreased, while the meeting was more focused on the expected consequence of solutions.

Meeting 6 was mainly targeted at a particular technical problem “how to solve the overheating of the board.” A number of alternative solutions were proposed accordingly. Due to the focus on this topic, the percentages of the structure issue and the syntactic process of reformulation I increased in this meeting compared to the previous meetings.

There was a topic shift between Meetings 6 and 7. The latter meeting did not continue the topics raised in Meeting 6. Rather, it reactivated the topics introduced in Meetings 1 and 4, such as CPU and batteries, during the testing process. Behavioral and evaluative aspects of design cognition thus became the focus of this meeting. The cognitive shifts between generative and evaluative modes of designing also indicate the iterative nature of engineering design activities. Later studies will present detailed analyses of design cognition during the critical situations leading to design decisions.

7 Conclusion

This paper presents a preliminary analysis of a multi-meeting engineering design project lasting 5 months during which there were eight design meetings. Design projects in practice regularly involve multiple meetings, and it is important in the development of the understanding of designing that such multiple meeting design projects be studied and comparisons made with single meeting design projects to determine differences. The increased scale of observation, compared to a single design session of 1 or 2 h in most design protocol studies, provides a more nuanced understanding of designing as can be seen in the statistically significant differences found between a number of the design meetings.

When the eight meetings are aggregated into a single set of measurements of design issues and syntactic design processes, Fig. 3, the design issues and syntactic design processes distributions follow the general behavior observed in the single engineering design meetings/sessions used in studies of designing [13, 14] masking any detailed behavioral differences that occur over time. This points to the need for a more detailed study of multi-meeting designing.

Multiple meetings with time gaps provide opportunities for incubation that are not directly available in single meeting design sessions [15, 16]. Incubation plays a role in all areas of human cognition but insufficient is known about the design cognition of incubation. Studies of multiple meetings of professional designers in practice are an alternate to laboratory studies of the cognition of incubation. They may provide the basis of insight into incubation in designing [17].

This paper has demonstrated that it is feasible to carry out a design cognition study of a multi-meeting engineering design project in such a manner that the results are commensurable with such studies of single design meetings. Multiple meetings are the norm in professional engineering design practice. Studying them is critical to the development of our understanding of engineering design. However, it may be that multiple meetings do not exhibit design behaviors that differ from single design meetings but this needs to be tested empirically. If that hypothesis is shown to be supported by the empirical evidence then design scientists need only study individual design meetings.

Later papers will present detailed comparisons of design cognition derived from multi-meetings with the behavior observed in single meeting design sessions. The specific findings in this paper are based on a preliminary coding of the meetings and need to be confirmed.

Acknowledgments This research is supported in part by grants from the US National Science Foundation Grant (Nos. IIS-1002079 and SBE-0915482). The authors gratefully acknowledge the Delft Center for Systems and Control for practical support of this research.

References

1. McDonnell J, Lloyd P (eds) (2009) About: designing: analysing design meetings. CRC Press, Boca Raton
2. Cross N, Christiaans H, Dorst K (1996) Analysing design activity. Wiley, Chichester
3. Gero JS (2010) Generalizing design cognition research. In: Dorst K et al (eds) DTRS 8: interpreting design thinking. University of Technology Sydney, Sydney, pp 187–198
4. Jiang H, Yen CC (2009) Protocol analysis in design research: a review. In: Proceedings of International Association of Societies of Design Research (IASDR) 2009 Conference, Seoul, Korea
5. Bainbridge L, Sanderson PM (2005) Verbal protocol analysis. In: Wilson JR, Corlett EN (eds) Evaluation of human work: a practical ergonomics methodology, 3rd edn. Taylor and Francis, Florida, pp 159–184
6. Waldron MB, Waldron KJ (1988) A time sequence study of a complex mechanical system design. Des Stud 9:95–106
7. Rowe PG (1987) Design thinking. MIT Press, Cambridge
8. Rowe PG (1982) A priori knowledge and heuristic reasoning in architectural design. J Architectural Educ 36:18–23
9. Gero JS (1990) Design prototypes: a knowledge representation schema for design. AI Mag 11:26–36
10. Gero JS, Kannengiesser U (2004) The situated function-behaviour-structure framework. Des Stud 25:373–391
11. Crewson P (2011) Applied statistics handbook (version 1.2). Available: http://www.acastat.com/statbook.htm
12. Dancey CP, Reidy J (2011) Statistics without maths for psychology, 5th edn. Prentice Hall/Pearson, Harlow
13. Kan JWT, Gero JS (2007) Using the FBS ontology to capture semantic design information. In: McDonnell J, Lloyd P (eds) DTRS7. University of the Arts, London, pp 155–165
14. Williams CB, Gero JS, Lee Y, Paretti M (2011) Exploring the effect of design education on the design cognition of mechanical engineering students. ASME IDETC2011 DETC2011-48357
15. Smith SM, Dodds RA (1999) Incubation. In: Runco MA, Pritzker SR (eds) Encyclopedia of creativity, vol 2. Associated Press, San Diego, pp 39–44
16. Smith S, Blankenship S (1991) Incubation and the persistence of fixation in problem solving. Am J Psychol 104:61–87
17. Gero JS (2011) Fixation and commitment while designing and its measurement. J Creative Behav 45:108–115

Integrating Different Functional Modeling Perspectives

Boris Eisenbart, Ahmed Qureshi, Kilian Gericke and Luciënne Blessing

Abstract The paper proposes a modular functional modeling framework, which aims at integrating the different functional modeling perspectives, relevant to different disciplines. The results of two extensive literature studies on diverse functional modeling approaches proposed in a variety of disciplines are consolidated. These studies identified specific needs for an integrated functional modeling approach to support interdisciplinary conceptual design. The presented framework aims at fulfilling these needs. It consists of a variety of associated views, represented through different matrices. This matrix-based representation facilitates the analysis of different functional modeling perspectives and their interdependencies. Finally, the implications of the presented approach are discussed.

Keywords Functional modeling · Functional modeling perspectives · Modeling framework · Interdisciplinary design

B. Eisenbart (✉) · A. Qureshi · K. Gericke · L. Blessing
Engineering Design and Methodology Group, University of Luxembourg, Luxembourg
e-mail: boris.eisenbart@uni.lu

A. Qureshi
e-mail: ahmed.qureshi@uni.lu

K. Gericke
e-mail: kilian.gericke@uni.lu

L. Blessing
e-mail: lucienne.blessing@uni.lu

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_7,

1 Introduction

Functional modeling is proposed in systematic design approaches across disciplines. It is intended to support early concept development for a technical system, i.e. the transition from a design problem to an early solution concept. Functional modeling results in a first abstract representation of the technical system under development. The term "technical system" encompasses both technical products as well as product/service-systems (PSS) in this paper.

Across and within different disciplines a large variety of function models is proposed and a common approach to functional modeling can hardly be found [1–4]. As a consequence, diverse ways of representing functions are competing when designers from different disciplines collaborate, potentially hindering the exchange expertise [1, 5]. Approaches to bridge the existing diversity, so far, have not been successful [2, 6].

This paper consolidates the results of two extensive literature studies on the diverse functional modeling approaches, proposed in a variety of disciplines [3, 4]. The considered studies identified specific needs for an integrated functional modeling approach linking the different functional modeling perspectives, which are prominently addressed in the proposed function models from different disciplines. This paper presents the concept of an integrated functional modeling approach, which aims at satisfying the identified needs.

2 Towards Integrated Functional Modeling

Eisenbart et al. [3] analyzed function models proposed in mechanical engineering design, electrical engineering design, software development, mechatronic system development, service development and PSS design. The particular content addressed by individual function models is linked to different functional modeling perspectives. Seven central perspectives have been identified, which are described in Table 1.

None of the reviewed function models from the different disciplines addresses all identified functional modeling perspectives [3]. In each considered discipline a different set of functional modeling perspectives is prominently addressed. However, Eisenbart et al. [4] identified the *transformation process perspective* to be prominently addressed in functional modeling approaches proposed across all reviewed disciplines. It may, hence, serve as a common basis in an integrated functional modeling approach. Based on the two literature studies by Eisenbart et al.[1] specific needs for such a modeling approach can be formulated. Accordingly, an adequate integrated functional modeling approach should:

[1] Eisenbart et al. considered 70 function models (54 original models plus variants proposed by different authors) and 41 systematic design approaches. The respective references may be taken from [3, 4].

Table 1 Functional modeling perspectives, after [4]

States	Representation of the states a system can be in, or of the states of operands before (input) and after (output) a transformation process. Operands are typically specifications of energy, material, and information
Effects	Representation of the required physiochemical effects, which have to be provided to enable, respectively support, the transformation process(es) changing one state into another state
Trans-formation processes	Representation of the processes executed by stakeholders or technical systems, which (from the designers' perspective) are part of the technical system under development in order to change the state of the system or of operands. *Technical processes* are transformation processes related to technical systems, while *human processes* are related to stakeholders (thus, including service activities)
Interaction processes	Representation of interaction processes of stakeholders or of other technical systems, which (from the designers' perspective) are *not* part of a system, with stakeholders or technical systems, which *are* part of the system under consideration
Use case	Representation of different cases of applying the technical system. This is typically associated to the interaction of stakeholders or another technical system with the technical system under development, which triggers, respectively requires subsequent processes to take place
Technical system allocation	Representation of the role of a technical system, which is supposed to perform or enable a (sub-) set of required *effects* or *processes*, either as part of the technical system under consideration or by interacting with it
Stakeholder allocation	Representation of the roles of different stakeholders, which may be users benefitting from a system or operators contributing to the system, e.g. through executing required processes or providing resources, etc

- …link the identified functional modeling perspectives, in order to relate between information, which is relevant to the designers from the different disciplines.
- …enable flexibly switching between considered functional modeling perspectives, in order to facilitate adaption of the modeling approach to different design approaches.
- …provide a condense and clearly structured representation, in order to ease comprehension of the modeled functions among collaborating designers. Often multiple complementary models are proposed in a functional modeling approach. Comprehensively capturing information distributed across different models can be a difficult cognitive task. However, *one* model covering a large number of functional modeling perspectives may quickly become confusingly packed with information.
- …facilitate linking functions in different ways, in order to be adaptable to discipline-specific representations. Depending on the particular discipline, functions may essentially be linked related to *time* (particularly prominent in software and service development), *input/output relations* (particularly prominent in mechanical engineering design) or *hierarchy*.

- …address impacts from, respectively on the environment, in order to facilitate finding viable solution concepts [7]. Only few authors explicitly consider the environment within functional modeling (e.g. [8, 9]). However, impacts from the environment on a technical system may impair function fulfillment. In turn, impacts from a technical system on the environment may be critical to e.g. safety requirements or environmental legislation.

Beyond these needs, additional options are discussed by Eisenbart et al. [3], which may considerably support the reasoning about functions within system conceptualization; such as considering function-sharing, the inclusion of quantities, as well as a stronger link between the functional model of a system and its structure.

3 Integrated Functional Modeling Framework

In order to meet the needs discussed in the previous section, this paper proposes the integrated functional modeling framework (IFM framework), which aims at supporting integrated modeling of the identified functional modeling perspectives.

3.1 Development of the IFM Framework

In the development of the functional modeling framework, different alternatives have been generated. Firstly, an attempt was made to adapt existing functional modeling approaches to satisfy the specific needs discussed above. For this, several approaches have been selected, which already cover a large variety of the different functional modeling perspectives. Each generated alternative has been applied for re-modeling examples of existing function models from the literature as well as an example from industry. The generated models and approaches have been comparatively evaluated.

From the authors' point view, merely expanding existing approaches has not resulted in suitable integrated modeling approaches: The respective models frequently seemed overburdened with the represented information and thus quickly became very difficult to comprehend. Often, the dependencies between the different functional modeling perspectives in relation to the central *transformation process perspective* could not adequately be addressed. Also, the link between individual functional modeling perspectives often became fuzzy, with the result that individual perspectives could hardly be reasoned upon disconnected from others.

Existing function models typically use blocks or circles for depicting transformation processes, states, effects, etc. These elements are typically arranged *circular* or in *vertical/horizontal* flows. The functional modeling framework presented in the following, instead, uses a modular, *matrix-based* representation, which allows modeling and retrieving information more clearly. The developed approach is related to the concept of multi-domain matrices (MDM) proposed by Lindemann and Maurer [10]. MDM map different design information, in order to facilitate analysis and representation of interdependencies. Similarly, the IFM framework aims at clearly representing information associated to the individual modeling perspectives and their dependencies.

3.2 Outline of the IFM Framework

The IFM framework consists of associated modular matrices representing different views onto the functions of a system under development. The central view (*process flow view*) addresses the *transformation process perspective*, which is prominent in functional modeling approaches across disciplines. Associated views use matrices to represent information about the different entities and their interdependencies in the modeling framework. The entities are directly linked to the specific functional modeling perspectives discussed above (see Table 2).

The framework of modular, adjacent views provides a clearly structured representation and allows taking different views on the functions of a technical system. This modular structure allows addition or omission of views related to the specific needs of the involved designers. The following sub-section describes the entities and their relations, which form the basis of the IFM framework. Section 3.2.2 describes the associated views, which form the representation of the IFM framework.

3.2.1 Entities and their Relations

The class diagram in Fig. 1 represents the relations between individual entities in the developed modeling framework. A technical system under development may support one or more use cases. Each use case may be decomposed into sub-use cases. Use cases may have dependencies among each other that may be bound by

Table 2 Entities in the IFM framework and addressed functional modeling perspectives

Entity	Addressed functional modeling perspective
Use case	Use case perspective
State	States (operands and system)
Process	Transformation process and interaction process perspectives
Effect	Effect perspective
Actor	Stakeholder and technical system allocation perspective; system state perspective
Operand	Operand state perspective

specific constraints (mutually exclusive, mutually inclusive etc.,). For all other situations, in Fig. 1, the dependencies shown will be used to depict the similar constraints.

A use case may have one or more transformation process associated to it. There may be dependencies between individual transformation processes, which may or may not be also composed of sub-processes. A transformation process results in the transformation of one or more operand and/or actor from a given state into another. Such state transformations are enabled, respectively supported by effects, which are provided by actors. Actors, by providing the necessary effects, act as operators in transformation processes. Actor is a super class which contains the sub classes of stakeholder, technical (sub-) system, and environment. The actor sub-class of stakeholder comprises (groups of) animate beings affected by or affecting the technical system under consideration (including any related services). The actor sub-class of technical (sub-) system encompasses technical systems which are sub-systems to the technical system under development. It can also be composed of more technical (sub-) systems. Actors also may have dependencies among each other. Environment includes all active and passive parts of nature in general surrounding the system under development.

3.2.2 Associated Views

The different views are strongly linked to each other through the adjacent placement and the respectively shared header rows and header columns in the specific matrices forming the individual views (see Figs. 2, 3, 4, 5). The aim behind this specific set-up is to interlink all the different functional modeling perspectives (i.e. the corresponding views), prominent in the different disciplines, via the *transformation process perspective* (i.e. the central *process flow view*), which is

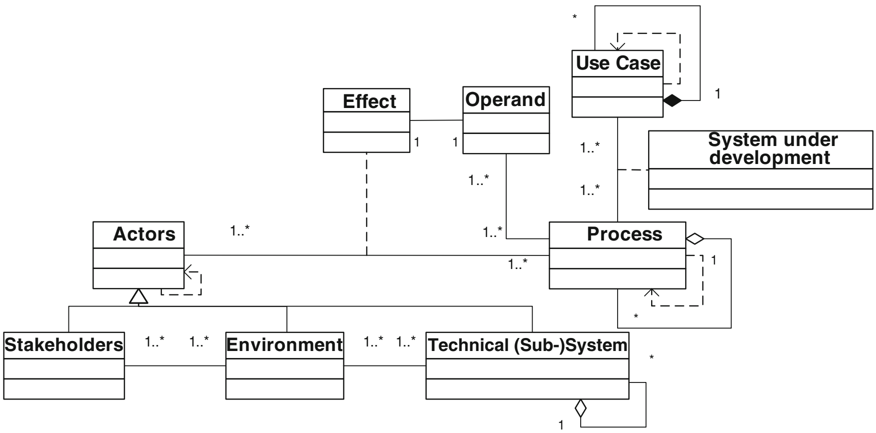


Fig. 1 Class diagram of the developed functional modeling framework

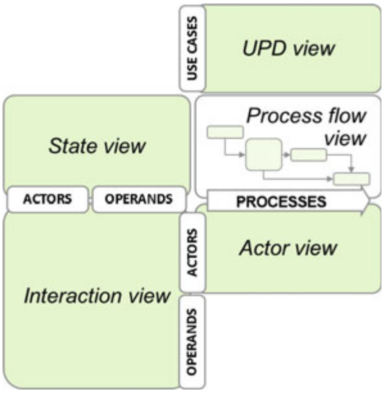


Fig. 2 Adjacent views in the IFM framework

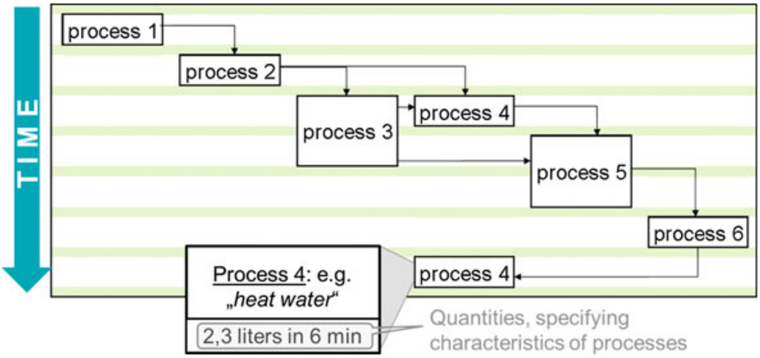


Fig. 3 Process flow view

prominent across disciplines. The individual views and how they link to each other are described in the following.

The *Process flow view* visualizes the flow of processes related to a specific use case. In the view individual processes are represented as chronologically numbered blocks. In the vertical direction, the process flow related to time is visualized. The flow qualitatively illustrates whether individual processes are expected to be carried out sequentially, in parallel or to be overlapping with other processes. The process blocks are furthermore spread horizontally from left to right, so as to enable a direct link to the *actor view* matrix, which is described further down. As an option, quantities related to individual processes can be included to specify processes further, as illustrated in Fig. 3.

The *Effect view* represents the effects, which enable individual transformation processes and are provided by actors. For each process block in the *process flow view*, a separate *effect view* may be created. Similar to the *process flow view*,

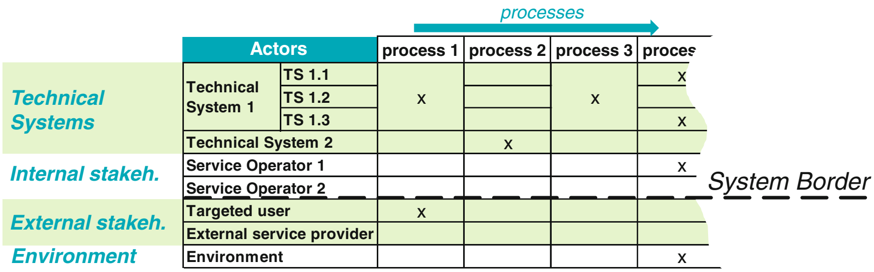


Fig. 4 Actor view matrix

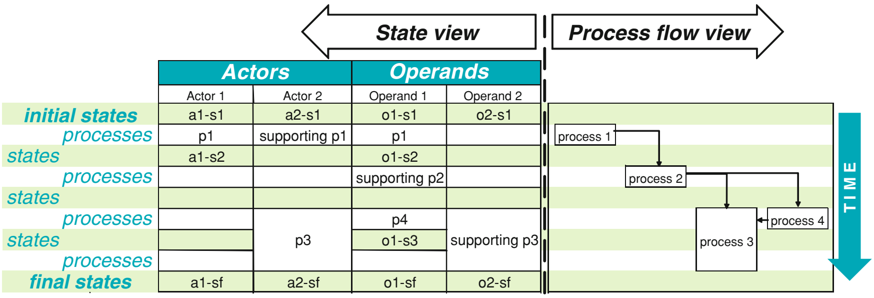


Fig. 5 System states view associated to process flow view

effects can be modeled related to time or flow of operands. Hierarchical trees or alternative models (similar to [7, 8]) may also be applied.

The *Use case/process dependency* (*UPD*) *view* indicates the involvement of individual processes within different use cases. The individual use cases are listed in the header column. The matrix is directly linked to the *process flow view*. The individual—strictly horizontally ordered—process blocks build up the header row for the *UPD view* (see Fig. 2). Dependencies between use cases and processes could affect their operability. For instance, the processes of "heating water" in one use case and the process of "cooling water" in another use case should not be executed in parallel for the same water sample; hence, neither should the respective use cases.

The *Actor view* indicates the involvement of specific actors in the realization of transformation processes. Transformation processes are spread in the header row, associated to the process flow view (see Fig. 2). Within the matrix, involvement may initially be indicated with an "x". As more information becomes available in the design process, the particular role of actors (e.g. as either "affecting" or "being affected" by a process) can be more concretely specified.

The *actor view* allows differentiating actors according to whether they—from the designers' point of view—are part of the system under development (e.g. service operators as part of a PSS) or not (e.g. the targeted users or external service providers). This differentiation is particularly important in PSS design [11]. Through this differentiated allocation, individual processes are separated between *transformation processes* (enabled by actors which are part of the system) and *interaction processes* (enabled by actors which are not part of the system).

The *States view* represents the specific states of operands and agents as well as the state changes caused by individual processes. The *system states view* consists of the *actor state matrix* and the *operand state matrix*, and is a modular addition to the *process flow view* (see Figs. 2 and 5). The adjacent placement of the *system state* and *process flow views*, as shown in Fig. 5, allows the development of the views and the verification of their consistency. Considering the required changes from initial to final states of operands and actors facilitates the development of the *process flow view* and vice-versa. The system state view also allows the indication of operands supporting a transformation process without changing their states.

Figure 5 illustrates, e.g., that a process "heat water" (process 1) is linked to a change of the technical system (actor 1) from switched-off (a1-s1) to switched-on (a1-s2), supported by an operator (actor 2), as well as a change of the state of water (operand 1) from liquid (state o1-s1) to steam (new state o1-s2). The steam may then be used to drive a turbine (process 2), which may give rise to changes to other operands and/or actors. During this process, the state of the water (i.e. steam) is not changing, but supporting process 2.

The *interaction view* depicts the specific interactions between actors and operands, as well as among each other, in the realization of processes. The view uses operands and actors as both heading column and heading row, as illustrated in Figs. 2 and 6. The specification of the interaction between actors or operands includes the number of the respective process (to provide clarity, as numerous interactions may occur related to different processes) and a short statement specifying the interaction. Analysis of interferences between actors and/or operands may highlight problems with function fulfillment. Also, information about how actors and operands may impact on each other facilitates the design of the interfaces between them accordingly in later design phases.

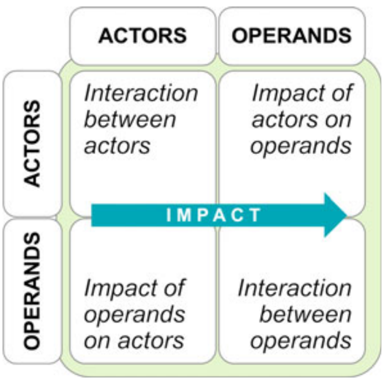


Fig. 6 Concept of interaction view matrix

To give an example, a stakeholder (actor) may have an impact on a technical system (actor) by pushing a button. Similarly, hot water (operand) may impact on a technical system (actor) through transmitting heat or vise-versa. Finally, operands may also impact on each other, as for instance, cold water (operand) may be used to cool hydraulic fluids (operand) and vise-versa. In case, the specifics of an interaction cannot be specified at an early point in the modeling process, the respective cell may initially be marked with an 'x'. Optionally, information about how the interaction is embodied may be included; such as 'mechanical contact' between the stakeholder's finger and the button being pushed.

3.3 Application

The presented framework may be applied in different ways, i.e. depending on the specific approach taken by designers, alternative entry points and sequences of steps may be applied. One potential sequence of modeling activities for an original design project is described in the following. Starting point may be a comprehensive requirements specification (or similar).

- Step 1—*Use Case definition* includes the consolidation of the different use cases (and their sub-use cases, if applicable) the system under development is expected to support in the different phases of its life-cycle. The use cases are represented in the respective column in the *UPD view*.
- Step 2—*Process flow modeling* involves modeling separate flows of required transformation and interaction processes related to each (sub-) use case. A multitude of alternative process flows may fulfill a use case. As described above, modeling and selecting an alternative process flow may be facilitated through considering the required state changes of (supporting) operands in the *operand states matrix* (as part of the *state view*). While modeling the process flows, the involvement of processes in multiple use cases (represented in the *UPD view*) needs to be considered.
- Step 3—*Effect modeling* involves modeling the required effects related to the specific process flows. Considering the basic required effects enabling transformation processes may considerably support the allocation of actors in the following step.
- Step 4—*Actor allocation* includes allocation of the actors, which are involved in the individual processes, either as affecting or being affected through the delivered effects. Actor allocation may be supported through applying the function-means pattern, morphological charts or similar approaches. Carefully considering re-use of allocated actors in different processes and use cases may facilitate function sharing.
- Step 5—*State modeling* includes modeling the state changes of allocated actors in the actor state matrix (as part of the *state view*) related to the chosen process flows.

- Step 6—*Interaction specification* involves analyzing and detailing the specific interactions (i.e. the bilateral impacts) among actors, among operands, and between actors and operands in the realization of processes.

There can be iterations within and between individual steps. For instance, depending on the specific choice of realizing actors, the chosen process flows may have to change, requiring iterations between steps 2–4. *Actor allocation* essentially marks the transition from the problem to the solution. However, the final set of *process flow view* and *actor view* merely represents one potential concept out of large number of variants.

Modeling starts on a high level of abstraction defining the use cases, associated processes etc. On the next level of detail, individual process blocks may then be regarded as use cases comprised of sub-processes. These are enabled by technical (sub-) systems (which may again be comprised of general function carriers or "organs" [8], which are gradually concretized) including any related service operator etc. Thus, the framework allows modeling the functions and actors of a system under development from very abstract to very detailed and concrete.

4 Discussion and Conclusion

Functional modeling is proposed across disciplines to support early concept development. The different functional modeling perspectives prominently addressed in the different disciplines need to be integrated in order to support interdisciplinary functional modeling. In this paper, an integrated modeling framework has been proposed, which aims at linking the different functional modeling perspectives. The proposed framework uses interlinked modular matrices, representing different views on the functions of a system under development. The different views represent individual functional modeling perspectives and/or dependencies between them. It is expected to provide designers from different disciplines with a valuable approach to functional modeling, as it.

- uses an established matrix-based approach for analyzing and representing interdependencies between functional modeling perspectives, similar to MDM;
- considers all identified functional modeling perspectives and their interdependencies;
- is expected to ease communication across disciplines, as the different views are linked via a central view, which is commonly prominent across disciplines;
- is modular, which enables addition or omission of views and related modeling activities depending on whether these are needed in a specific design context;
- allows using different views separately; the designers may flexibly switch between considered views, which allows focusing on specific functional modeling perspectives;

- the strong links between the modular matrices representing the different views provide a clearly structured representation supporting comprehension of complex systems;
- allows embedding existing (discipline-specific) function models[2];
- is open for existing functional taxonomies to be embedded;
- can address the functions of a technical system on different level of detail/abstraction;
- is expected to be easily transferrable into a software tool;
- finally, integrated the consideration of the environment.

In summary, the proposed functional modeling framework aims at fulfilling the formulated needs and—through its specific structure—is expected to support the exchange of discipline-specific expertise during system conceptualization. The explicit inclusion of the specific interactions between individual actors is further expected to provide links to models used in subsequent design phases (e.g. system structure, interface matrix, etc.,). Apart from the presented views, the framework may be further expanded. For instance, additional views may address the dependencies among different states (for both operands and actors), different use cases, different processes (across use cases) etc.

Future research will address the practical application of the developed framework by designers in industry. That will include workshops, wherein practical designers from different disciplines apply the developed framework in conceptual design of mechatronic systems and PSS. It will be of particular interest which specific functional modeling perspectives are most relevant to designers from different disciplines and how designers reason between the different proposed views in different design contexts. The gained insights and feedback from the designers will be used to develop the framework further, in order to improve its applicability in different design contexts.

Acknowledgments The authors would like to thank the Fonds Nationale de la Recherche Luxembourg for funding this research as well as Prof. Mogens Myrup Andreasen (DTU Copenhagen), Prof. Pierre Kelsen (Luxembourg University), and Hubert Moser (LuxSpace) for valuable feedback on earlier versions of the presented functional modeling framework.

References

1. Erden M, Komoto H, van Beek TJ, D'Amelio V, Echavarria E, Tomiyama T (2008) A review of function modeling—approaches and applications. Artif Intell Eng Des Anal Manuf 22:147–169

[2] This has only been briefly discussed related to the description of the *effect view*. However, numerous other cases wherein alternative existing models may be applied (either complementing or in exchange for matrices associated to a specific view) can be thought of.

2. Vermaas P (2011) Accepting ambiguity of engineering functional descriptions. Proceedings of 18th international conference on engineering design, ICED, pp 98–107
3. Eisenbart B, Blessing LTM, Gericke K (2012) Functional modeling perspectives across disciplines—a literature review. Proceedings of 12th international design conference, design
4. Eisenbart B, Gericke K, Blessing L (2012) A shared basis for functional modeling. Proceedings of 9th Nord design conference
5. Müller P, Schmidt-Kretschmer M, Blessing L (2007) Function allocation in product-service-systems—are there analogies between PSS and mechatronics? AEDS Workshop
6. Carrara M, Garbacz P, Vermaas P (2011) If engineering function is a family resemblance concept. Appl Ontol 6:141–163
7. Pahl G, Beitz WFJ, Grote K-H (2008) Engineering design—a systematic approach. Springer, Berlin
8. Hubka V (1984) Theorie technischer systeme—grundlagen einer wissenschaftlichen konstruktionslehre. Springer
9. Watanabe K, Mikoshiba S, Tateyama T, Shimomura Y, Kimita K (2011) Service design methodology for cooperative services. Proceedings of the ASME IDETC/CIE
10. Lindemann U, Maurer M (2007) Facing multi-domain complexity in product development. In: Krause FL (ed) The future of product development, Springer, Berlin
11. Tan AR (2010) Service-oriented product development strategies

Part II
Design Creativity, Synthesis, Evaluation and Optimization

Information Entropy in the Design Process

Petter Krus

Abstract In this paper the design process is viewed as a process of increasing the information of the product/system. Therefore, it is natural to investigate the design process from an information theoretical point of view. The design information entropy is introduced as a state that reflects both complexity and refinement, and it is argued that it can be useful as some measure of design effort and design quality. The concept of design information entropy also provides a sound base for defining creativity as the process of selecting areas for expanding the design space in useful direction, "to think outside the box", while the automated activity of design optimization is focused, so far, on concept refinement, within a confined design space. In this paper the theory is illustrated on the conceptual design of an unmanned aircraft, going through concept generation, concept selection, and parameter optimization.

Keywords Information entropy · Design complexity · Product platform

1 Introduction

During the process of design, information is gradually increased as the design progress, and the uncertainty of the design is reduced. Every design decision reduces the uncertainty of the design, as well as parameter calculations do. It could be argued that this is the central aspect of design. Design in general is about

P. Krus (✉)
Department of Management and Engineering, Division of Fluid and Mechatronic Systems, Linköping University, Linköping, Sweden
e-mail: petter.krus@liu.se

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_8, © Springer India 2013

increasing the information of the product/system. This can be viewed as a learning process, as described in [1]. Therefore, design theory should really be a theory of design information. Although there is a rich literature regarding design process, there has been little or no effort to describe the generation of information in quantitative terms.

The classical information theory of communication was founded in 1948 by C.E. Shannon with his paper "A Mathematical Theory of Communication" [2]. Subsequently it has been recognized that information is a key property of design, and for describing and analyzing the design process. The notion of information theory in design has been introduced by several authors. Notables are Suh [1, 3], Kahn and Angeles [4] and Frey and Jahangir [5]. The two first are discussed later in the text. Frey and Jahangir deals with the transformation of information content in design parameters to information content in the functional characteristics, so is Bras and Mistree [6] where robustness is defined from maximizing the signal to noise ratio, which also deals with the relation between design parameters and functional characteristics. Information theory was also used to analyze design optimization in Krus and Andersson [7]. Information theory has also been used to define complexity in software, and notably by Bansiya et al. [8] to describe complexity in object oriented systems, which is very close to general design.

The notion of information is used in the second axiom of Suh's Axiomatic design, which states that the information content in a design should be minimized [9].

2 The Characteristics of Design Information Entropy

2.1 Design Information

In a product, the design information x is transformed into functional attributes y

$$\mathbf{y} = \mathbf{f}(\mathbf{x}) \tag{1}$$

The design information could be the bit string in a CAD-file, and/or the set of parameters in a design that at some stage are free. It could also be the genome in an organism. The design information is the code of the design space *D*; every bit-combination represents a unique design in the design space. At this stage it is not necessary to separate design parameters from system architecture, it is all included in x. If only little information is present, only parts of the design space can be excluded, the design can be any of several unique designs. This introduces a presence of uncertainty, since the design is not precisely known. An important aspect of design information is that it can only be defined relative to a design space. The design space need not, however, be static, but can be expanded if found necessary. This is also the case in the genome in biological systems, where, different organism has different sizes of the genome. The definition of design information used here is therefore:

> Design information is the information needed to define a design, relative to a design space, to within a certain precision.

As a consequence, information is the inverse of uncertainty since lower precision results in less design information needed to describe a design.

2.2 Design Space

In order to generate a concept, a design space has to be established first. The design space contains all the possible designs. A Lego™ set is an example of a design space. A large number (although finite) number of designs can be build from a particular set. Another design space is represented by all the different Lego pieces. Different finite design spaces are then represented by the different number of pieces allowed in the design i.e. 1, 2… n pieces.

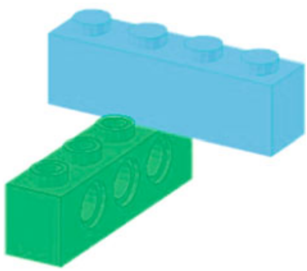
Figure 1 The design space of a set of Lego bricks represents all (discrete) combinations of arranging these bricks, n_{Dstate}. With a set of only two bricks with four knobs on each there are 51 discrete possible arrangements (two of these represents picking only one brick and one state is to pick no one).

The 51 different configuration (states) means that the amount of information needed to specify a particular design is:

$$I_x = \log_2 n_{Dstate} = \log_2 51 = 5.7 \text{ bits} \tag{2}$$

Another example is the design space provided by all standard components, or a product platform i.e. a car platform that is used to generate different cars in a product family. Design space generation is also made in parameterization of models such as CAD models or simulation models. By coupling parameters to each other to reflect different constraints in the design, a smaller more efficient design space can be produced, where waste in the form of unfeasible designs is

Fig. 1 Design in a design space of two Lego bricks



minimized. This means that less information is needed to arrive at a particular design from the design space.

2.3 Design Information Entropy

The definition of Information entropy for the discrete case is defined by Shannon [2]

$$H_d = \sum_{i=1}^{n} p_i \log_2 p_i \tag{3}$$

Here the system can be in n different states with probabilities p_i for each of them.

A more general definition than the information entropy for the discrete case is the differential information entropy for continuous signals, defined by Shannon [2] as:

$$H_c = -\int_{-\infty}^{\infty} p(x) \log_2(p(x)) dx \tag{4}$$

This gives a measure of the average information content of a variable x. Here $p(x)$ is the probability density function. One problem with this expression is that it does not make sense unless x is dimensionless, since the probability density function has the unit of the inverse of x. If not, the differential entropy of the probability density function $p(x)$ needs to be related to another distribution $m(x)$. The result is called the Kullback-Leibler divergence [10] from the distribution $m(x)$. This is the relative entropy, and it is defined as:

$$H_{rel} = \int_{-\infty}^{\infty} p(x) \log_2\left(\frac{p(x)}{m(x)}\right) dx \tag{5}$$

This is the difference in entropy between having information that a random variable is within $m(x)$, and knowing that it is within the distribution $p(x)$. Furthermore, it represents a measure of information in bits. It can also be generalized to any dimensionality.

$$H_{rel} = \int_{-\infty}^{\infty} \cdots \int_{-\infty}^{\infty} p(x_1 \ldots x_n) \log_2\left(\frac{p(x_1 \ldots x_n)}{m(x_1 \ldots x_n)}\right) dx_1 \ldots dx_n \tag{6}$$

A rectangular distribution of $m(x)$ in the bounded interval $x \in [x_{\min}, x_{\max}]$, with $x_R = x_{\max} - x_{\min}$, would mean that the distribution $m(x)$ of the *design spac*e is a space of equal possibilities, where no particular region can be considered more likely than another a priori. Other distributions can also be considered but they can always be mapped on a rectangular distribution by transforming the design space, which can be very useful (this also includes infinite distributions), for i.e. design optimization. Equation (5) can then be rewritten as:

$$I_x = H_{rel}(x) = \int_{x_{\min}}^{x_{\max}} p(x) \log_2(p(x)x_R)dx \tag{7}$$

The letter I is here used here to indicate relative information entropy related to a rectangular distribution, and it has the unit *bits*. For the multidimensional case it becomes:

$$I_x = \int_{x_{1,\min}}^{x_{1,\max}} \cdots \int_{x_{n,\min}}^{x_{n,\max}} p(x_1 \ldots x_n) \log_2(p(x_1, \ldots x_n)x_{R1} \ldots x_{Rn})dx_1 \ldots dx_n \tag{8}$$

This can also be written in a more compact form as:

$$I_x = \int_D p(\mathbf{x}) \log_2(p(\mathbf{x})S)d\mathbf{x} \tag{9}$$

where D is the design space. I_x is defined as the *design information entropy* where the design $\mathbf{x}$ is defined within the design space D. S is the size of the design space and is defined as:

$$S = \int_D \mathbf{x}d\mathbf{x} \tag{10}$$

If the range of one variable is divided into equal parts Δx that have the same probability, the probability density distribution will be:

$$\begin{aligned} p(x) &= \frac{x_R}{\Delta x} : x \in \left[x_{0,\min}, x_{0,\max}\right] \\ p(x) &= 0 : x \notin \left[x_{0,\min}, x_{0,\max}\right] \end{aligned} \tag{11}$$

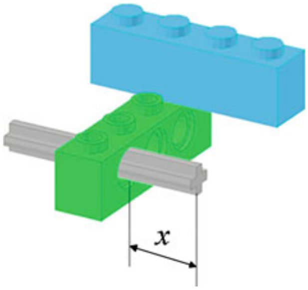
where:

$$x_R = x_{0,\max} - x_{0,\min} \tag{12}$$

This yields the information content (in bits) for that variable as:

$$\begin{aligned} I_x &= \int_{-x_{\min}}^{x_{\max}} \frac{x_R}{\Delta x} \log_2\left(\frac{x_R}{\Delta x}\right)dx \\ &= \log_2 \frac{x_R}{\Delta x} = \log_2 \frac{1}{\delta_x} = -\log_2 \delta_x \end{aligned} \tag{13}$$

Fig. 2 Design with both discrete and continuous variables



where Δx is the uncertainty of the variable, and x_R its design range. δ_x is introduced as the relative uncertainty in parameters. The same expression holds if the probability distribution is normally distributed. In that cases:

$$\delta_x = \frac{2\sigma_x}{x_R} \tag{14}$$

Here σ_x is the standard deviation in x. In the following text it is assumed that the uncertainty can be described by δ_x. If the lego^{TM} example is expanded with an axis, the position of the inserted axis represents a continuous variables x. The information entropy associated with that, is dependent on the accuracy Δx with which it is specified, and the number of discrete positions (three) where it can be placed Fig. 2.

$$I_x = \log_2 n'_{Dstates} + \log_2 \frac{x_R}{\Delta x} \tag{15}$$

The axis can be in three positions (adding three discrete states) and if the position of the axis within one hole is specified within 10 % the total information entropy is:

$$I_x = \log_2(51 + 3) + \log_2 \frac{1}{0.1} = 8.2 \text{ bits} \tag{16}$$

The concept of design information entropy hence provides a framework for defining design information in very general terms. It is the information that causes the uncertainty of the design to be shrunk from an initial state high uncertainty, to another state with less uncertainty.

3 Design Information Entropy in the Design Process

3.1 Design Space Generation

In information theoretical terms the design space corresponds to the reference distribution $m(x)$ of the Kullback-Leibler divergence, or in this case the design

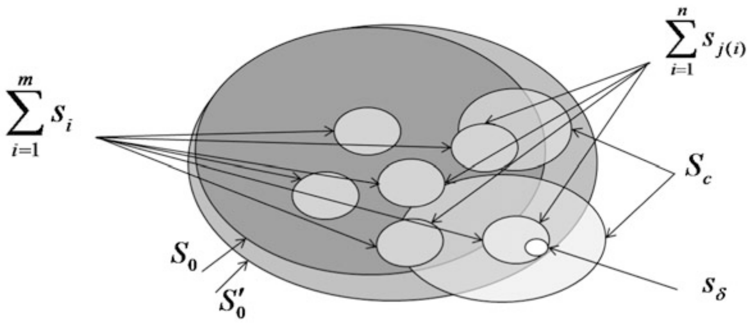


Fig. 3 Subspaces of the design space

space D_0, with the size S_0, against which the design information entropy is defined. Within the design space concepts s are generated. In general only part of the design space falls within the constraints of the design D_c, with the size S_c, finally the refined final design represents only a small fraction of a concept Fig. 3 s_δ.

3.2 Concept Generation

In concept generation, the design space is limited by selecting n_0 subsets of possible concepts for further analysis. This represents an increase in information. If the design space distribution $m(x)$ is rectangular and uniform over the design space D_0 and each concept i occupies the region with the size s_i the information generated in this phase is:

$$I_I = -\log_2 \frac{\sum_{i=1}^{n_0} s_i}{S_0} \tag{17}$$

In general the amount of information generated in this stage is quite large. It involves selecting a few concepts from a highly dimensional multi modal design space.

3.3 Concept Screening

In this phase concepts that have no or little possibility of being successful are eliminated. If the concepts are reduced from n_0 to n concepts in this phase, the information added is:

$$I_{II} = -\log_2 \frac{\sum_{i=1}^{n} s_{j(i)}}{\sum_{i=1}^{n_0} s_i} \tag{18}$$

For the special case that all regions are of the same size it becomes:

$$I_{II} = -\log_2 \frac{n}{n_0} \tag{19}$$

3.4 Aircraft Design Example

Aircraft design is a good example of a complex product that involves all the phases illustrated in Fig. 6.

Design space generation constitute the process of collecting possible elements needed for the design in response to functional requirements. Looking at existing design there is a variety in concepts that can be dissected into components to recreate a design space from where they all can be derived. From the example in Fig. 4, there are various arrangements for wing and tail arrangements, engine location, etc.

There is a tail at the end of the fuselage, or at a twin boom arrangements, there are inverted butterfly tail and conventional tail. The engines can be mounted front or rear. The horizontal stabilizer can be mounted aft or forward (canard configuration) and

With these as example a design space can be defined some design elements can be identified.

- The horizontal stabilization front, aft or integrated in the main wing. In the aft configuration it can also be integrated with the vertical stabilizer in a butterfly tail.
- Vertical stabilization can be central or at wing tip, or integrated with horizontal configuration. It can be upwards or downwards.
- The tail arrangement can be located on a single fuselage or on twin boom arrangements.

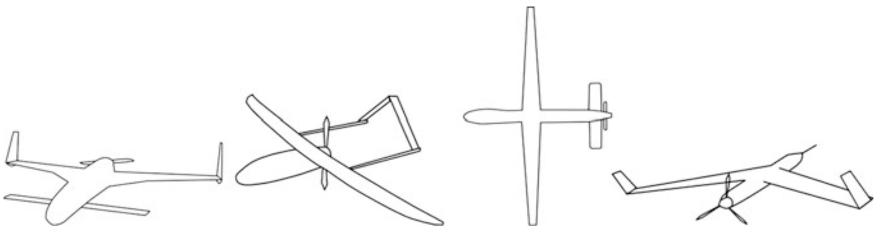


Fig. 4 Some UAV configurations

Table 1 Morphological matrix for aircraft

Design elements	Alternative solutions			
Horizontal stabilization	Front (canard)	Aft	Aft fin integrated	Wing integrated
Vertical stabilization	Central	Wing tip	Integrated	Upper
Tail mount	Single fuselage	Twin Boom		
Propulsion	Tractor	Pusher		

- Although these example all have pusher prop (in order to have a clear front view for sensors), a prop in the front is of course also possible. The fuselage could be a single or with a twin boom after section.

One popular tool for concept generation is the morphological matrix (or table). It was introduced in [6]. Here a table is set up where, for each function, a list of alternative solution elements is presented. A specific concept is obtained by selecting one solution element for each function. The morphological matrix represents a tool to display a design space of possibilities. Table 1 shows a morphological matrix for aircraft configuration.

The total number of possibilities, n_s, is in the general case:

$$n_s = \prod_{i=1}^{n_f} n_{m,i} \tag{20}$$

where n_s is the number of functions. In the example this becomes functions:

$$n_s = 4 \times 5 \times 2 \times 2 = 80 \tag{21}$$

This represents information entropy of

$$I_w = I_c = -\log_2 \frac{s_c}{s} = -\log_2 \frac{1}{80} = 6.32 \text{ bit} \tag{22}$$

That means that selecting one of the configurations in the design space represents 6.32 bits of information. An interesting property of the information entropy is that it is roughly proportional to the number of design elements.

3.5 Concept Optimization and Selection

For making concept selection, it is really necessary to do an optimization of each concept left, to investigate its properties at the optimal parameter set. The optimization process then represents the contraction of the domain for each concept down to a domain of specified tolerance s_δ. The increase in information for optimizing all concepts and selecting one concept, k, is represented by:

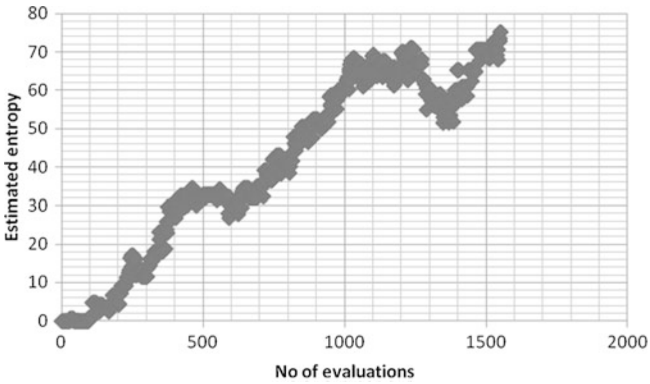


Fig. 5 Accumulation of information as a function of number of objective function evaluations

$$I_{III} = -\log_2 \frac{s_{\delta k}}{\sum_{i=1}^{n} s_{j(i)}} \tag{23}$$

An initial optimization of aircraft concept can be done using handbook formula based on physics and statistics from existing designs as in [11], especially if the concept is similar to an existing product.

For the aircraft example typical design parameters would be; wing span, root cord, tapering, thickness, and sweep, structural weight, fuel weight, engine size, wing position, span of horizontal tail, cruise speed.

Other parameters could be established using simple design rules, e.g. the vertical fin. Here the Complex-RF method [7] is used for the optimization. It is a method that is interesting because it is easy to estimate the information entropy as the optimization progress as a function of the spread of parameter set, as the optimization start with a spread the same size as the original design space (given by the constraints of the parameters). In this example 11 parameters was used as the accumulation of information entropy for one particular concept is shown in Fig. 5. The information entropy is estimated as:

$$\hat{I}_x = -n \log_2\left(\max\left(\delta_{x,i}\right)\right) \tag{24}$$

where $\delta_{x,i}$ is the relative uncertainty in the ith parameter. It is defined as:

$$\delta_{x,i} = \frac{x_{i,\max} - x_{i,\min}}{x_{0,i,\max} - x_{0,i,\min}} \tag{25}$$

Here the denominator represents the original design space for the optimization. At about 1,200 evaluations there is a reduction in estimated entropy as the solution moves away from a false optimum. In the end the entropy has increased about 75 bits.

4 Discussion

The design information entropy should be seen as a measure of the design space that has been under consideration during the design process. As such it provides some measure of the effort that has been going into the design.

To be effective it is desirable to have a small design space, but that still contain sufficiently good designs. A hallmark of a good design space is therefore that it is easy to assemble viable designs from a limited set of design elements, where there are ready to use sub systems and components that can be combined into new products e.g. like in a Lego set, or a good product platform. It can also be applied to parameterization of a design. In a perfect parameterization, all parameter combinations should yield viable designs, or at least possible geometries. In fact the fraction of viable parameter combinations can be seen as a quality of a parameterization [9]. This means that a smaller design space needs to be searched during design optimization.

The concept of design information entropy also provides a sound base for defining creativity as the process of selecting areas for expanding the design space, "to think outside the box", it can also be the process of navigation in highly dimensional multimodal design spaces for concept generation, which is simplified by a limited design space, with few unviable designs.

5 Conclusions

A formal theory of design should be based on the generation and transformation of information during the design process, and information theory provides a set of tools that can be used in this context. In this paper it is demonstrated that introducing design information entropy as a state, can be used for quantitative description for various aspects in the design process, both regarding structural information regarding architecture and connectivity, as well as for parameter values, both discrete and continuous. It is consistent with the view that the design process is a learning process i.e. where information is gained as uncertainty is reduced.

It is also clear that the design of the design space as such, is critical to promote creativity by making viable design alternatives clear to the designer, not obstructed among noise of a sea of unviable designs.

References

1. Ullman DG (1992) The mechanical design process. McGraw-Hill Book Co, Singapore. ISBN 0-07-065739-4
2. Shannon D (1948) A mathematical theory of communication. Bell Syst Tech J 27:379

3. Suh NP (2001) Axiomatic design: advances and applications. Oxford University Press, USA, ISBN-0-19-513466-5
4. Khan WA, Angeles J (2007) The role of entropy in design theory and methodology. In: Proceedings of CDEN/C2E2 2007 conference, Winnipeg, Alberta, Canada
5. Frey D, Jahangir E (1999) Differential entropy as a measure of information content in axiomatic design. In: Proceedings of the 1999 ASME design engineering technical conference, Las Vegas, USA
6. Bras B, Mistree F (1995) Compromise design decision support problem for axiomatic and robust design. J Mech des Trans ASME 117
7. Krus P, Andersson J (2004) An information theoretical perspective on design optimization. ASME, DETC, Salt Lake City, USA
8. Bansiya J, Davies C, Etzkorn L (1999) An entropy-based complexity measure for object oriented design. Theor Pract Object Syst 5(2):111–118
9. Amadori K, Lundström D, Krus P Automated design and fabrication of micro-air vehicles. Accepted for publication on journal of aerospace engineering, proceedings of the institution of mechanical engineers part G [PIG], doi:10.1177/0954410011419612
10. Kullback S, Leibler RA (1951) On information and sufficiency. Ann Math Stat 22:79–86
11. Torenbeek E (1982) Synthesis of subsonic airplane design. Kluwer Academic Publishers, ISBN 90-247-2724-3
12. Zwicky F (1948) The morphological method of analysis and construction. Courant, Anniversary volume, Intersciences Publisher, New York, pp 461–470
13. Krus P, Jansson A, Palmberg JO (1993) Optimization using simulation for aircraft hydraulic system design. In: Proceedings of IMECH international conference on aircraft hydraulics and systems, London
14. Rosenbrock HH (1960) An automatic method for finding the greatest or least value of a function. Comput J 3:175–184

Mitigation of Design Fixation in Engineering Idea Generation: A Study on the Role of Defixation Instructions

Vimal Viswanathan and Julie Linsey

Abstract Design fixation is considered to be a major factor influencing engineering idea generation. When fixated, designers unknowingly replicate the features from their own initial ideas or presented examples. The study reported in this paper investigates the effects of warnings about the undesirable features on design fixation. The authors hypothesize that if designers are given warnings about the undesirable example features along with the reasons for those warnings, fixation to those features can be mitigated. In order to investigate this hypothesis, a controlled experiment is conducted with novice designers. The participants are randomly assigned to one of the three experiment groups: a Control, Fixation or Defixation. Participants in all the groups generate ideas for the same design problem. It is observed that even when the warnings are present, designers replicate the flawed features in their ideas. Further, this paper compares said result with the findings in the existing literature.

Keywords Concept generation · Defixation instructions · Design fixation

1 Introduction

In the current competitive economy, introduction of novel products and services to the market is necessary for any industry to exist and being profitable. Engineering design attempts to satisfy the needs in the market through effective generation,

V. Viswanathan · J. Linsey (✉)
School of Mechanical Engineering, Georgia Institute of Technology,
Atlanta, GA 30332, USA
e-mail: julie.linsey@me.gatech.edu

V. Viswanathan
e-mail: v.viswanathan@gatech.edu

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_9,

development and implementation of novel and creative ideas. In this process, early concept generation plays a very vital role. For the success of any engineering design effort, generation of novel and creative ideas at this stage is highly crucial.

While considering creativity and innovation in early concept generation, it is essential to consider design fixation. According to Jansson and Smith, design fixation is the adherence of a designer to his or her initial ideas or features of presented examples [1]. When design fixation is present, it limits the solution space where the designers search for their ideas. This restricts the generation of novel ideas to a great extent. In most of the cases, design fixation causes serious threat to the early concept generation stage.

In recent times, many researchers have investigated the issue of design fixation and potential ways of mitigating fixation [2–6]. In this paper, the authors investigate the role of defixating instructions in the forms of warnings in the mitigation of design fixation to a flawed example. Building on the prior work [2, 5], the authors hypothesize that with the help of proper warnings about the undesirable features in a fixating example, design fixation can be mitigated. This paper outlines a controlled between-subject experiment conducted to investigate this hypothesis. The obtained results provide mixed support to the hypothesis. Further sections in this paper summarize the relevant literature review, method followed and a discussion of the results obtained.

2 Background

The first set of experiments that revealed design fixation effects in engineering design were performed by Jansson and Smith [1]. They found that when an example was present, both expert and novice designers replicated the features of that example in their solutions. After the publication of said study, many other researchers successfully demonstrated fixation effects of pictorial examples in concept generation. In a replication of Jansson and Smith's study, Purcell and Gero [7] found that design fixation effects varied across engineering disciplines. They observed that industrial design students fixated less compared to mechanical engineering students. More recent research showed that more realistic representations like photographs [8] and physical prototypes [9, 10] could also lead to design fixation.

Many researchers have investigated the possible ways to mitigate design fixation. Incubation and provocative stimuli are two potential candidates for this purpose. In incubation, fixated designers set their design problem aside temporarily. Many times, they can generate innovative ideas once they return their attention to the problem [11–13]. In the cases of provocative stimuli, some external stimuli provide a change of reference to the designers, in that process breaking their fixation [14, 15]. Linsey et al. [3] demonstrate that design fixation in faculty can be mitigated to a significant extent with the help of defixation materials that include alternate representations of the design problem. These defixation materials include a list of potential analogies, some back-of-the-envelope calculations and a direct list of energy sources that the designers can use. However, a more recent study shows that the defixating effect of these materials depends on the level of expertise of the designers [6].

In a very recent study, Youmans shows that when the example is presented in the form of a physical model and when the designers are allowed to test that model, they do not copy the example features in their designs [4]. In a very similar study, Viswanathan et al. [5] show that novice designers building and testing the physical models of their ideas, identify the problems with fixation and mitigate those gradually. Providing a physical example instead of a pictorial one also causes an improvement in the quantity of non-redundant ideas generated [10].

A very interesting study on mitigation of design fixation is conducted by Chrysikou and Weisberg [2]. They replicate Jansson and Smith's experiments [1] in extremely similar conditions. They observe that when the designers are warned about the flaws in an example, they tend to fixate less to the features of the same. These warnings also include explanations about why the features are flawed. Based on this result, Viswanathan et al. [5] provide warnings to novice designers about the flaws in a poor example, without specifying why those features are flawed. Interestingly, it is observed that the designers fixate more when they are given such warnings. One potential explanation is the curiosity of designers about the flawed features, due to lack of explanation about the flaws. Building upon said studies, this paper extends the investigations on the potential of proper warnings in mitigating design fixation to a more complicated design task. The hypotheses investigated further in this paper are the following:

Fixation Hypothesis: Designers fixate to the features of the flawed example presented to them.

Defixation Hypothesis: The fixation of designers to a flawed example can be mitigated with the help of warnings about the undesirable example features along with the reasons for those warnings.

3 Method

In order to evaluate the hypotheses presented above, a between-subject controlled experiment was conducted. This experiment was designed based on the some prior studies on design fixation [3, 6]. In the experiment, the participants were randomly assigned to one of the three experiment groups: Control, Fixation or Defixation. All the participants generated ideas to solve a design problem. The materials provided to the participants varied across the conditions. The occurrence of fixating features across the conditions was analyzed to infer the effects of fixating and defixating materials provided. The following subsections detail of the design problem, experiment conditions, procedure followed and the metrics used for evaluation of the data.

3.1 Design Problem

All participants in the experiment solved a "peanut sheller" design problem. This problem was successfully used in many prior studies dealing with various aspects of design cognition [3, 6, 16, 17]. This design problem instructed participants to generate ideas for a device that can quickly and efficiently shell a large quantity of peanuts without using electricity. The device was expected to be used by the farmers in West African countries. The device was expected to control the extent of damage to the peanuts while shelling them. This problem presented the challenges of a real-life design to the participants. None of the participants were familiar with this design problem before the experiment, but they all had experienced the routine task of shelling peanuts.

3.2 Experiment Groups

The participants were randomly assigned to one of the three experiment groups: Control, Fixation or Defixation. The details of each group are described below:

3.2.1 Control Group

The Control Group generated ideas to the above mentioned design problem without the help of any additional materials. They received a design problem statement along with the instructions to record their ideas. They were instructed to sketch and label their concepts along with one or two sentences describing the working of the concept on plain sheets of paper.

3.2.2 Fixation Group

This group received the same design problem and instructions as the Control Group along with the sketch of an example solution to the design problem. The sketch of the example provided to the participants is shown in Fig. 1. This example was developed originally by Linsey et al. [3, 16] and consisted of features that commonly appeared in participant solutions. These common solution features had higher potential to fixate designers [18, 19]. This example featured a gasoline (gas)-powered press that crushed the raw peanuts to shell them. The raw peanuts were imported to the system by a hopper and guided to the press by a conveyor-inclined surface combination. After shelling, the shells and peanuts fell into a collection bin at the bottom of the press. This system possessed certain shortcomings. A gas-powered system was too complicated and un-economical for manufacture and use in a less industrialized economy. With a gas-powered press, it was very difficult to control the damage to peanuts. Also, after shelling, this system did not necessarily separate the shells from the peanuts. Though these shortcomings were not stated explicitly, all the participants had sufficient mechanical engineering background to infer these.

3.2.3 Defixation Group

The defixation group received the same design problem and instructions along with the sketch of example solution shown in Fig. 1. In addition to those, the participants also received warnings about the flawed features of the example. Specifically, the following sentences were provided to the participants along with the example sketch: "Note that this system is NOT a good solution for peanut shelling. The gas press is costly and complex for usage in rural parts of African countries. This system does not have any control on the damage to peanuts from the pressure applied. Also, the system cracks the shell, but does NOT necessarily remove the shell from the nut." These warnings specifically warned the participants about the flawed features in the example along with the reasoning for those features to be flawed. According to the Defixation Hypothesis, these warnings were expected to help the participants in the mitigation of their fixation to the example.

3.3 Participants

All the participants in this study were senior undergraduate students attending a capstone design course at Mechanical Engineering Department of Texas A&M University. A total of 33 students (9 female) volunteered for this experiment and they were equally distributed across the three groups. One to four students par-

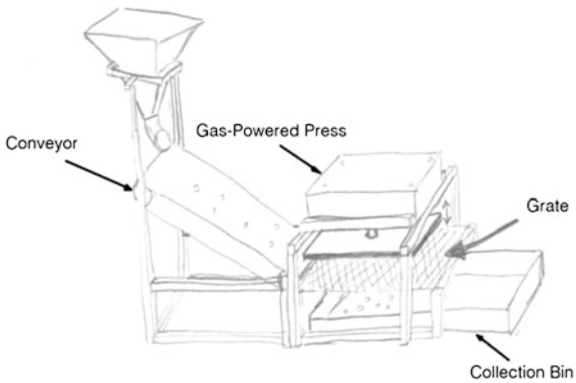


Fig. 1 Sketch of the example solution provided to the participants

ticipated in the experiment at a time, with their work spaces separated with dividers. The participants received extra credit in their design class or monetary compensation for their participation. In order to encourage generation of many ideas, a prize was announced for the person with greatest number of concepts. However, in order to ease the logistics, this prize was given to all the participants at the end of their experiment. None of the participants possessed significant design experiences.

3.4 Procedure

As the participants entered the experiment room, they were guided to randomly assigned work spaces. When the experiment began, they received the design problem statement and instructions along with the additional materials (example sketch or example with warnings about the flawed features), depending on their experiment group. They were given 5 min to read and understand the problem and instructions. Then they were instructed to generate as many concepts as possible within the available time (45 min) for idea generation. Multiple colors of pens were used to track the time interval in which a concept was generated. The pens of the participants were exchanged at 5, 10 and then every 10 min. At the end of idea generation, the participants were asked to mark any analogies they used to come up with their concepts. Finally, the participants were asked about their prior exposure to the peanut sheller design problem or its solutions.

3.5 Metrics for Evaluation

According to the hypotheses presented, the example sketch was supposed to fixate designers to its own features and the warnings about the flawed features in the example were expected to mitigate this fixation to some extent. For evaluating these arguments, design fixation at two different levels were measured: fixation to the example as a whole and fixation to the specific flawed features that the participants were warned about. The fixation to the whole example was measured using two different metrics: Quantity of non-redundant ideas and the percentage of example ideas used. The fixation to said flawed features was measured using the percentage of concepts with each flawed feature.

Quantity of non-redundant ideas was based on the metric originally proposed by Shah et al. [20] and further developed by Linsey et al. [16]. For the purpose of this study, an idea was defined as the one that solved one or more functions in the functional basis [21]. A number of ideas constituted a concept, which was defined as a solution to the problem in hand. Each concept generated by the participants was broken down to a number of ideas with the help of the functional basis. For calculating the quantity, repeated ideas were counted only once. For the Fixation and Defixation groups, the ideas presented by the example were counted as redundant and hence were not included in the calculation of the quantity. The number of example features used by a participant was normalized by the total number of ideas in the example to obtain percentage of example ideas. This metric provided a measure of the extent of fixation to example concept. These two metrics were found to be reliable with high inter-rater agreements in the prior studies by the authors [6, 10].

As specified by the warnings provided to the Defixation Group, the example concept contained three flaws: the use of gas as power source, lack of control to the damage of peanuts and the failure to separate the shelled peanuts from the shells. In order to measure the fixation to these flaws, the occurrences of these flaws in participants' concepts were identified. The number of occurrences of these flaws in a participant's concepts was normalized by the total number of concepts generated by that participant to obtain the percentage of concepts with flawed features.

4 Results and Discussion

This study aims to understand the usefulness of warnings about flawed features in mitigation of design fixation to a flawed example. As stated in the previous section, the fixation is studied in two different levels: fixation to the example as a whole and fixation to the flawed ideas that the participants are warned about. The following subsections provide the details of the results obtained for each of these categories.

4.1 Fixation to the Whole Example

4.1.1 Quantity of Non-Redundant Ideas

Variation of quantity across the experiment groups reveals interesting trends. Figure 2 shows the variation of mean quantity across the experiment groups. As evident from the figure, the Fixation Group produced a lower quantity of non-redundant ideas, demonstrating that the participants in that group are fixated to the presented example. At the same time, the Defixation Group produce a higher quantity compared to the Fixation Group, showing evidence of defixation. Overall, this metric provides support to the argument that designers can be defixated with the help of suitable warnings about the fixating features.

A one-way ANOVA with a priori contrasts [22] is performed to analyze the data statistically. The quantity of non-redundant ideas is not normally distributed, but it is homogeneous in variance. As the sample size is large, ANOVA is robust to the violation of normality. The results show that the quantity varies significantly across the experiment groups ($F = 5.13$, $p < 0.01$). Further, the results from a priori comparisons show that the Fixation Group varies significantly in quantity

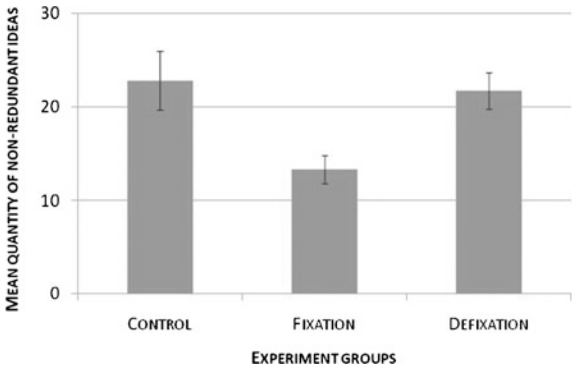


Fig. 2 Variation of mean quantity of non-redundant ideas across the experiment groups. The *error bars* show (±) 1 standard error of the mean

from the Control (F = 8.56, $p < 0.01$) and Defixation (F = 6.72, $p < 0.02$) groups. At the same time, there is no significant difference between the Control and Defixation groups.

These results provide support to both Fixation and Defixation Hypothesis. The significantly lower quantity in the Fixation Group compared to the Control Group provides evidence of design fixation. This indicates that the participants in the Fixation Group are replicating more example ideas in their concepts thereby reducing their overall quantity of non-redundant ideas. At the same time, providing warnings about fixating features does help them in improving their quantity in the Defixation Group, showing evidence for mitigation of design fixation.

4.1.2 Percentage of Example Ideas Used

This metric measures the extent of participants' fixation to the example provided. The results demonstrate interesting trends in the data. Figure 3 shows the variation of mean percentage of example ideas used by the participants in their concepts.

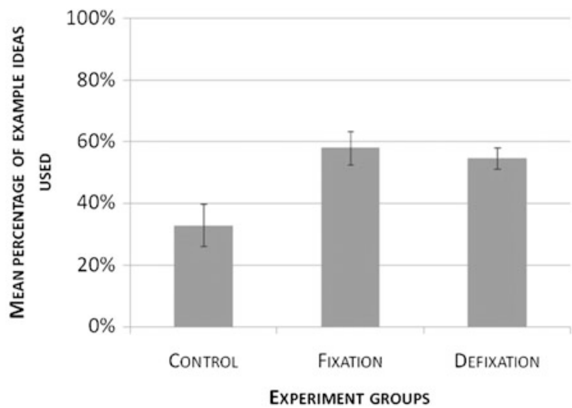


Fig. 3 Variation of mean percentage of example ideas used by the participants in their concepts. The *error bars* show (±) 1 standard error of the mean

As evident from Fig. 3, both the Fixation and Defixation groups copied the example ideas to the same extent in their concepts.

A one-way ANOVA with a priori contrasts shows evidence of significant difference of this metric across the experiment groups (F = 6.29, $p < 0.01$). These data also violates normality of distribution, but are homogeneous in variance, making ANOVA robust to the violation of normality. The a priori contrasts show that both the Fixation and Defixation groups differ significantly from the Control Group in percentage of example ideas used (Fixation: F = 10.69, $p < 0.01$; Defixation: F = 8.00, $p < 0.01$). Meanwhile, the Fixation and Defixation groups do not differ significantly from each other, statistically.

These results support the Fixation Hypothesis, but do not provide evidence supporting the Defixation Hypothesis. Evidently, when participants are exposed to the example solution, they replicate a higher percentage of ideas from the example in their concepts. As observed from Fig. 3, the Control Group also generates some ideas from the example. This is expected, as the example concept consists of most common ideas generated by participants in the previous experiments. At the same time, the Fixation and Defixation groups use the example ideas in significantly more times compared to the Control Group, showing design fixation. According to this metric, providing warnings about the flaws in the example concept does not help participants in reducing their fixation to that overall example.

4.1.3 Discussion: Fixation to the Whole Example

Both quantity and percentage of example ideas metrics provide strong support to the Fixation Hypothesis. They show that in the presence of an example, designers fixate to the features of that example. This result is consistent with many prior studies on design fixation [1, 3, 6–8, 10]. At the same time, these two metrics provide conflicting recommendations about the influence of warnings about flawed features on design fixation. The presence of warnings about the flawed features does cause an increase in the quantity of non-redundant ideas, but the participants still fixate to the same percentage of example ideas as the Fixation Group. It may be possible that the warnings lead participants deliberately generate non-redundant ideas for the flawed features leading them to higher quantity. At the same time, they may be still fixating to the example features that they are not warned about. In order to get a more complete picture, it is necessary to separately study the fixation to the individual flawed features. The following subsection deals with this issue.

4.2 Fixation to the Flawed Features of the Example

As described in the previous section, it is interesting to see if the warnings have any effect on the fixation to the flawed example features. Figure 4 shows the variation of the mean percentage of concepts that use the flawed example features in them. It is observed that in two cases (usage of gas as power source and separation of shells from the shelled peanuts), the warnings have some influence the extent of design fixation. At the same time, in the case of controlling the damage to the peanuts, there is no difference across the three experiment groups.

One-way ANOVA with a priori contrasts is performed on all these three metrics for the statistical analysis. The results show that for none of the metrics, the variation across the experiment groups is significant. Similarly, none of the a priori pair-wise comparisons provide significant differences across the pairs of groups.

Though these data do not provide any statistically significant comparisons, these do reveal interesting trends in the data. The Fixation Group generated more percentage of concepts with gas as power source, showing evidence of design fixation. At the same time, the Defixation Group generated lower mean percentage of concepts using gas as power source, showing evidence of mitigation of this fixation. At the same time, neither the presence of the example, nor the warnings influence the percentage of concepts that do not control damage to the peanuts. In all the three groups, only less than 30 % of concepts (approximately) provide explicit means to control the damage to the peanuts. One possibility is that during idea generation, the participants focus more on the novel ideas to shell the peanuts, ignoring the constraint about the extent of damage to peanuts, as that constraint limits their ideas. In the Defixation Group, the lack of control to the damage to the peanuts is presented as a design flaw. Even the knowledge about that design flaw does not help participants in eliminating that flaw from their designs.

The variation of percentage of concepts that separate shells from peanuts shows another interesting trend. As evident from Fig. 4, when the participants are presented with the warning that a concept that does not separate shells from peanuts is a flawed one, they generate more concepts that complete the said function. The lack of variation of this metric across the Control and Fixation groups suggests that the participants do not focus on this function, when they are not told explicitly about it. In other words, the participants do not perceive the need of separating the shells from the peanuts when they are not told that it is an important part of the design.

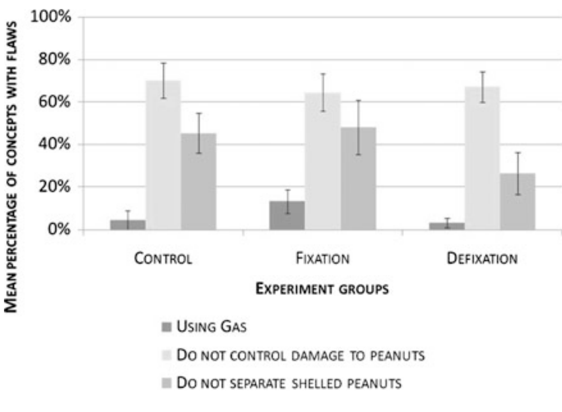


Fig. 4 Variation of the percentage of concepts with flawed example features across the experiment groups. The *error bars* show (±) 1 standard error of the mean

Overall, the results provide mixed support to the defixation effects of warnings about flawed features. Similar to the study by Chrysikou and Weisberg [2], the participants in the current study are provided with the warnings about the flawed features of the example and the reason for considering those as flaws. However, unlike [2], the warnings do not show any significant mitigation effect. The complexity of the design problem can be a potential factor affecting the usefulness of such defixation instructions. The design problem in the current study is significantly complex compared to that from [2] and consists of more functions to be solved by the designers' concepts. Psychological inertia [23] may be another contributing factor, because of which the designers are reluctant to change their way of solving complex problems, even in the presence of warnings. In summary, the effectiveness of such defixation tactics may vary across the levels of design problem complexity.

5 Conclusions

Design fixation is considered to be a major challenge in engineering idea generation. Building upon prior studies on mitigation of design fixation, this paper hypothesizes that the fixation to a flawed example can be mitigated with a help of a set of defixating instructions in the form of warnings about the flawed features of the example along with the reasons for those warnings. The results provide mixed support to the hypothesis. The warnings cause an increase in the quantity of non-redundant ideas; however, do not cause any reduction in the fixation to the example features. An investigation of the appearance of flawed features in the concepts generated by the participants further shows that the effect of warnings is very limited on the fixation to those specific features. These results contradict the prior findings in the literature. At the same time, this study uses a significantly more complex design problem compared to the prior studies. Overall, it can be argued that the defixation effects of warnings about flawed features in an example depend on the level of complexity of the design problem.

Acknowledgments Partial support for this work was provided by the National Science Foundation Award No. CMMI-1000954. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

1. Jansson D, Smith S (1991) Design fixation. Des Stud 12(1):3–11
2. Chrysikou EG, Weisberg RW (2005) Following the wrong footsteps: fixation effects of pictorial examples in a design problem-solving task. J Exp Psychol Learn Mem Cogn 31(5):1134

3. Linsey J, Tseng I, Fu K, Cagan J, Wood K, Schunn C (2010) A study of design fixation, its mitigation and perception in engineering design faculty. ASME Trans J Mech Des 132: 041003
4. Youmans RJ (2011) The effects of physical prototyping and group work on the reduction of design fixation. Des Stud 32(2):115–138
5. Viswanathan V, Esposito N, Linsey J (2012) Training tomorrow's designers: a study on design fixation. ASEE Annual Conference, San Antonio, TX
6. Viswanathan VK, Linsey JS (2012) A study on the role of expertise in design fixation and its mitigation. ASME International Design Engineering Technical Conferences, Chicago. IL
7. Purcell AT, Gero JS (1996) Design and other types of fixation. Des Stud 17(4):363–383
8. Cardoso C, Badke-Schaub P (2011) the influence of different pictorial representations during idea generation. J Creative Behav 45(2):130–146
9. Kiriyama T, Yamamoto T (1998) Strategic knowledge acquisition: a case study of learning through prototyping. Knowl-Based Syst 11(7–8):399–404
10. Viswanathan V, Linsey J (2012) Physical examples in engineering idea generation: an experimental investigation. ICDC 2012, Glasgow, UK
11. Perkins DN (1981) The mind's best work. Harvard University Press, MA
12. Lawson B (1994) Design in mind. Butterworth Architecture, Oxford
13. Finke RA, Ward TB, Smith SM (1992) Creative cognition: theory, research, and applications. MIT press, Cambridge
14. De Bono E, Arzt E, Médecin I, Malta GB (1984) Tactics: the art and science of success. Little, Brown Boston
15. Shah JJ, Vargas-Hernandez NOE, Summers JD, Kulkarni S (2001) Collaborative sketching (C-sketch)—an idea generation technique for engineering design. J Creative Behav 35(3):168–198
16. Linsey J, Clauss EF, Kurtoglu T, Murphy JT, Wood KL, Markman AB (2011) An experimental study of group idea generation techniques: understanding the roles of idea representation and viewing methods. ASME Trans J Mech Des 133(3):031008-1–031008-15
17. Fu K, Cagan J, Kotovsky K, Maier JRA, Troy T, Johnston PJ, Bobba V, Summers JD (2010) Design team convergence: the influence of example solution quality case study research using senior design projects: an example application. ASME Trans J Mech Des 132(11): 111005–111011
18. Dugosh LK, Paulus PB (2005) Cognitive and social comparison processes in brainstorming. J Exp Soc Psychol 41(3):313–320
19. Perttula M, Sipilä P (2007) The idea exposure paradigm in design idea generation. J Eng Des 18(1):93–102
20. Shah JJ, Kulkarni SV, Vargas-Hernandez N (2000) Evaluation of idea generation methods for conceptual design: effectiveness metrics and design of experiments. ASME Trans J Mech Des 122(4):377–384
21. Stone RB, Wood KL (2000) Development of a functional basis for design. ASME Trans J Mech Des 122:359
22. Tabachnick BG, Fidell LS (2007) Experimental designs using anova. Thomson/Brooks/Cole, 2007
23. Kowalick J (1998) Psychological inertia. TRIZ J, August 1998, Available at http://www.triz-journal.com/archives/1998/08/d/index.htm. Access date 4 Oct 2012

Multidisciplinary Design Optimization of Transport Class Aircraft

Rahul Ramanna, Manoj Kumar, K. Sudhakar and Kota Harinarayana

Abstract A 70–80 passenger transport aircraft has been designed using third generation MDO technique. The MDO framework is used to parametrically explore the design space consisting of variables from aerodynamics, structure and control disciplines thereby studying the effects of alternative aerodynamics, structural and material concepts. It employs a panel code for aerodynamic analysis of aircraft and a finite element method for wing level structural optimization and weight estimation. The outputs from these codes are used to perform mission analysis and performance estimation. Stability constraints are implemented by calculating the amount of control power required for static stability and design concepts that do not fulfill the constraints are rejected. This integrated design environment is completely automated. The aircraft is optimized for maximum range using genetic algorithm.

Keywords MDO · Optimization · Aircraft · Preliminary design

1 Introduction

1.1 Aircraft Design

Aircraft Design is an iterative process of amalgamating various disciplinary knowledge to develop and analyze an affordable concept that can adequately satisfy customer requirements. Aircraft design can be divided into three phases [1]:

R. Ramanna (✉) · M. Kumar · K. Harinarayana
Aeronautical Development Agency (ADA), C/O Aeronautical Development Establishment (ADE) Campus, New Thippasandra, Bangalore 560075, India
e-mail: rahul.vrp@gmail.com

K. Sudhakar
Department of Aerospace Engineering, IIT Bombay, Powai, Mumbai 400076, India

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_10, © Springer India 2013

conceptual where a design configuration is generated and analyzed to meet given top level performance requirements; preliminary where specialists from each discipline analyze and optimize the configuration and detailed design where all components are extensively analyzed and verified to meet required criteria, redundancies are established to meet reliability levels for certification and production plans are developed.

Aircraft design apart from being an iterative effort requires extensive knowledge from disciplines such as aerodynamics, stability, controls, structures, propulsion, system layout, cabin interior planning etc. These disciplines are complex, interdependent and require a large pool of skilled engineers and scientists which makes aircraft design a highly complex task.

1.2 Multidisciplinary Design Optimization

Multidisciplinary Design Optimization (MDO) empowers a designer to simultaneously consider multiple disciplines and optimize the system as a whole. It has the potential of producing designs that are superior to those obtained by disconnected sequential optimization because it addresses and exploits the interactions between the disciplines. MDO performed at the conceptual to early preliminary stages using sufficient fidelity, can also avoid costly design changes that invariably occur at later stages. It also provides the decision makers more knowledge about the problem early in the game so that the risks and uncertainty about the program can be minimized. (refer to [2] for more information on MDO applications in preliminary design).

There are three generations of MDO technology that can be found in literature [3]. In the first generation all the disciplinary streams are integrated and analyzed. This is acceptable for simple designs but for complex designs with large number of interactions it becomes unmanageable and not viable. In the second generation medium fidelity tools with more focus on distributed analysis and analysis management was used. In the third generation MDO, higher fidelity disciplinary codes are used and more emphasis is provided to manage complexity and improving efficiency. The current paper falls under third generation MDO.

The art of designing an aircraft involves finding the best compromise between conflicting system level goals. In traditional sense, design is performed sequentially with each discipline optimizing for their disciplinary goals without considering the impact their decisions have on the overall aircraft. For example, consider a design interaction between aerodynamics and structures team. Aerodynamics team optimizes Lift to drag ratio (L/D) which has a huge influence on fuel burn and hence range and emissions of the aircraft. This is frequently accomplished by increasing AR, but there are disadvantages. Increase in AR implies an increase in the length of the wing resulting in increased bending loads. This means that the wing has to be reinforced to absorb these extra loads. Thus more fuel has to be burned to fly this extra weight along. Initially, with moderate increase in AR, the fuel burn is reduced because the weight increase is not that severe, but at some limit, the opposite occurs. The increase in AR results in such a severe weight increase that it actually increases fuel burn. This limit is difficult to establish because the increase in weight due to increased bending load is not tangible until the wing is analyzed by the structures team. An iteration loop thus ensues between aerodynamics and structures. If L/D and weight that influence system level performance metrics are not modeled with their strongly coupled nature, the resulting design will not be the optimum.

There are several other design parameters like wing area, taper ratio (TR), thickness to chord ratio (t/c) of airfoil, sweep angle, dihedral angle, tail area, tail aspect ratio, tail taper ratio, fuselage diameter, seat pitch/arrangement, placement of landing gear, fuel tank locations, placement of engines, location of wing on the fuselage which affect final system level (aircraft) objectives.

2 Design

Air traffic is increasing globally and it is estimated that India needs about 400 medium range aircraft in the next 20 years that can carry 70–100 passengers. This will increase the connectivity between tier-2 and tier-3 cities leading to all round economic growth. In the current paper, a transport aircraft that can carry 70–80 passengers is designed for maximum range. Three major disciplines: aerodynamics, structures and controls are considered and the aircraft is designed with a known propulsion system. An MDO framework is established where data flows freely between the three disciplines. More information on MDO frameworks is available in Ref. [2]. In the current paper, a two step optimization framework is used as shown in Fig. 1.

2.1 Integration Framework

An integrated environment is best suited for conceptual and early preliminary studies as the design freedom available during these stages is better exploited to obtain good designs early on in the design cycle. The tools used in this environment must have adequate fidelity to address design trades and automated to obtain results within reasonable time limits. Further, the tools adopted have to be commonly used in the organization and be endorsed by disciplinary experts to promote confidence among the engineers in the results obtained from the environment.

Commercially available integration frameworks ease the automation process by supporting an extensive list of pre-built software interfaces and scripting languages. They also provide frequently updated packages for design of experiments, optimization algorithms, surrogate modeling algorithms and post processing options which substantially reduce the time required to integrate disparate disciplinary tools and automate the environment. In the current paper ESTECO modeFrontier is used as an integration framework.

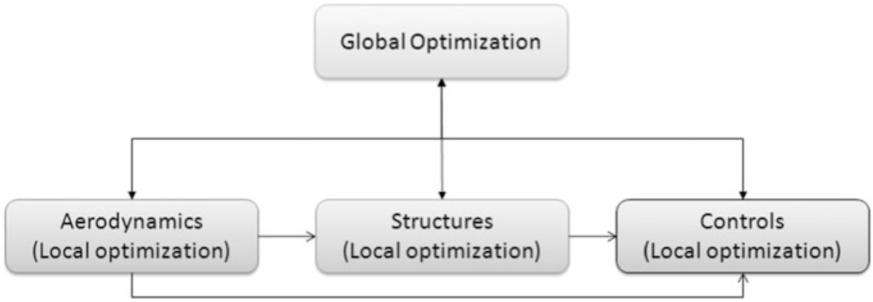


Fig. 1 Two step optimization process

2.2 Disciplines

2.2.1 Aerodynamics

Aerodynamics drives the shape of the aircraft. The main goal of aerodynamics is to increase lift to drag ratio. Lift, mainly generated by wings, counters the weight of the aircraft while drag acts opposite to thrust reducing the effectiveness of the engines. Higher drag requires more energy to move the aircraft from point A to point B.

In conceptual design, aerodynamic data for a given configuration is traditionally estimated using empirical/semi-empirical relations or historical data. In current paper, higher fidelity panel method [4] is used to estimate the aerodynamics of the configuration. This methodology enables the designer to evaluate newer configurations that do not have any empirical relations or historical data. The first step in this approach is to discretise the geometry into panels (collection of surface quadrilateral patches), which, in the current paper is accomplished by the pre-processing software called Point wise [5]. The discretised geometry then forms the input to Vsaero (the panel code). The lift and drag of the aircraft are thus estimated at different angles of attack to arrive at the drag polar. The drag polar then forms one of the inputs for the performance of the aircraft. The lift is also projected onto the structural grid as loads for structural analysis.

2.2.2 Structures

The main goal of the structures discipline is to estimate the weight of the aircraft while ensuring that the airframe is designed to meet the safety and airworthiness requirements.

In the current paper, finite element methodology (FEM) [6] is used to analyze the aircraft wing structure. This involves discretising the geometry into finite elements (quadrilaterals and triangles) using Hypermesh software [7] and analyzing the structure for the aerodynamics loads projected onto it. The wing is then optimized using the software called Optistruct [8]. Advanced composite materials are used to reduce weight of the wing and the whole process is automated. The final weight, C. G and inertia information are the outputs from this module.

2.2.3 Controls

Controls ensure that the aircraft is capable of performing required maneuvers within the flight envelope. There are three main surfaces to control the aircraft along the three axes. Elevators (horizontal tail) control nose up and nose down moments, rudders control nose left and nose right moments and ailerons control rolling of the aircraft.

Trim drag is the incremental drag experienced in setting all the moments to zero by application of controls. Reducing trim drag while providing adequate controllability is one of the main goals of the stability and control discipline.

In the current design module control power required to perform 1 g Trim, basic maneuverability, steady sideslip and single engine trim are considered. This is compared to the control power available from the control surfaces of the current configuration. Only those designs that have enough control power to perform the maneuvers are considered for further stages [9].

2.3 Process

Figure 2 shows the design process. The arrows and boxes drawn using dashes represent outputs and light shaded blocks with dotted outline represent constraints.

The design process is initiated with a user chosen design of experiments (DOE) (full factorial, reduced factorial, Latin hypercube etc.). The number of cases in the DOE represents the population in the first generation of the genetic algorithm. Each case in DOE starts by invoking CATIA software to generate aero and structural geometries reflecting the current design variables. Aero geometry is processed through gridgen software and is analyzed by Vsaero. Structural geometry is processed through hypermesh and the mesh is sent to Vsaero for load mapping. The updated FEM model is analyzed in Optistruct and the thicknesses are subsequently optimized. The controls module calculates the control power required for the current DOE case using aerodynamic derivatives from aero module and weights, inertia and C. G data from structures module. There are 4 constraints in the design process. $CL(struct) < CLmax$ and $CD > 0$ are both sanity checks to ensure physics of the problem is not violated. $1 < Pcr/P < 1.01$ represents that the critical buckling load should be higher than the current load. $Cpreqd < Cpmax$ implies that the control power required must be less than the maximum control power available from this configuration.

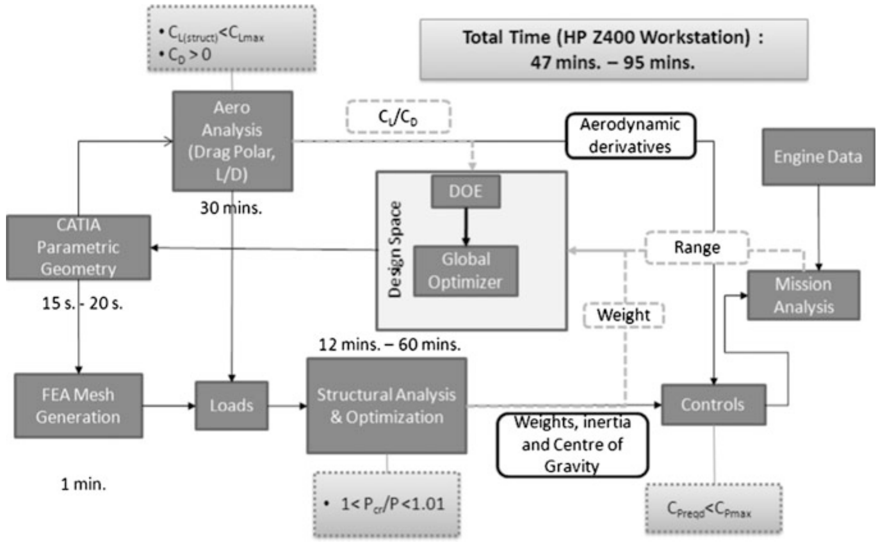


Fig. 2 Process flow diagram

2.3.1 Aerodynamic Analysis

In the current paper, aerodynamic analysis is performed on the full aircraft without landing gear and propeller (Fig. 5, note: propellers are for illustration only and not used in analysis).

Point wise software is used to mesh the geometry and the actions are recorded using the journal option. The script file can then be executed for different cases in DOE; provided the points, lines and surface numbers remain the same. This condition is satisfied by drawing a parametric geometry in CATIA. The meshed geometry is exported into Vsaero readable format and analyzed for a given flight condition. The analysis is repeated for different angles of attack to obtain the drag polar. Matlab scripts are used to extract the required values from Vsaero output file.

The structural mesh data obtained from the structures module is used to define interpolation points in Vsaero where the pressure has to be quantified. This pressure data is later applied on the mesh by the structures module for analysis and optimization.

Aerodynamic derivatives are found by unit deflection of control surfaces. These derivatives are fed into the controls module to calculate control power.

2.3.2 Structural Analysis

Structural analysis is performed on the aircraft wing. A sandwiched composite wing structure is analyzed and optimized using the design framework for a single design load case. The methodology is however amenable to be expanded to more load cases.

The quality of mesh generated using any pre-processing software is dependent on the quality of the CAD model. In the present paper, a parametric wing structural model was created using CATIA. It was ensured that all the rib-spar, spar-skin and rib-skin intersections were modeled correctly. Unnecessary fixed points were removed and a clean geometry was exported into '.igs' format. This geometry was imported into Hypermesh and the surfaces were further cleaned. The wing geometry was then meshed in hypermesh. The centroids of all elements in the FEA mesh were exported for generating pressure distribution using VSAERO.

The FEA mesh is completed by adding thickness and material data and is exported to Optistruct readable format. The aerodynamic loads are used to create a load file that is read by Optistruct using the "INCLUDE" feature. This procedure is integrated by ModeFrontier and is completely automated requiring no user intervention.

Optistruct is used for performing linear static analysis, linear buckling analysis, normal modes analysis and thickness optimization.

The composite structure was assumed to be composed of 4 types of plies (45, 0, 90 and −45 deg). The total thickness is a design variable and decides the number of plies. This approach is viable in this case because the wing configurations are compared with one another. The methodology is quite general and not dependent on the above assumption. This assumption greatly simplifies the complexity and reduces computational time. It is recommended that stacking sequence optimization be performed later in the design stage.

Another assumption made to reduce computational time without affecting the quality of results is to use parabolic thickness variation function. This reduces the number of thickness design variables in optimization.

The optimizer controls the parabola parameters which are used to create thickness zones on the wing and is analyzed by Optistruct.

2.3.3 Control Analysis

The control analysis was performed for 4 cases. 1 g trim, maneuverability, steady sideslip, and one engine out trim (as per FAR-25 [10]). The Ref. [9] gives a detailed description on the process.

The aerodynamic derivatives required to find the control power were found using a panel CFD code rather than empirical relations. This provides the environment to analyze novel and unconventional configurations while also providing required fidelity.

2.3.4 Mission Analysis

The goal of mission analysis module is to estimate the range of the aircraft as per a given flight profile and check whether the particular design meets all the constraints [1]. This was performed using an in-house code developed at ADA.

2.4 Input and Output Variables

2.4.1 Design Variables

Global: Aspect Ratio, Wing Area, Taper Ratio

Local (structural): Parabola parameters (k and c) for spars (front spar and rear spar) and wing skin, thickness of ribs, width and thickness of spar and rib caps.

2.4.2 Other Parameters

Number of thickness zones, number of ribs, sweep angle, dihedral angle, load factor for maneuver, sideslip angle

2.4.3 Output Variables

L/D, wing weight, overall weight and range of aircraft.

2.5 Optimization Algorithm

A general description on different optimization algorithms and their applications can be found in [11].

2.5.1 Non-Dominated Sorting Genetic Algorithm (NSGA-II)

The NSGA algorithm was developed by Deb et al [12] from Kanpur Genetic Algorithm Laboratory (KanGAL) at IIT Kanpur and is available in public domain. It is one of the algorithms included in modeFrontier and is widely used for complex multi-objective problems.

2.5.2 Structural Optimization

Gradient based algorithms are generally employed in structural optimization since they are quicker and provide satisfactory results for size optimization problems. Optistruct automatically chooses the best algorithm for a given problem from the following [8]:

- Optimality criteria method
- Convex approximation method
- Method of feasible directions
- Sequential quadratic programming

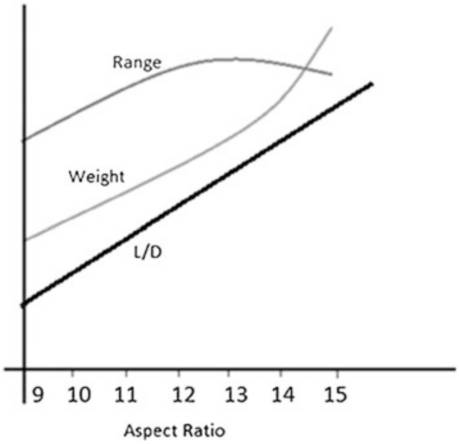


Fig. 3 Variation of metrics with Aspect Ratio

3 Results and Discussions

A notional transport aircraft was designed for maximum range using the MDO environment.

A family of designs is generated by varying AR, S and TR using a reduced factorial DOE. This is used as the initial population for the genetic algorithm. The objective function for optimization is to maximize the range of the aircraft. The genetic algorithm chooses the fittest individual (maximum range) among the initial population and propagates them to the next generation. Crossover and mutation operations are performed to provide a variety of designs for the next generation. As the optimization progresses, only those designs that give higher range are retained. The optimization is stopped when the populations of successive generations remain same or the maximum number of generations is reached.

Figure 3 shows a plot of wing weight, Range, L/D v/s AR of the aircraft. The wing weight and L/D increases with increase in AR. However Range depends on both Weight and L/D. Range is higher for lower weight and high L/D. Therefore Range first increases and then reduces with AR.

All of the designs considered in the MDO environment were of composite wing structure. This reduces the weight of the aircraft. A plot of wing weight for both composite and an Aluminum wing is shown in Fig. 4 for comparison. The aluminum wing has more weight and hence lower range.

The final aircraft configuration is shown in Fig. 5.

In the current paper a single objective function is chosen to provide more emphasis on the design process rather than on the results. However in reality there are a multitude of design objectives which are conflicting in nature. The best compromised design in such cases can be chosen using multi attribute decision making tools such as TOPSIS and AHP. The reader is referred to [13] for a good discussion on TOPSIS, AHP and other decision making tools.

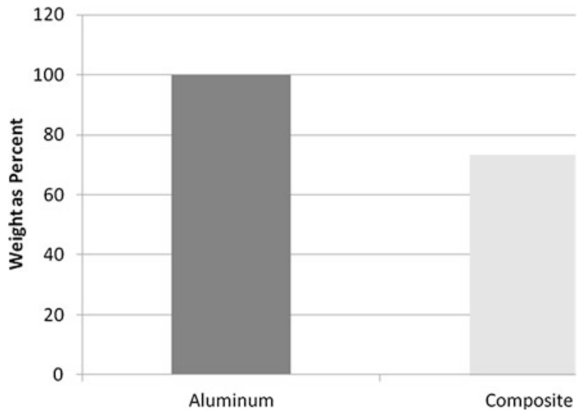


Fig. 4 Weight of wing made of aluminum and composite

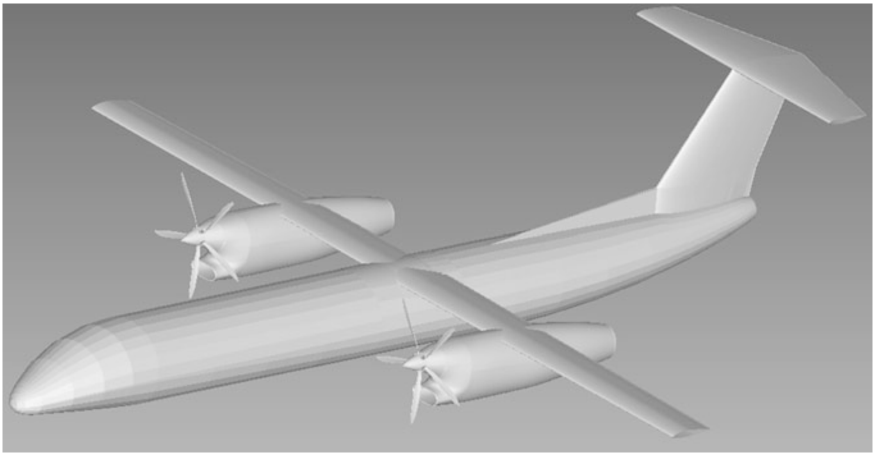


Fig. 5 Final optimized aircraft (Propellers: not used in optimization; for illustration only)

4 Summary and Future Work

A 70–80 passenger transport aircraft was designed using multidisciplinary optimization technique using a two step optimization process. Three disciplines were considered, of which, aerodynamics and structures were included into the optimization while controls was used only as a constraint. It was found that to maximize range of the aircraft, a wing with medium aspect ratio, lower area and higher taper ratio is preferred.

Our next goal would be to use multiple objectives, include controls and fuselage into the optimization loop and to prove the current design methodology for an unconventional configuration such as flying wing.

Acknowledgments Mr. Abhishek Burman, Aeronautical Development Agency (ADA) and Mr. Vikas Munjal, National Aerospace Laboratories (NAL) for their inputs on aerodynamic analysis; Dr. Vijay Patel, ADA and Mr. Mandal, ADE for their valuable inputs on controls; Dr. Pavan, NAL and Dr Shyamsundar, NAL for inputs on structures.

References

1. Raymer DP (1992) Aircraft design: a conceptual approach. AIAA Inc, Reston
2. Kroo I (1997) MDO applications in preliminary design: status and directions. AIAA Paper 97, p 1408
3. Willcox K (2008) Advanced multidisciplinary optimization techniques for aircraft design. Bangalore: Indo-US workshop on systems and technologies for regional air transportation, 2008. Indo-US workshop on systems and technologies for regional air transportation
4. AMI Corporation. VSAero User Manual
5. Pointwise Inc. Pointwise v16 user manual
6. Bathe KJ (1996) Finite element procedures. Klaus-Jurger Bathe, Cambridge
7. Altair Engineering. Hypermesh User Manual
8. Altair Engineering (2011) Optistruct user manual. Altair
9. Kay J et al. (1993) Control authority issues in aircraft conceptual design: critical conditions, estimation methodology, spreadsheet assessment, trim and bibliography. Virginia Polytechnic Institute and State University, Blacksburg
10. Federal Aviation Regulation. Part-25 airworthiness standards: transport category airplanes. www.faa.gov/regulations_policies/faa-regulations (Accessed 2012)
11. Vanderplaats (2007) Multidiscipline design optimization, 1st edn. Vanderplaats Research and Development, Inc, Monterey
12. Deb K et al. (2002) A fast and elitist multi-objective genetic algorithm—NSGA-II, vol 2. KanGAL Report Number 2000001, Kanpur, April 2002, IEEE Transactions on Evolutionary Computation, Vol. 6
13. Triantaphyllou E (2000) Multi-criteria decision making methods: a comparative study. Kluwer Academic Publishers, Dordrecht

Using Design-Relevant Effects and Principles to Enhance Information Scope in Idea Generation

Zhihua Wang and Peter R. N. Childs

Abstract This paper explores the use of a database of effects to facilitate generative activity and access to information. Some design challenges involve applications with which designers or design teams may not be familiar. This can readily be addressed by consultations with subject experts. A challenge associated with this, however, is access to expert and effective dialogue and information. Key to dialogue between a specialist expert and designer is framing of questions and understanding context. In order to improve access to expert information, a database of effects, call the Effects Database, arising from TRIZ, has been extended to enhance use across a wide range of domains by including psychological and design principles. It includes over 300 design-relevant technical effects and principles from physics, chemistry, geometry, design, and psychology. The aim of the database and associated procedures is to provide ready access to expertise at any stage within the design process.

Keywords Design · Idea generation · Knowledge accumulation · Effects

1 Introduction

It is a common view that innovation is essential in both updating original products and designing new products [1]. Based on empirical studies, innovation tends to begin with the generation of creative ideas [2, 3]. Thus, creative idea generation plays a key role in fundamentally determining the type of products which prosper modern business [4–6].

Z. Wang (✉) · P. R. N. Childs
Design Engineering, Department of Mechanical Engineering, Imperial College London, South Kensington, London SW7 2AZ, UK
e-mail: z.wang09@imperial.ac.uk

P. R. N. Childs
e-mail: p.childs@imperial.ac.uk

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_11, © Springer India 2013

The ability of designers in generating creative ideas is determined by many factors. Knowledge accumulation, also known as expertise, is one of the main factors [7]. Accumulation of fundamental knowledge in a field is important for the promotion of new insights in that field. This is implicit in the systems model of creativity where expertise as well as resources, motivation and communication are all essential components for creativity [2, 8]. Therefore, if a designer wants to generate creative ideas that have originality and appropriateness to a design problem, it is important for the designer to have a certain level of knowledge accumulation in the related fields.

In real design processes and opportunities, designers often face a design task that relates to fields they are relatively unfamiliar with and the knowledge accumulation they have is not specific to the design task [9]. In this situation, in order to compensate for shortages of knowledge accumulation in problem related fields, designers may learn the related knowledge by themselves or consult experts for guidance. However, with the development of science, the quantity and complexity of knowledge has led to increased diversity in the category of fields [9]. Moreover, the amount of attention in everyday life is limited [8]. Therefore, once designers face a problem that lies in unfamiliar fields, they may spend a long time on obtaining a basic accumulation of knowledge. Meanwhile, experts may be stymied by ineffective dialogue with limited understanding of subject subtleties or design context. In modern business, because time pressures for product design progress often dominate, both of these approaches are challenging and can be ineffective.

In this paper a creativity assistance tool called the Effects Database is proposed to help designers cope with the situation, and its performance is partially evaluated. A survey to investigate the reasons for time pressures in the design processes is reported in Sect. 2, along with the principle for the establishment of the database. In Sect. 3, the proposed Effects Database is illustrated. Based on a case study in Sect. 4, the effectiveness and efficiency of the Effect Database is explored in Sect. 5.

2 Theory

2.1 Survey

In order to explore approaches to design amongst novice designers, a survey was undertaken with the Innovation Design Engineering double masters students. This is a joint programme run by the Royal College of Art and Imperial College London. In this survey, there were 21 male and 10 female participants. The intake of participants is diverse with approximately one-third of the students coming from product, industrial and graphics design backgrounds, one-third coming from engineering backgrounds and the rest from diverse backgrounds. The average age on the programme is between approximately 27 and 29 years, depending on the cohort, and all of them have over 3 years design experience.

The survey results are listed in Table 1. For a 6 month project in an unfamiliar field, over 60 % of participants used over 1 month on information gathering. A significant proportion of time budget was used on problem related information gathering. The designers acquired knowledge by self-study with over 90 % of participants reporting that the time available for knowledge gathering was not enough, and over 70 % of them believed that if they had more time for knowledge gathering, their design outputs will be more creative. For situations where designers consulted experts for knowledge guidance, around 80 % of participants agreed that the consultant experts improved their work performance. Nearly 30 % of participants, however, were sometimes unsure which kind of experts they should approach when their design problems were related to unfamiliar fields. Around 88 % of participants admitted that there were communication problems between them and the experts who they consulted. According to the survey results, two principal indications are concluded as follows:

Indication 1: When designers face a design problem related to unfamiliar knowledge fields, they have to spend a significant proportion of time budget to define the correct knowledge scope for the problem, which causes time pressure for knowledge gathering.

Indication 2: When designers consult experts for help in knowledge gathering, experts may provide ineffective guidance because of limited understanding of subject subtleties or design context.

2.2 Basic Theories

One of the purposes of knowledge accumulation is for the generation of creative ideas. Creativity can be described as "the ability to invent or develop something new of value" [10]. For a design problem, a creative idea can be regarded as an idea that brings "new value" which can be of societal or financial benefit or indeed both of these. There are usually two approaches to add "new value" for design products:

Approach 1: A new design that has never appeared before is proposed.

Approach 2: Improvement updates have been undertaken on an existing design, such as integrating new functions, or improving the performance of some components.

As the majority of designs stem from new incorporations of earlier inventions [11], Approach 2 is more widely used than 1 as the main route to achieve "new value" in products and systems. The description of Approach 2 suggests the requirement that designers have to understand and be able to explore earlier inventions before making improvement updates on existing designs. Therefore, it seems valuable to have, or to build, a database that includes all earlier inventions in a field. Once designers face a task that relates to this field, they can directly receive task related knowledge assistance from the database. Thus, the first hypothesis principle for the establishment of the database could be as follows:

Table 1 Selected survey results from the IDE1 cohort

Survey question	Results (31 participants in total)				
For a 6 month project in a domain which you are NOT familiar with—normally how much time do you allow for information gathering?	Within 1 week	1–3 weeks		1–3 months	Over 3 months
	1	11		18	1
	Strongly agree	Agree	Undecided	Disagree	Strongly disagree
The time for information gathering is normally NOT enough	4	16	8	3	0
If you had more time for information gathering, would your output be better	4	20	2	5	0
Do you know which kind of expert you should approach for knowledge guidance?	5	17	6	3	0
If you go to an expert for knowledge guidance on information gathering, the work will be MORE efficient than if you work alone	5	12	7	6	1
If you go to an expert in a domain that you are unfamiliar with and the expert is unfamiliar with your design question, there are communication problems between you	1	18	8	4	0

Principle 1: The database includes all earlier inventions in a field.

However, there are many reasons to doubt the feasibility of this principle. Because the categories of fields are extremely diverse [9], it is hard to cover all earlier inventions in all fields. Moreover, because of the specification of each database, the more fields the design task is related with, the more inventions designers have to analyse, and the more time the analysis process would cost. Therefore, the principle of the database should consider the complexity of the fields and the time cost for information analysis.

It was indicated that an invention in one field can be transformed as the integration of coordinated fundamental technical effects in that field and other associated fields [12]. A technical effect is defined as any influence, transformation, phenomenon, or function that is used as a principle of a technical system for the development of the system itself. Based on this theory, Principle 1 could be upgraded into Principle 2 as follows:

Principle 2: The database includes all known effects in all fields.

Since the majority of designs are new incorporations of earlier inventions, the effects used in a new design may inherit from effects used in earlier inventions. Therefore, the total number of basic effects in a field is limited and it is possible to build such a database to include all known effects in all fields.

3 Effects Database

3.1 Effects Conclusion

Based on the investigation from [11], effects should be collected from the conclusions from existing domains or from design knowledge from existing designs. A successful design demonstrates the conclusion of design thinking. Principles from each subject domain are readily available in handbooks and reviews. Interdisciplinary research has also augmented knowledge in this area. In addition the research that led to the development of TRIZ identified patterns in the use of specific physical, chemical and geometric effects in successful inventions [12].

As these effects come from various fields, it may be difficult for designers to understand all of them and select problem relevant ones quickly. To provide reliable and solid definitions for effects, reference books, websites and journal papers were studied. 128 physical effects, 78 chemical effects and 28 geometric effects were selected for this initial phase of activity. For each effect, a definition, a book reference and a web reference were developed and selected. An example is shown in Table 2.

Since the effects from TRIZ are predominantly engineering-relevant, the Effects Database provides limited support outside the engineering domain. For example, in toy design for children, it is valuable to know the basic psychological effects of children to make toys more enjoyable, such as colour bias, shape bias, etc. To compensate for this limitation, the Effects Database was supplemented by further 47 psychological principles and effects and 46 design principles and effects. After it was finished, the Effects Database included over 300 design-relevant technical effects and principles from physics, chemistry, geometry, design, and psychology. Some generic effects and principles are listed in Table 3.

3.2 System Development

The main function of the Effects Database is to provide problem related effects and principles to assist designers rapidly define the knowledge scope of design tasks. The system is designed as an online ready access data search system. Users can access the website through the URL provided. The detailed framework has two parts: search page (a in Fig. 1) and results list page (b in Fig. 1).

Search page: The left side is a search dialogue for the input of problem related keywords and the right side is an instruction for the keywords selection.

Results list page: On the left hand side of this page, the matched effects and principles are listed. The right side shows the detailed definition of each selected result. Users can explore more information about each search result by referring to its web reference.

Table 2 An example effect

#	Physical principle	Definition	Book or Journal reference	Web reference
3	Thermal-electrical phenomena	The direct conversion of temperature differences to electric voltage and vice versa.	Serway, R., Jewett, J. W. Jr., 2002. *Principles Of Physics: A Calculus - Based Text.* 3rd ed. Press: Thomson Learning.	http://www.metacafe.com/watch/1944815/you_gotta_see_this/

Table 3 Examples of selected generic effects and principles in the effects database

Category	Effects and principles
Physical effects and principles	Thermal expansion, Radiation spectrum, Curie point, Hopkinson effect, Barkhausen effect, thermal conduction, thermal convection, thermal radiation, phase transition, Joule–Thompson effect, magneto-caloric effect, electro-magnetic induction, electric heating, electric discharge, radiation absorption, shrinking, thermal insulation, reflection of light, radiation of light, photoelectric effect, X-ray, Doppler effect, nuclear reaction, magnetic field, radioactive ray
Chemical effects and principles	Thermo-chromatic reactions, chemiluminescence, endothermic reactions, exothermic reactions, explosion, electrolysis, transport reactions, synergistic effect, oxidation–reduction reaction, deoxidization reactions, use of helium, dissolving bonds, photo-chemical reactions, electro-chemical reactions, biodegradable materials, phase transitions, energy transformation, self-clustering molecules, oxidation reactions, hydrophilic materials
Geometric effects and principles	Compact packing of elements, compression, construction with several floors, Mobius tape, Reuleaux triangle, Crank-cam propulsion, cone-shaped ram, paraboloids, ellipse, cycloid, transition from a linear process to a face process, eccentricity, screwing spirals
Psychological effects and principles	Childhood amnesia, Cathartic effect, baby's facial preference, baby's taste and smell, Piaget's stage theory, colour, 3D vision of human eyes, top-down lighting bias, opponent-colour theory, dark adaptation, Snellen acuity
Design effects and principles	Uniform connectedness, proximity, similarity, expectation effect, Kamin's blocking effect, evaluation apprehension, social facilitation, performance load, over justification effect, Fitts' law, open system theory, isolated system theory, Golden ratio, Fibonacci sequence, signal-to-noise ratio, Hick's law

4 Case Study

4.1 The Early Stages of the Stage-Gate™ Process

The Stage-Gate™ process has been widely used for new product development [13]. It provides effective and efficient conceptual and operational direction for the design process of new products from concepts to market [14]. After observations in more

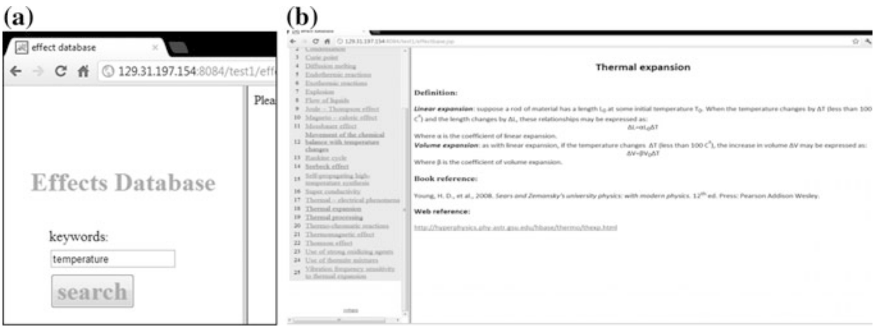


Fig. 1 The framework of the effects database. **a** Search page. **b** Result list page

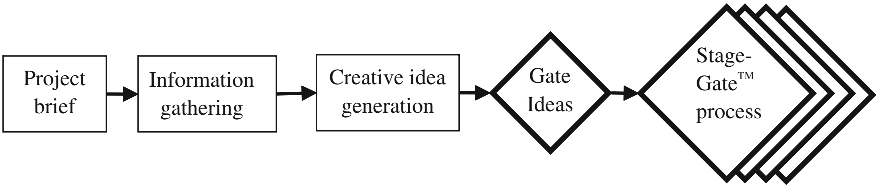


Fig. 2 The standard idea generation process in companies and industries. *Source* [7]

than 500 companies, which used Stage-Gate™ in their product developments, an Idea Discovery stage should be added at the front end of the process to supply more product ideas [13]. The investigations from [6] revealed that many companies ran idea generation sessions to directly provide product ideas. The standard idea generation process in these industries and companies is shown in Fig. 2.

Project brief: During this stage, the latest status of the project is introduced, along with the requirements and expectations for the final output.

Information gathering: In this stage, designers need to explore as many project related information sources as possible under a pre-set time budget.

Creative idea generation: This stage plays an essential role in the idea generation process. The idea pool can be populated by the creative thinking of designers which can be stimulated by using various idea generation tools.

4.2 *Integration of the Effects Database into the Early Stages of the Stage-Gate™ Process*

At the idea generation stages, design groups can maintain the creative performance at certain levels when they face design problems related with familiar knowledge fields [15]. However, groups fail to reach the same level of performance when they cope with design problems related with unfamiliar knowledge fields. Both the

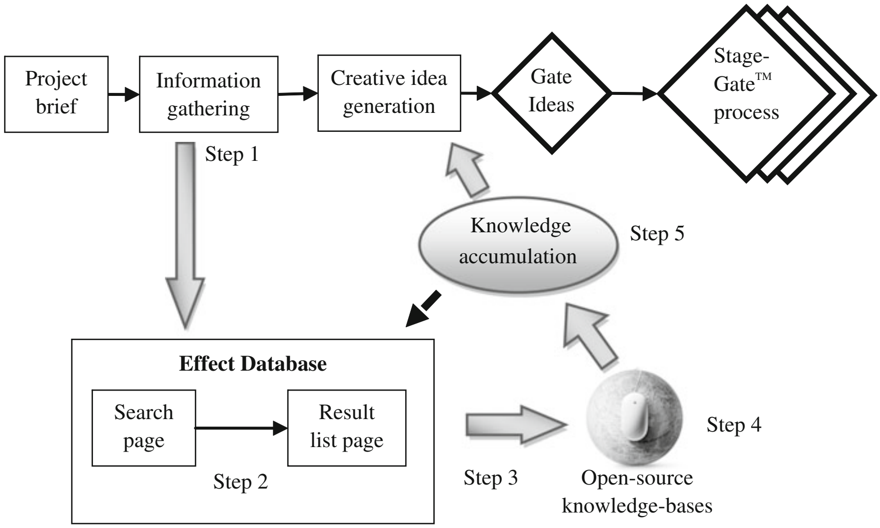


Fig. 3 Using the effect database in the first stage of the Stage-Gate™ process

quality and quantity of the generated ideas can decrease dramatically. This situation is matched with the survey in Sect. 2.1. To overcome the two indications, the Effects Database is integrated with the standard idea generation process to enhance the knowledge accumulation of designers. The detail working process (shown in Fig. 3) is illustrated as follows:

Concluding problem related keywords (*Step* 1): Based on the information and facts from previous stages, some keywords are proposed. A keyword should be a simple word that is related with the design problem.

Searching the database (*Step* 2): In this step, once designers enter a keyword into the database, the background programs search keyword related effects or principles in the database and then list results obtained in the results list page.

Exploring information for each effect identified (*Step* 3): This step is for designers to briefly examine the information of each effect or principle in the results list page including its definition, book reference and web reference. After finishing examination of keyword related results, designers can revisit Step 2 to enter another keyword.

Exploring more information for the specific effects identified (*Step* 4): During step 3, designers can refer to the book reference and the web reference of an effect or principle to explore more information from open-source knowledge-bases.

Enhancing the knowledge accumulation in problem related fields (*Step* 5): After all the keywords have been entered and keyword related results examined, designers have an indication of the scope of knowledge they may need to explore in the problem related fields. Moreover designers could "inform" the experts that these effects or principles were related with their design tasks and ask for related specific knowledge guidance even though the experts may not understand the design tasks. Thus, the problem related effects and principles could be selected to enhance their knowledge accumulation.

Sometimes, the knowledge guidance from experts may stimulate designers to conclude new keywords or replace previous keywords by more appropriate ones. In this situation, designers may repeat the database searching process using the new keywords.

4.3 Case Project Details

To evaluate the effectiveness and efficiency of the Effects Database in the idea generation process, some industry-based projects from IDE alumni were explored. Four of them were selected here as examples and were shown in Table 4. The IDE course combines design with engineering, technical mastery and innovation. It has an emphasis on making students engage with technology and cultivate their innovation-focused thinking and realisation in both societal and business context. Many of their designs have been commercialised.

The Effects Database has been applied hypothetically to 4 projects using the 5 step process. It should be noted that this was undertaken for illustration processes and that the original design work did not use this approach.

At step 1, the keywords of each project were determined. For example, the 2nd task was to design a portable smoke detection system, from which the keywords "smoke" "flame" "heat" and "network" were concluded. After information on conventional smoke detectors had been explored, the keywords as "combustion" "heat" "sensor" and "portable" were also suggested.

At step 2, the keywords were used as input in the search page of the database. In the 3rd task, the "Baby's hearing" and "Baby's vision" principles were related with the "infant" keyword. The "Feature integration theory" and "Opponent-colour theory" effects were related with the "colour" keyword.

At step 3 and 4, each effect or principle was examined and its related information was also explored through the references provided.

At step 5, only problem related effects and principles were remained according to self-exploration and the guidance from experts. In the 1st project, effects such as "Bioluminescence" "Chemiluminescence" and "Electro-luminescence" were discarded because of the lack of relationship with the design question. The effects and principles "Dark adaptation", "Polarised light", "Thermo-chromatic reactions", etc., were added into knowledge accumulation for the design task.

After step 5, the knowledge scope of the design question was defined depending on the selected design-relevant effects and principles. In the 4th project, the main knowledge scope was specified on geometrical structure.

Table 4 Example use of the effects data using innovations associated with IDE alumni

#	Design question	Step 1	Step 2	Step 3	Step 4	Step 5	Product
1.	After being made, the degree of ophthalmic lens is fixed. Once eye degree changes, people have to buy a new pair of glasses. Can the degree of ophthalmic lens is also adjustable?	Light, lens, reflection, glass, focal	Bioluminescence, chemical reactions in gases that in the active area of lasers, chemiluminescence, colour, dark adaptation, electro-luminescence, highlighting, photoacoustic effect, polarized light, reactions of reversible electro sedimentation, stroboscopic motion, top-down lighting bias, thermo-chromatic reactions, reflection of light, symmetry,	Exploring information for each effect identified	Exploring more information for the specific effects identified	Dark adaptation, polarized light, thermo-chromatic reactions, reflection of light, symmetry	Adjustable eyewear
2.	The positions of smoke detectors in a home are fixed and are not always placed in ideal locations. Current portable smoke detectors are isolated from each other. Can these two systems be incorporated?	Smoke, flame, heat, combustion, sensor, portable, network	Combustion, condensation, dielectric heating, endothermic reactions, energy transformation, exothermic reactions, explosion, self-propagating high-temperature synthesis, shrinking, thermal chromes, thermal conduction, thermal conductivity, thermal insulation, thermal processing, Weber-Fechner law, periodic reaction			Combustion, Condensation, endothermic reactions, energy transformation, exothermic reactions, explosion, self-propagating high-temperature synthesis, shrinking, thermal conduction, thermal conductivity, thermal insulation, Weber-Fechner law, periodic reaction	Echo smoke detector

(continued)

(continued)

#	Design question	Step 1	Step 2	Step 3	Step 4	Step 5	Product
3.	Infants are unable to tell designers their feelings about toys. How to design infant-enjoyable toys?	Infant, toy, psychology, colour, enjoy, fun	Baby's hearing, baby's vision, Piaget's stage theory, colour, feature integration theory, highlighting, illusory conjunction, opponent-colour theory, photo chromes, photochromatic effect, thermo-chromatic reactions, trichromatic theory, use coloured materials to track the changes of some reactions			Baby's hearing, baby's vision, piaget's stage theory, colour, feature integration theory, highlighting, opponent-colour theory, thermo-chromatic reactions	Infant's toy
4.	Can wheels be foldable to save storage space?	Round, fold, curve, flexible, material	Balls, cycloid, ellipse, good continuation, spirals, use of diaphragms, Bauschinger effect, bi-metallic or bi-material construction, changes in the optical-electromagnetic properties of materials, electrostriction, input-process-output model, isolated system theory, Johnson-Rahbeck effect, Kragelski phenomenon, magnetic separation, shape-changing objects, use a magnet to influence an object or a magnet that is connected to the object			Balls, cycloid, ellipse, good continuation, spirals, use of diaphragms, Bauschinger effect, bi-metallic or bi-material construction, shape-changing objects, use a magnet to influence an object or a magnet that is connected to the object	Foldable wheel

Note That the original design work did not use the methodology developed in this paper and the examples are provided for illustrative purposes

5 Conclusions

In this paper, an Effects Database is proposed to aid designers to generate creative ideas in short periods of time compatible with modern business. Some design applications involve subjects that the designer or design team may not be familiar with. This is commonly addressed by consultations with a subject expert or subject expertise, which, however, can be time-consuming or stymied by ineffective dialogue with limited understanding of subject subtleties or design context. A survey (in Sect. 2) indicated a link between the time for knowledge gathering and time for defining appropriate knowledge scope. In addition, issues of communication between the designers and the experts have been identified with both unfamiliarity with the subject domain and understanding the context of design questions being important factors. In order to improve access to expert information, a database of effects, arising from TRIZ, has been extended to enhance use across a wide range of domains by including psychological and design principles. The Effects Database generated includes over 300 design-relevant technical effects and principles from physics, chemistry, geometry, design, and psychology. The use of the database has been illustrated by application to a series of design tasks, indicating its suitability for promoting expert relevant suggestions.

References

1. Soosay C, Hyland P (2004) Driving innovation in logistics: case studies in distribution centres. Creativity Innov Manag 13(1):41–51
2. Amabile TM (1996) Creativity in context. Westview Press, Boulder
3. Mumford M (2000) Managing creative people: strategies and tactics for innovation. Hum Resour Manag Rev 10(3):313–351
4. Bharadwaj S, Menon A (2000) Making innovation happen in organizations: individual mechanisms, organizational creativity mechanisms or both? J Prod Innov Manage 17: 424–434
5. Amabile TM (1998) How to kill creativity. Harvard Bus Rev 76(5):76–87
6. Howard TJ, Culley S, Dekoninck EA (2010) Reuse of ideas and concepts for creative stimuli in engineering design. J Eng Des 22(8):565–581
7. Mumford MD, Hester KS, Robledo IC (2011) Knowledge. In: Runco MA, Pritzker SR (eds) 2nd Encyclopaedia of creativity volume 2. Elsevier Science and Technology, Amsterdam, pp 27–33
8. Csikszentmihalyi M (1996) Creativity: flow and the psychology of discovery and invention. Harper Collins Publishers, New York
9. Lidwell W, Holden K, Butler J (2003) Universal principles of design. Rockport Publisher
10. Childs PRN (2004) Mechanical design, 2nd edn. Elsevier Butterworth-Heinemann Ltd., Oxford
11. Henderson K (1991) Flexible sketches and inflexible data bases: visual communication, conscription devices, and boundary objects in design engineering. Sci Technol Human Values 16(4):448–473
12. Orloff MA (2006) Inventive thinking through TRIZ: a practical guide, 2nd edn. Springer, Berlin

13. Cooper RG, Edgett SJ, Kleinschmidt EJ (2002) Optimizing the stage-gate process: what best-practice companies do-I. Res Technol Manage 45(5):21–27
14. Cooper RG (2008) Perspective: the Stage-Gate (R) idea-to-launch process-update, what's new, and NexGen systems. J Prod Innov Manage 25(3):213–232
15. Howard TJ, Dekoninck EA, Culley SJ (2010) The use of creative stimuli at early stages of industrial product innovation. Res Eng Design 21(4):263–274

Determining Relative Quality for the Study of Creative Design Output

Chris M. Snider, Steve J. Culley and Elies A. Dekoninck

Abstract Design creativity is often defined using the terms "*novel*" and "*appropriate*". Measuring creativity within design outputs then relies on developing metrics for these terms that can be applied to the assessment of designs. By comparing design appropriateness to design quality, this paper develops a systematic method of assessing one element of design creativity. Three perspectives from literature are used; the areas in which quality is manifest, the categories into which quality assessment criteria fall, and how well criteria are achieved. The output of the method is a relative ranking of quality for a set of designs, with detailed understanding of the particular strengths and weaknesses of each. The process of assessment is demonstrated through a case study of twelve similar designs. Through such analysis insight into the influences on quality can be gained, which in turn may allow greater control and optimisation of the qualities that design outputs display.

Keywords Creativity · Quality · Assessment · Design output

1 Introduction

There are a number of existing definitions of creativity within design literature aiming to distil the term into its necessary constituent parts. They also deal with the criteria by which creativity can indirectly be measured [1–3]. Although defined in many ways, amongst the terms most frequently used are "*novelty*", "*appropriateness*" and

C. M. Snider (✉) · S. J. Culley · E. A. Dekoninck
University of Bath, Bath, UK
e-mail: C.M.Snider@bath.ac.uk

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_12, © Springer India 2013

"*unexpectedness*" [4]. These are used to denote how novel an output is in terms of the field and alternative problem solutions; how suitable an output is as a solution to the specific problem that has been described; and how surprising or unusual a solution is in context of similar solutions that already exist, or the features of the output itself. Through these terms, an output that is creative is defined as a new solution that is recognised as highly and particularly suited to the problem that has been set, likely denoting it as the superior design solution available within the market.

To determine the creative properties of an output it is necessary to identify and assess these terms. To allow assessment of appropriateness of solutions, this paper presents a system of classification and comparison of design quality metrics, using existing quality assessment procedures; forming one vital part of creative assessment of design outputs.

Literature presents several methods by which creativity terms can be assessed, such as those developed by Shah et al. [3] and Sarkar and Chakrabarti [5]. However, perhaps due to the variation in terms used to describe this factor, those methods relating to the term "*appropriateness*" are often variable. As an example, Shah recommends use of the term "*quality*" and subsequent assessment according to a number of methods typically measuring adherence to product specification [3]; while Sarkar and Chakrabarti [5] recommends the term "*usefulness*", then creating a method assessing an output based on its societal importance and expected in-life use by customers. Further, if taking forward the term "*valuable*" [2, 6] as used in the sense referred to by the field of value engineering, it is necessary to consider not only the benefits of an output, but also a full breakdown of the costs [7]. This task is difficult to complete accurately and robustly at earlier stages in the design process when less information exists, or when considering more subjective criteria [8].

All of these terms refer to the same aspect of creativity [4]. While the potentially difficult and subjective tasks of determining "*value*" and "*usefulness*" do present information on how well an output solves a problem, the focus need only lie on comparison of the output with the specification and requirements that governed its design. Each output must be assessed according to how "*appropriate*" it is as a solution to the problem and its context. For example, while a solution may provide high functionality, it may also be of excessive cost to customer or company, and inappropriate for the problem that it must solve. "*Appropriateness*" can be described as a solution of appropriate quality in context of its problem, assessed through output quality as proposed by Shah et al. [3], using any existing method (such as QFD [9], or decision tables [10]).

However, the work presented in this paper shows that beyond the assessment of quality according to the above methods or otherwise, through detailed categorisation of quality manifest in a design output, significant additional understanding can be gained. Particularly in the case of creative design, additional design features may greatly improve the quality of certain elements of a design output, or indeed of generate additional parameters not originally anticipated. By detailed classification of the categories to which any parameter of any form can belong, the influence of such additional criteria can be understood and evaluated in the appropriate context. The method presented within this paper then has two functions: first to stimulate the identification of criteria which contribute to overall quality beyond those included in the original specification, and second to categorise and allow assessment with those criteria in a useful and robust manner. These are described in the next two sections; following which the paper then presents a case study demonstrating the proposed process.

It should be noted that the focus of this paper is not on the method used to assess quality, but rather on the classification of assessed criteria against one another, and the consequent understanding that can be gained. Within this paper, and due to the stage at which designs were assessed, the Pugh [11] method was most suitable, but another could be used should it provide higher detail or higher appropriateness to the assessment situation. By appropriately classifying and weighting assessed criteria, the classification method attempts to demonstrate additional understanding that can be gained, allowing more detailed understanding of final output quality between several design outputs.

2 The Assessment of Quality

2.1 The Hierarchy of Quality Criteria

As discussed by O'Donnell and Duffy [12] in their work on design performance, both the *design* itself and the *design activity* must be considered. A systematic classification of quality criteria in terms of this distinction is proposed, showing separation between criteria that are of quality in different ways. This more detailed view recognises the importance of quality both in context of the design output and of the design development process. For example, a change that greatly saves in manufacture cost without changing design output quality is valuable, but is potentially different to a change that greatly alters design output quality alone. Distinction is also made between the design output and its super-system, and the design activity and its super-system; recognising quality both specifically and induced in the design output and the design activity's environment. The proposed categories are defined in Fig. 1.

Design quality [referred to as Internal Direct (ID)]—performance characteristics of the design such as speed of operation, precision, range of operation, etc.

Design super-system quality [Internal Indirect (II)]—performance characteristics of the super-system to which the design belongs, as influenced by the design itself. For example, lower design mass may allow the super-system to operate for longer on a single charge, or to operate with higher precision. Here, lower mass does not increase quality of the design itself, but produces additional benefit in the super-system.

Design process quality [External Direct (ED)]—performance characteristics within the development and production of the design, such as in manufacturing (e.g., high use of standard parts, lower manufacture cost) or assembly (e.g., fewer assembly operations).

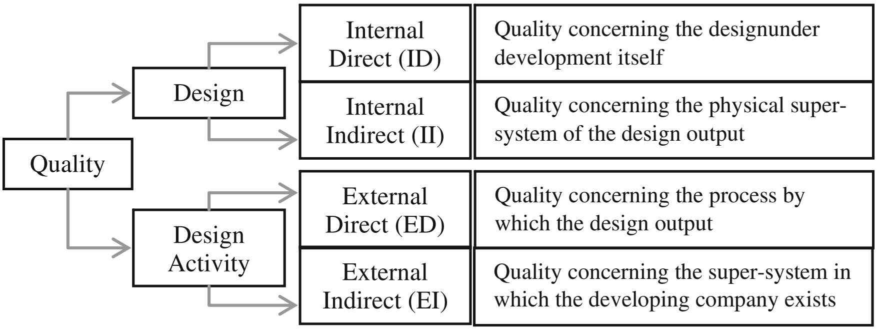


Fig. 1 Systematic hierarchy of possible categories for quality criteria

Design process super-system quality [External Indirect (EI)]—performance characteristics relevant to the company within its super-system, as induced by the design itself. For example, adherence to brand identity or conformance with environmental standards may improve the perceived quality of the company within its market.

Using such a hierarchy, it is possible to describe how a design or feature is of quality. Distinction can be made, for example, between mediocre design performance quality and exceptional manufacturing quality, an important trade-off that may need to be considered. This decomposition is particularly useful in creativity research as it enables assessment of creative quality through the product lifecycle; for example, higher quality in terms of ID is more manifest to the customer. Also of benefit is the equal credence given to high quality in terms of development, which may have little impact on the customer or product use, but is still a valid area of creative product development.

2.2 Specific Quality Metrics

The hierarchy provides understanding of the areas that assessment criteria should concern but does not state what they should be, a task requiring distinct categories of criteria.

Much literature addresses the need for categories of assessment by developing criteria from the specification [7, 8, 11, 13]. Within the work presented here, the "eight dimensions of quality" presented by Garvin [13] are used to develop specific criteria.

Performance: a design outputs' primary operating characteristics.

Features: those characteristics that supplement basic functionality.

Reliability: the probability of malfunction or failure within a specified time period.

Conformance: the degree to which an outputs' design meets established standards.

Durability: the amount of use one gets from an output before it deteriorates.
Serviceability: the speed, courtesy, competence and ease of repair.
Aesthetics: how an output looks, feels, sounds, tastes or smells.
Perceived quality: interpretation of the output through reputation.

By including criteria that relate to each of these "dimensions of quality", a highly detailed and complete assessment of the quality of a design output can be created. Together, the dimensions of quality present a thorough description of all characteristics that contribute to the overall quality of a design output. These characteristics define whether a product is of appropriate quality, and hence a vital part of the interpretation of a product as creative. The particular strength of the metrics proposed by Garvin as opposed to other metrics is in their breadth, including those relating to design output and also more subjective metrics relating to human interpretation. It is not always possible to judge criteria in a quantifiable manner, due to a lack of detail and information of the design output in question, or because the dimension of quality itself defies numeration. Considering the importance of context and human interpretation given by many to the determination of what is creative [14], such subjective criteria are vital.

It should be noted that although using the hierarchy produces a significant number of prompts for the development of assessment criteria that contribute to overall quality, not all will be relevant to each product or each company. For example, some branches of the tree require criteria that are unusual or likely irrelevant in many scenarios (such as aesthetics of manufacture process). However, as with all elements of assessment, the decision of what is relevant must be made by the assessor on a case-by-case basis.

2.3 Ensuring Quality When Meeting Criteria Output

Finally, it is also important to consider not only if a product is achieving each criteria, but also whether it is achieving them *well*. For example, while performance goals of a design output may be met, if the operation is wasteful or time consuming the output is likely not of appropriate quality. Analysis of how well a category is achieved in this work is described as performance in relation to the individual categories of assessment. Therefore, an output that achieves each category well can be said to achieve them *efficiently* and *effectively* [12, 15]. Each term is defined as such [12]:

Effectiveness: the degree to which the actual result meets the original goal.
Efficiency: the relationship between what has been gained and level of resource used.

2.4 A Combined Hierarchy of Quality

Quality is then a product of to whom it is manifest, the categories of criteria by which it is judged, and how well the criteria in those categories are achieved. Through these three levels, a hierarchy can be created that considers each aspect of design quality, and categorises in a way that gives highly detailed information of the particular strengths and weaknesses of quality and the stakeholders to whom it concerns (Fig. 2). Detailed understanding of design quality can be gained by systematically proceeding through this hierarchy when identifying criteria for assessment and when performing analysis.

2.5 The Development of a Weighting Scale

Clearly, different branches of the hierarchy will have different levels of importance in relation to the overall quality of the design output, thereby requiring weighting. In this work, weightings have been developed using the Analytic Hierarchy Process (AHP) [16], a widely used, multi-disciplinary method of ranking and assessment developed within the past two decades [17]. Through the use of standard pair-wise comparison [8], AHP produces fair and proportional values of importance for each assessed criteria in relation to every other assessed criteria. The particular strength of this system is the robust manner in which weightings are assigned in relation to the importance of each criterion, rather than the subjective weights attached by some other methods.

2.6 Using the Hierarchy to Assess Quality

To use this system for assessment of relative quality, the following steps are completed. This process is demonstrated in the case study.

1. The hierarchy must be formed depending on relevance of each category to the specific design output in question. At this point the assessor must select the branches of the hierarchy that may influence final quality in the specific case.
2. The hierarchy is populated with as many criteria as is possible by systematically working through each category, adding criteria from the specification and thinking of others that fit.
3. Each selected category is weighted according to the AHP method. This then provides as complete a set of criteria for quality assessment as possible, and places them within a hierarchy that allows easy and detailed analysis.
4. Quality assessment occurs according to the method of Pugh [11]; a datum concept is chosen (using the most complete design concept available) and all others are compared to it on a scale of better/worse/same.
5. Ratios are taken of the number of better to worse criteria in each category, multiplying by the appropriate weights during the process.

Addition of ratio values then gives a decomposable ranking of all concepts; capable of stating not only which products are of highest quality, but also to whom that quality is of importance, the specific criteria under which that quality falls, and quality of the manner in which those criteria are met.

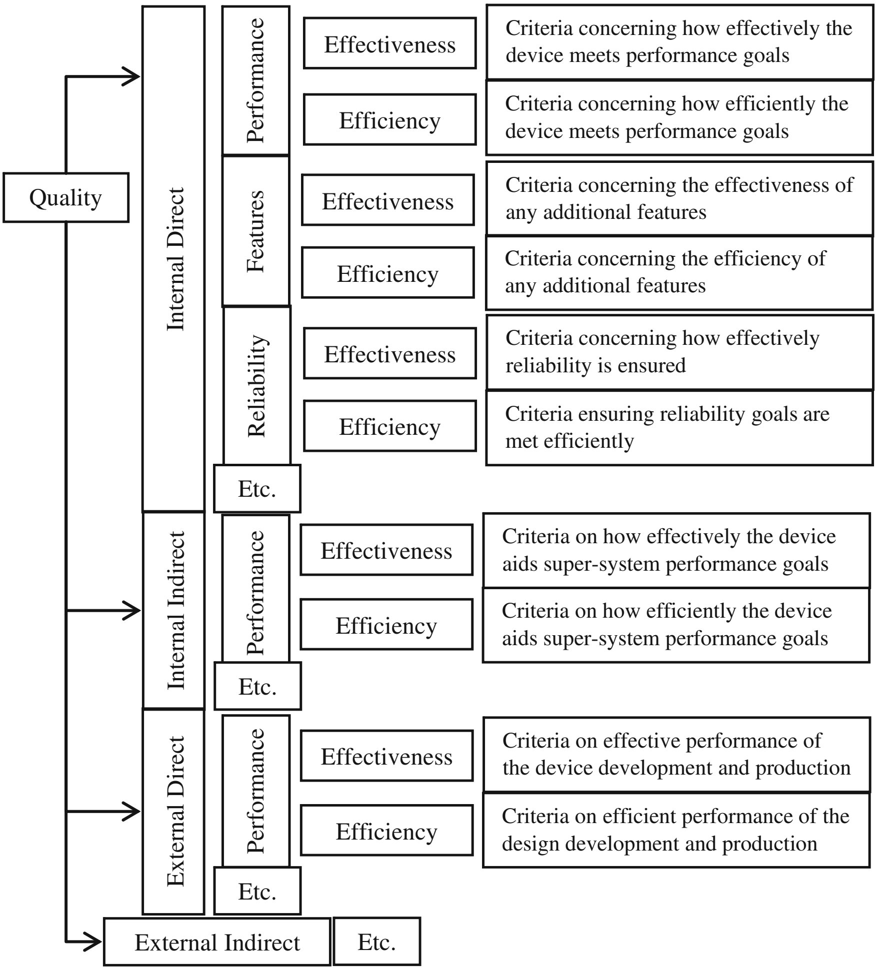


Fig. 2 Partial structure of the perspectives of quality used within this work. Complete structure contains all eight "dimensions of quality" under each category (*ID*, *II*, *ED* and *EI*)

2.7 Output of the Classification Method

The particular use of the classification method is in the breadth of additional information it provides for comparison of design outputs. Beyond assessment and comparison of single criteria (such as comparing mass of two designs), categorisation of criteria provides understanding of the broader implications of each design alternative, such as the relative influence of entirely different criteria in relation to one another.

Through the categorisation and weighting method it is possible to understand the summation of different quality criteria and their influence on the final design output. For example, although one design may perform better, it may also be more difficult to manufacture. Through the proposed hierarchy it is possible to quantify and assess this trade-off accurately, and choose the final solution that has the highest final output quality.

3 Case Study—Assessment of Quality

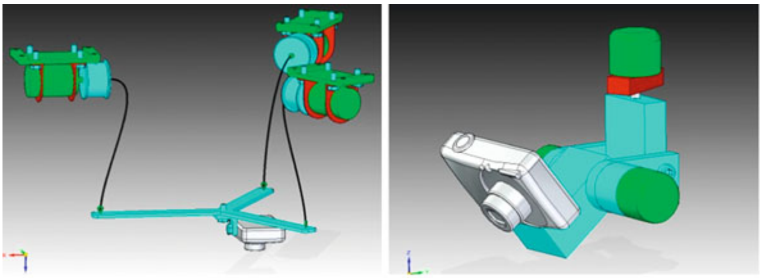
An example of the method in use is provided through assessment of 12 designs produced during a previously reported experiment [18], each designed to solve the same problem.

The problem was to design a hanging camera mount to be placed beneath a balloon, with controllable hemi-spherical motion pointing downwards. The design was to accept any amateur camera and be controlled remotely. Designers received identical briefs, and were given 90 min to individually produce their design to a high level of detail (Fig. 3).

3.1 Assessment

Assessment occurred according to the process within Sect. 2.6. Each level of the hierarchy in Fig. 2 was considered with respect to the design problem in order to prompt the generation of as many criteria (that could be applied to all designs) as possible, and to categorise each in a manner that enhanced understanding. Due to relevance to the brief and the development stage at which the designs were compared, only categories shown in Table 1 could be assessed. In all, 24 criteria were assessed.

Weight was assigned to each category using the AHP method. To judge importance, four engineering assessors (between 7 and 45 years' experience, average 25) were presented with the relevant categories and asked to perform pair-wise comparison between. Comparison achieved a sufficient value of Krippendorff's alpha of 0.74 (a measure of inter-coder reliability), and the resulting weights were averaged (Table 1).



Design F (datum) Design B

Fig. 3 Example designs produced within the experiment

Table 1 Hierarchy used for assessment of designs (with selected examples from total of 24)

Hierarchy of quality	Quality metrics	Quality within criteria	Weight	Example criteria
Internal direct	Performance	Effectiveness	0.179	Range of motion
		Efficiency	0.179	Length of single charge
	Features	Effectiveness	0.0798	Protect cargo
	Reliability	Effectiveness	0.143	Security of connection etc.
Internal indirect	Performance	Effectiveness	0.306	Operational mass of balloon etc.
External direct	Performance	Effectiveness	0.292	Manufacture using existing tooling
External indirect	Insufficient information for assessment in this case			

As the experts asked within this study have only a general experience of the output and its context, this work demonstrates only the process and reliability of the weighting process. In reality, weighting would occur through experts with extensive understanding of the design, market, and other important influences. Weighting in reality would likely vary depending on the background of the experts; e.g., should they be heavily involved in manufacturing, then that would likely receive a higher value. Hence, although the weightings presented here represent the opinions of highly experienced engineers and so are valid; those used by a company may vary. It is for the company to decide the importance of each category depending on priority.

3.2 Results

In all, the designs were compared on 24 criteria fitting into these categories. One of the designs (Design F) was selected as a datum, against which all others were compared for each criteria on a better/same/worse scale [as shown for the Internal Direct (performance) criteria within Table 2]. Ratios of better scores to worse scores (in relation to the datum) are then taken for each individual category and multiplied by the weight, to produce a final weighted ratio for each design (Table 3). The value for this weighted ratio determines the ranking of quality of designs in relation to the original datum.

3.3 Discussion of the Results

By this method, each design can be ranked according to the criteria that contribute to its interpretation as of appropriate quality. Extra insight can also be gained; Design F performed poorly in terms of ID criteria, therefore showing a poorer

Table 2 Comparison with datum for all criteria within internal direct (performance) category

Criteria	A	B	C	D	E	F	G	H	I	J	K	L
Range of motion	+	+	0	+	+	Datum	+	–	+	+	–	+
Speed of operation	–	–	–	–	–		–	–	–	–	0	–
Stability in position	+	+	+	+	+		+	+	+	+	+	+
Ease of connection	–	0	–	0	0		–	0	–	–	0	0
Operational range	0	0	0	0	0		0	0	0	0	0	0
Type of control	0	0	0	0	0		0	0	+	0	0	0
Power requirement	0	0	+	0	0		+	0	+	+	+	+
Mass	–	+	–	+	+		+	–	0	+	0	–
Volumetric size	0	+	0	+	+		+	+	0	+	+	0
Length of single charge	+	+	+	+	+		+	+	+	+	–	+

Table 3 Ratios, weighting and final ranking

Criteria	A	B	C	D	E	F	G	H	I	J	K	L
ID (performance)	3:3	5:1	3:3	5:1	5:1	Datum	6:2	3:3	5:2	6:2	3:2	4:2
ID (features)	1:1	1:0	1:1	1:1	0:0		1:1	0:0	1:1	1:1	0:0	0:0
ID (reliability)	0:0	0:0	0:2	1:1	0:0		0:0	0:0	0:0	1:0	1:0	0:1
II (performance)	0:1	3:1	0:1	3:1	1:0		3:1	2:2	0:0	3:1	0:0	2:2
ED (performance)	0:4	1:3	0:5	1:3	0:4		0:4	0:5	0:4	1:4	1:3	0:5
Overall ratio (decimal)	0.44	2.0	0.31	1.6	1.2	1.0	1.3	0.50	0.86	1.5	1.0	0.55
Weighted ratio (decimal)	0.30	1.6	0.21	1.5	0.89	1.0	1.1	0.44	0.61	1.3	0.79	0.46
Ranking	11	1	12	2	6	5	4	10	8	3	7	9

design in itself, but excelled in terms of ED, therefore being more appropriate to company capabilities such as manufacturability and assembly. Conversely, Design L has strong ID performance capabilities, but is particularly poor in terms of manufacturing and assembly.

4 Discussion of the Process

While information from ranking aids selection of designs for development, it is for additional information that this method was designed. Many research opportunities result from breaking down the manner in which quality is displayed. Deeper understanding can be gained by comparing how quality appears with designer behaviour, the prescribed design process and brief, and the ways in which designers are creative, for example. Information about these potential relationships will provide a valuable insight into preferable behaviours leading to different forms of output with different forms of quality. This will perhaps allow designers to focus their work to the specific priorities of the company and the brief that they are presented, or will allow greater understanding and optimization of the way in which outputs are developed to maximise their quality in an appropriate manner. Such analysis has begun, and will continue in further work.

5 Conclusions

The aim of this paper has been to present a systematic, hierarchical system to generate criteria and assess quality, in the context of what is appropriate to the design problem.

This is with the goal of allowing assessment of *appropriateness* in design outputs (a fundamental part of the interpretation of creativity) described here as the appearance and recognition in a design output of quality appropriate to the problem that it must solve. Through the categories used, the method also creates deeper understanding about the quality of the design output, which can in turn be used to better inform design decisions, or as a research tool to better understand quality development through the design process.

By assessing through separate perspectives used within multiple fields of literature, this method stimulates the assessment of quality in terms of to whom the design output is of quality, the specific "dimensions" in which its quality is manifest, and how well those dimensions are achieved. Thus, when used to as full an extent as is feasible, this method ensures that all criteria affecting quality are considered.

In assessment, this method uses the well-established process of AHP to determine weights for each category, then assigning these weights to the ratios used for ranking. Weighting is flexible, occurring based on the companies discretion and priorities.

Through the presented example, this assessment method has shown capability in ranking of relative quality of multiple designs, as well as the ability to produce additional information of how that quality appears. Following further validation and comparison of quality with traits of designers and the design process (as will occur in further work), understanding can be gained of the relationships and dependencies of designer, process and quality; information that can then be used to enhance methods of designer support.

Acknowledgments The work reported in this paper has been undertaken with support from the Engineering and Physical Sciences Research Council (EPSRC) at the Innovative Design and Manufacturing Research Centre (IdMRC) University of Bath.

References

1. Chakrabarti A (2006) Defining and supporting design creativity, in design 2006. In: The 9th international design conference 2006. Dubrovnik, Croatia
2. Gero JS (1996) Creativity, emergence and evolution in design. Knowl-Based Syst 9(7):435–448
3. Shah JJ, Smith SM, Vargas-Hernandez N (2003) Metrics for measuring ideation effectiveness. Des Stud 24(2):111–134
4. Howard TJ, Culley SJ, Dekoninck EA (2008) Describing the creative design process by the integration of engineering design and cognitive psychology literature. Des Stud 29(2):160–180

5. Sarkar P, Chakrabarti A (2011) Assessing design creativity. Des Stud 32(4):348–383
6. Simon HA (1979) Models of thought. Yale University Press, London
7. Ullman DG (1997) The mechanical design process, 2nd edn. McGraw-Hill, London
8. Cross N (2000) Engineering design methods—Strategies for product design, 3rd edn. Wiley, Chichester
9. Kolarik WJ (1995) Creating quality: concepts, systems, strategies, and tools. McGraw-Hill, London
10. Pahl G, Beitz W (1984) Engineering design: a systematic approach. Springer, London
11. Pugh S (1990) Total design: integrated methods for successful product engineering. Prentice Hall, Harlow
12. O'Donnell FJ, Duffy AHB (2002) Modelling design development performance. Int J Oper Prod Manage 22(11):1198–1221
13. Garvin DA (1987) Competing on the eight dimensions of quality. Harvard Bus Rev 65(6):101–109
14. Boden M (2004) The creative mind: myths and mechanisms. Routledge, London
15. Neely AD et al (2002) Strategy and performance: getting the measure of your business. Findlay Publications, Horton Kirby
16. Saaty TL (1990) How to make a decision: the analytic hierarchy process. Eur J Oper Res 48(1):9–26
17. Vaidya OS, Kumar S (2006) Analytic hierarchy process: an overview of applications. Eur J Oper Res 169(1):1–29
18. Snider CM et al. (2012) Variation in creative behaviour during the later stages of the design process. In: The 2nd international conference on design creativity (ICDC2012), Glasgow, Scotland

Development of Cognitive Products via Interpretation of System Boundaries

Torsten Metzler, Iestyn Jowers, Andreas Kain and Udo Lindemann

Abstract Cognitive products use cognitive functions to work autonomously and reduce the amount of interaction necessary from the user. However, to date no method exists to support the integration of cognitive functions in common products. This paper presents a method that supports designers when exploring ideas for new cognitive products. The method is based on functions/actions that humans perform while using a product, as well as functions/actions performed by the product itself, all of which can be consistently modelled in an activity diagram. Initially, the system boundary of the product is drawn around the functions/actions performed by the product. Cognitive functions are then identified that are currently performed by the user, and can possibly be integrated into a new cognitive concept. The resulting concept is specified systematically by interpreting the system boundary of the product to include cognitive functions. This method has been verified via design projects performed by interdisciplinary student design teams, and an example of this work is presented.

Keywords Cognitive products · Functional modelling · Activity diagrams

T. Metzler (✉) · I. Jowers · A. Kain · U. Lindemann
Institute of Product Development, Technische Universität München, Munich, Germany
e-mail: metzler@pe.mw.tum.de

I. Jowers
e-mail: jowers@pe.mw.tum.de

A. Kain
e-mail: kain@pe.mw.tum.de

U. Lindemann
e-mail: lindemann@pe.mw.tum.de

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_13,

1 Introduction

Cognitive products are tangible and durable things with cognitive capabilities that improve robustness, reliability, flexibility and autonomy [1]. They meet and exceed customer expectations by using cognitive functions e.g. *to perceive*, *to learn*, *to plan*, etc., to reduce the need for human input, for example when such input is difficult or repetitive. However, no method exists to support the integration of cognitive functions into common products. This paper presents such a method, with the intention of supporting designers as they explore ideas for new cognitive products.

The research presented here is concerned with identifying how cognitive functions can be included in the functional modelling process. Functional modelling is core to many product development activities, and numerous methods have been introduced that result in a holistic representation of a product according to its functional structure [2]. The resulting functional models are often represented as flow diagrams with functions described according to some taxonomy, e.g. [3], and linked according to the material flows between them e.g. [4]. In the method presented here, the functions of a product are represented as actions in an activity diagram. The diagram is then extended to include the actions of the user during product use, with the system boundary of the product surrounding the actions performed by the product. The user actions are compared to a taxonomy of cognitive function and flows [5] to identify those that could be integrated into the functionality of the product. Finally, the system boundary of the product is interpreted to include those cognitive functions that are identified and have the potential to improve the product as a cognitive product. This systematic variation of the system boundary results in gaining a holistic perspective which can support the design of cognitive products, and the method has been validated via design projects conducted by interdisciplinary student design teams, as described in [6].

The next section provides an overview of the role of functional modelling in product development, and an overview of modelling with cognitive functions. In Sect. 3, the problem of using cognitive functions in product development is presented, and in Sect. 4 a method is introduced which seeks to overcome this problem. The method is illustrated with reference to a cognitive washing machine which was developed by a student design team. The paper concludes with a discussion exploring the potential of the method to support cognitive product development, and an outlook towards future research.

2 Background

2.1 Functional Modelling in Product Development

Functional modelling is central to many product development activities, particularly conceptual design [4]. It supports a systematic, top-down approach to product definition, starting from a description of the required core functionalities of the product. These can then be sequentially decomposed into lower-level sub-functions, resulting in an abstract specification of the product that describes how the required functionalities can be realised by sub-functions and the relations between them, e.g. [7]. There are various approaches to formally representing the resulting functional models, a review of which are provided by Erden et al. [2]. A common approach, and the one that is employed in this paper, is to represent functions according to a flow-oriented model [4]. In particular, functions can be defined as a general input/output relation that is used to perform a task, and can be described by verb-noun pairs, e.g. *mix water and detergent*. The relations between these functions can then be defined as flows characterised according to types e.g. *material*, *energy* or *signal*, and the resulting functional models are represented as flow diagrams, as illustrated in Fig. 1. Here, the functionality of a washing machine is presented as a system of functions and sub-functions, and the flows of material, energy and signal between them.

Functional models are well suited for supporting modern design processes, in which multi-disciplinary teams collaborate to develop complex products [2]. They provide a common representational framework for defining a product as a system of functions and sub-functions, which is accessible to all members of the team, regardless of engineering discipline. A functional model provides an abstract but holistic view of the system which allows designers to better understand the complex products with which they are working, individually and in collaboration with team members [8]. If a functional model is constructed based on an accepted language of functional descriptions then this reduces potential ambiguity in the model, increases uniformity and increases the potential to reuse the model either manually or in an AI-based system. For example, the NIST Reconciled Functional Basis is a taxonomy in which functions are input/output relations connected via flows and represented in flow-oriented models [3].

In systems engineering, flow-oriented functional models can be represented as activity diagrams. These are flow diagrams representing activities, which are defined according to constituent actions and their inputs/outputs [9]. Activities/actions are an abstract formalism for describing behaviour in the same way that functions/sub-functions are an abstract formalism for describing behaviour [7].

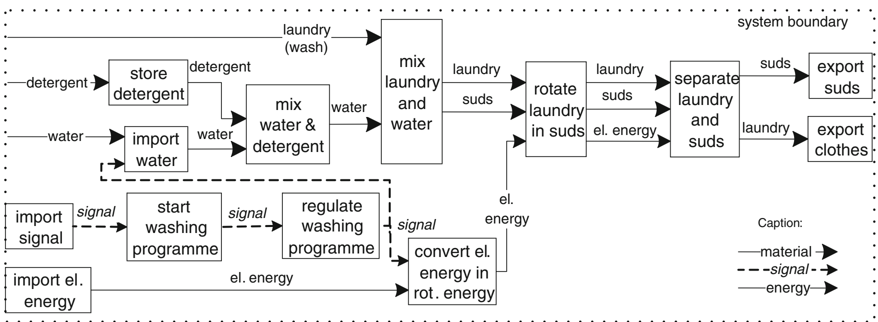


Fig. 1 Flow-oriented functional model for a washing machine

So activity diagrams can be used to model the functions carried out by a system as actions, but with additional capabilities beyond those provided by a flow-oriented model. For example, control nodes such as fork/join nodes or decision nodes can be included in a diagram to represent control logic and provide additional constraints on the timing and order in which actions execute [9]. The combination of object flows with control flows is a powerful formalism for modelling products as systems of functions. Also, the additional capabilities provided by activity diagrams mean that when they are defined formally, using a language such as SysML, they can be mapped to executable constructs which in turn support evaluation, for example through simulation. For these reasons activity diagrams will be used in the remainder of this paper, to represent the functional structure of products and support development of cognitive products via introduction of cognitive functions.

2.2 Functional Modelling for Cognitive Products

Cognitive products are tangible and durable things with cognitive capabilities that consist of a physical carrier system with embodied mechanics, electronics, microprocessors and software. The surplus value is created through cognitive capabilities enabled by flexible control loops and cognitive algorithms. Customer needs are satisfied through the intelligent, flexible and robust behaviour of cognitive products that meet and exceed customer expectations. Cognitive products have all or a subset of capabilities of Cognitive Technical Systems (CTSs) and the solid grounding of an everyday product that meets user needs and desires [1].

What makes products cognitive are their special properties stemming from the integration of CTSs. The implementation of cognitive capabilities results in high-level performance. In particular, in contrast to products which have deterministic control methods, cognitive products do not only act autonomously, they do so in an increasingly intelligent and human-like manner. This means that they are more robust than non-cognitive products since they are able to adapt to a dynamic environment, such as human living environments. Cognitive products should be able to maintain multiple goals, conduct context sensitive reasoning, and make appropriate decisions. This results in higher reliability, flexibility, adaptivity and improved performance.

Incorporation of cognitive capabilities in a product concept requires specific descriptions of cognitive functions, as discussed by Metzler and Shea [1]. The term *cognitive function* is used to refer to basic functions that enable cognition, e.g. *learn*, *perceive*, *understand* or *decide*. Such functions perform operations on flows of information, or they process data flows to create information. However, there is no commonly agreed list of cognitive functions that are required for a cognitive system, neither human nor artificial. Typically, researchers in particular areas compile their own list of cognitive functions. Metzler and Shea [5] present a comprehensive set of cognitive functions and flows structured in a taxonomy that incorporates views from engineering and cognitive sciences. The taxonomy of cognitive functions and flows is tailored for mechanical engineers and supports consistent functional modelling through a standardised representation. It can be used to model a wide range of cognitive products and is used throughout this paper. As discussed, functional modelling results in an abstract representation of a product that is useful for multi-disciplinary concept development phase. An example of using the taxonomy of cognitive functions and flows to define flow-oriented functional models is presented in Metzler and Shea [5].

3 Problem Identification

There are many factors that are driving the introduction of cognitive functionality in today's consumer products, i.e. functionality that introduces cognitive capabilities so that products can operate with robustness, reliability, flexibility and autonomy. The need for companies to differentiate themselves from the competition means that they are constantly looking for opportunities to develop their products in innovative ways and they often want to be seen to be on the cutting-edge of technological development. Also, consumers expect more functionality from their products and want the user experience to be as enjoyable as possible. AI algorithms and methods have reached a high-level of maturity which means that they can be reliably incorporated into cognitive products. And, the steady reduction in the cost of components necessary to utilise these algorithms, such as CPUs, digital cameras, actuators, etc. means that they are cost effective. Cognitive products use cognitive functions to enable products to work more autonomously so that they can reduce the amount of interaction necessary from the user, while exceeding their expectations. For example, iRobot's Roomba is an autonomous robot vacuum cleaner that uses cognitive functions to map, navigate and plan routes and significantly reduces the need for human interaction [10].

Although there is a drive to incorporate cognitive functions in consumer products it is not always obvious how to include such functions in a design. As discussed in the previous section, functional modelling is central to many product development activities, but cognitive functions are rarely considered. The taxonomy of cognitive functions and flows (as described in Sect. 2.2) defines a language for describing the required cognitive functionality of a product in the same way that the NIST Reconciled Functional Basis defines a language for describing non-cognitive functions. Despite this, it is not obvious how to incorporate the taxonomy when introducing cognitive functions to an existing product concept.

The difficulty that arises with respect to developing cognitive products was observed during a series of student projects, as described by Metzler and Shea [6]. Since 2007, 6 projects have been set in which 16 teams of students were tasked with inventing or adapting household products that address user needs by using cognitive functions. The students who participated were from varied backgrounds including mechanical engineering, electrical engineering or computer science, and worked in multi-disciplinary teams of 3–5. They were tasked with developing cognitive products that address a general problem, e.g. *saving energy* or *recycling,* by incorporating cognitive functions into existing products. For example, the washing machine design that is used throughout this paper was developed by one student team in response to a project where they were asked to introduce cognition into a household product so that it can be more easily used.

Before starting the projects, the students were introduced to a user-centred process that supports early phases of development of new products that are useful and usable [11]. The process was adapted to the context of cognitive product development to assist in the identification of user needs; to aid in the development of a product concept; and to support the building of a functional prototype. The students were also encouraged to use functional modelling to support the development of a product concept and were presented with the taxonomy of cognitive functions and flows to aid in the specification of cognitive functions.

During the projects the performance of the students was observed, and it was found that the teams were able to identify product market opportunities and needs, and they constructed functional prototypes of adequate quality. However, it was also observed that many of the teams had difficulties incorporating cognitive functions into a product concept. The major difficulty for the students was on the one hand translating the user needs into cognitive functions and on the other hand identifying and incorporating functions related to or required by the cognitive functions in the new product concept. Most teams did not use a systematic approach that could assist in the integration of cognitive functions into product concepts. The result was product concepts that had to be adapted in the following development phases, resulting in additional iterations of the design process and delayed development of the cognitive product.

4 A Method for Incorporating Cognitive Functions

The method described in this section addresses the incorporation of meaningful cognitive functions into existing product concepts. The goal is to turn existing product concepts into cognitive product concepts by identifying and incorporating cognitive functions that are currently carried out by the user. To achieve this goal four steps have to be carried out, as described in Fig. 2. These steps are explained in the following sub-sections.

4.1 Model a Product Concept as an Activity Diagram

Step 1 of the method is concerned with creating an activity diagram as a model of the product concept into which cognitive functions will be incorporated. The model can be derived from a product already existing in the physical world or from a product concept under development. This makes the method applicable to new

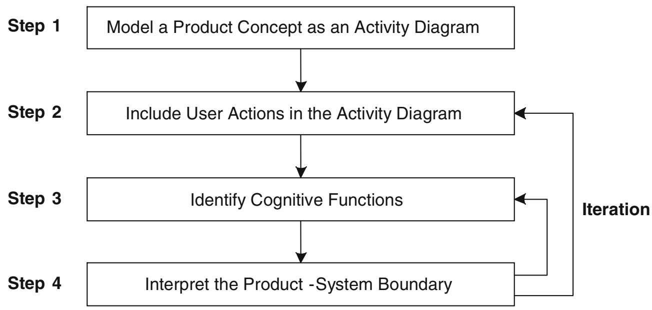


Fig. 2 Procedural model of the method

product development as well as incremental product development. As discussed in Sect. 2, activity diagrams are an abstract formalism to describe behaviour. They represent activities as flow diagrams, defined according to constituent actions and their inputs/outputs. When applied to product modelling they are used to represent the product according to object flows which represent the input/output of functions represented as actions, and control flows which represent the chronology of the actions. If a functional model of a product concept already exists, such as the flow-oriented functional model of the washing machine illustrated in Fig. 1, then it is a trivial task to translate this into an activity diagram. In Fig. 1, the functionality of the internal operations of the washing machine is described with active verbs and objects from the NIST Reconciled Functional Basis. In the translated model, these functions are represented by actions, and the functionality of the product is represented as a system of actions and the flows between them.

4.2 Include the User Actions in the Activity Diagram

In Step 2, the user's interaction with the product (during intended use) is considered, and the system of actions represented in the activity diagram is extended to include the actions of the user. To achieve this, the user experience is considered chronologically. First, start and end nodes are included; these indicate the beginning and the end of product use. Next, all possible (within the limits of the design) user actions are added to the activity diagram. Finally, these are connected by flows, which are either object flows, such as those commonly used in flow-oriented functional modelling, i.e. material, energy, signal, etc., or control flows that model the chronology of actions by specifying when and in which order actions are executed [9]. The authors recommend using the taxonomy of cognitive functions and flows and the NIST Reconciled Functional Basis to model the user actions. For example, Fig. 3 shows an extended activity diagram of the washing machine that includes, in addition to the functionality of the washing machine, illustrated in Fig. 1, the user's pre-wash actions. The post-wash actions of the user

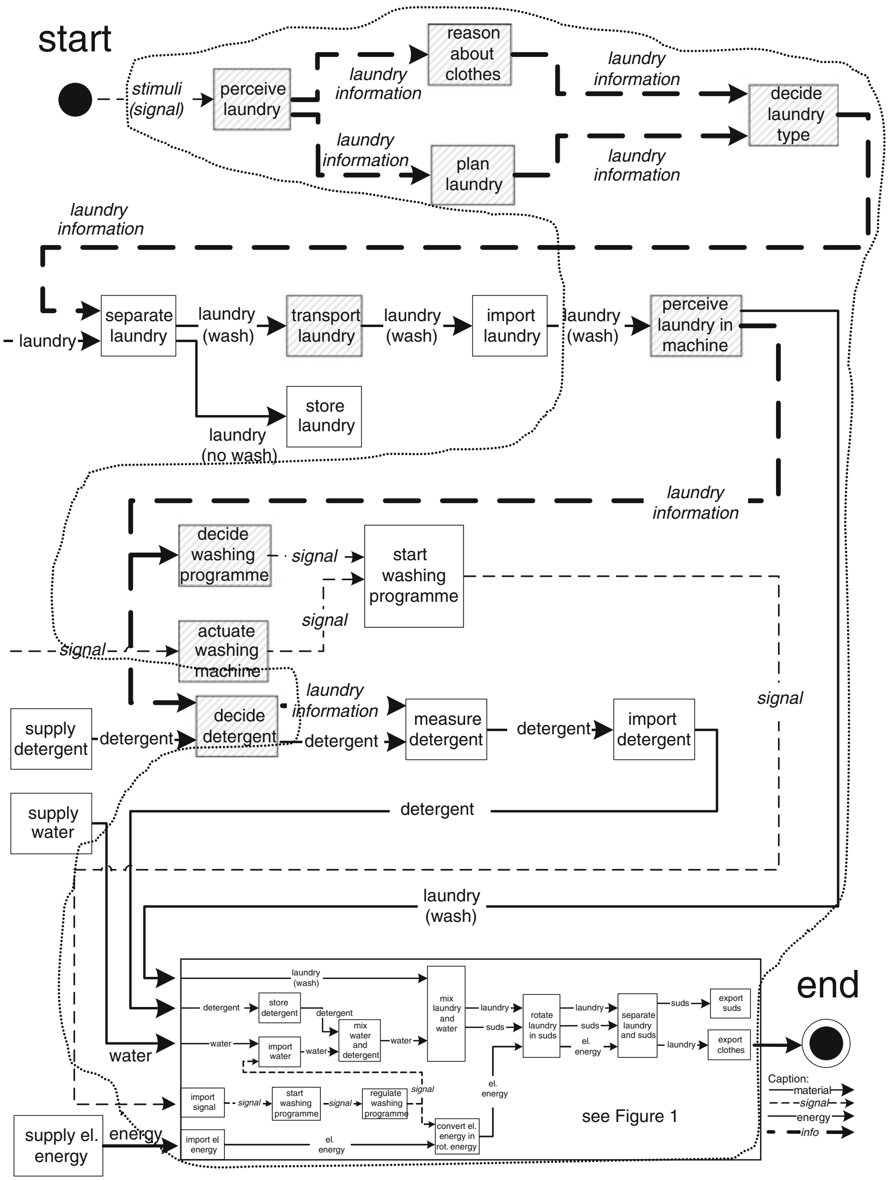


Fig. 3 Activity diagram including product actions and user actions

are not included due to space limitations, and the activity diagram ends when the wash cycle terminates. The functionality of the washing machine was presented in Fig. 1, and in Fig. 3 is enclosed in one block as a subsystem. The actions included describe the user's process of planning and executing a washing programming, for example deciding the type of laundry to wash, separating the laundry, putting the laundry in the machine, choosing appropriate detergent, etc. The flow between these actions describe the materials that are needed for input/output, and also structure the actions chronologically.

4.3 Identify Cognitive Functions

After incorporating the user actions into the activity diagram, Step 3 is concerned with identifying the cognitive functions currently implemented by the user. As discussed in Sect. 2, these are basic functions that enable cognition by performing operations on flows of information, or by processing data flows to create information. Such functions offer a great potential for innovation by shifting complicated or often repeated tasks from the user to the product. The taxonomy of cognitive functions, defined by Metzler and Shea [5] is an aid to identifying cognitive functions and provides a comprehensive set for comparison. For example, comparison of the user actions specified in the use of the washing machine in Fig. 3 with the taxonomy of cognitive functions gives rise to a list of cognitive functions performed by the user during interaction with the product. In Fig. 3, these cognitive functions are highlighted as striped blocks, and include *perceive laundry*, *decide laundry type*, *decide washing programme*, etc.

4.4 Interpret the Product-System Boundaries

In Step 4, the product's system boundary is interpreted to include some of the cognitive functions that were identified in Step 3. Currently these functions are actions of the user, but can potentially be an action of a new cognitive product concept. Here, the critical decision is to decide *which* of the identified cognitive functions to include in the new product. The following questions could assist in this decision:

1. How close is the cognitive function relative to the product?
2. How many flows link the cognitive function to other functions?
3. How difficult is it to technically realise the cognitive function?
4. How annoying is the cognitive function for the user when carried out?

Question 1 can be addressed by considering the activity diagram defined in Step 2. Here, the distance between functions is measured according to any intermediate functions. In the activity diagram, the cognitive functions closest to the original product concept are likely to be suitable for integration in the product. This is because the closer a function is to the original product, the more likely it is that this function is associated with the product, and would be acceptable as part of the product. Conversely, the more functions that have to be carried out by the user between a cognitive function and the functions carried out by the product, the less it is associated with the product.

Question 2 can also be addressed by considering the activity diagram. In the activity diagram, the more a cognitive function is linked to other functions, the more complex the functional model becomes. If there are many flows linking a cognitive function to the original product concept it is expected that many components in the concept will have to be adapted to accommodate the new functionality. Similarly, if there are many flows linking a cognitive function to other cognitive functions outside the original system boundary it is expected that the user has to strongly interact with this cognitive function.

Question 3 relates to the technical feasibility of implementing a cognitive function. Its answer relies on the expertise available to realise such a function in a physical device, and also on the current state of the art, since some cognitive functions may not be realisable using currently available technology.

Question 4 focuses on the user and asks which actions would make the experience of using a product more enjoyable, if they were implemented by the product. A study investigating product market opportunities and user needs is an appropriate method to explore this question.

After answering the questions a pair-wise comparison can help to identify which cognitive function(s) should be integrated into the new cognitive product concept. This results in an interpretation of the product's system boundary to include the identified cognitive functions, as well as other required non-cognitive functions, as part of the product's functional structure. For example, in Fig. 3 cognitive functions have been incorporated into the system boundary for a new cognitive washing machine concept, as identified by the new system boundary represented by the dotted line. The new washing machine concept perceives the laundry and, based on how much is available of each type, e.g. colours, whites, delicates, etc., decides which laundry should be washed. The machine suggests to launder the most homogeneous laundry group with the highest capacity utilisation first. However, the final choice of which type of laundry to wash is made by the user; this avoids dissatisfaction due to the paternalism of the washing machine. The user then separates this laundry and places it in the machine. The machine perceives which laundry is inserted and adapts its behaviour to the user's decision. For example, the washing machine determines the ideal washing programme or which detergent suits best, how much detergent is needed for the current laundry group and if softener is needed. In case the user mixes two different laundry groups accidentally the washing machine can output a warning to inform the user and avoid staining. This new concept improves the experience of clothes washing by carrying out some of the tedious and repetitive actions usually carried out by the user. It was implemented as a physical prototype by the multi-disciplinary team of students who designed it.

5 Discussion

The method described in the previous section was applied by student teams during the development of cognitive products, including the cognitive washing machine concept represented in Fig. 3. These initial applications provide evidence for the usefulness of the method as a way of identifying cognitive functions that are involved in the use of an existing product concept. The method is visual in nature, allowing the system boundary between the user and the product to be interpreted according to identified cognitive functions. This visual nature means that the approach is intuitive for the designer, and easy to communicate to other members of a multi-disciplinary design team. A more thorough evaluation of the method, including comparisons with other approaches and a control group, remains to be conducted.

When applying the method, cognitive functions could easily be identified by following Steps 1–3. As discussed, in these steps cognitive functions are identified as user actions modelled in an activity diagram. However, Step 4 involving the decision of *which* cognitive functions to incorporate is more difficult, and required input from experts with sufficient experience in CTSs to make informed and realistic decisions. The fact that the realisation of cognitive functions in hardware and software is difficult is known and further research is being carried out to improve the decision making process and support implementation of Step 4. This includes the definition of design catalogues that provide patterns of how to realise cognitive functions. Also, analysis of aspects of a generated activity diagram, e.g. according to number, type and direction of flows, may be sufficient to estimate the feasibility of incorporating a cognitive function.

In addition to the difficultly of carrying out Step 4, there are other open issues that remain to be investigated in further research. For example, it is not known if the initial product concept has to be modelled and how detailed this model should ideally be. It may be beneficial to use a black box to represent the initial product concept, with input and output flows indicated. User actions could then be modelled around the black box as illustrated in Fig. 3. This may be sufficient to inform and motivate the designers of cognitive products, without having to take the time and effort to model the existing product in detail. This could also avoid issues with design fixation, which may arise through consideration of the original functional structure of the product. However, this approach may be detrimental, since there is no available information about how the flows link to structure and how the structure has to be changed when incorporating a certain cognitive function.

6 Conclusion

The method described in this paper provides a systematic approach for extending product concepts to include cognitive functions that would otherwise be implemented by the user. This results in products which implement cognitive functions previously carried out by the user and therefore require less interaction and provide a more enjoyable user experience. The approach was illustrated with reference to a cognitive washing machine concept which was developed and built by a multidisciplinary team of students. This initial use of the method is promising and suggestive of its potential as an aid in cognitive product development.

Acknowledgments This research is part of the Cluster of Excellence, Cognition for Technical Systems -CoTeSys (www.cotesys.org), funded by the Deutsche Forschungsgemeinschaft (DFG).

References

1. Metzler T, Shea K (2010) Cognitive products: definition and framework. In: 11th international design conference—DESIGN 2010, pp 865–874
2. Erden MS, Komoto H, van Beek TJ, D'Amelio V, Echavarria E, Tomiyama T (2008) A review of functional modeling: approaches and applications. Artif Intell Eng Des Anal Manuf 22(2):147–169
3. Stone RB, Wood KL (2000) Development of a functional basis for design. J Mech Des 122(4):359–370
4. Pahl G, Beitz W, Feldhusen J, Grote K-H (2007) Engineering design: a systematic approach, 3rd edn. Springer, Berlin
5. Metzler T, Shea K (2011) Taxonomy of cognitive functions. In: International conference on engineering design (ICED11), pp 330–341
6. Metzler T, Shea K (2011) Lessons learned from a project-based learning approach for teaching new cognitive product development to multi-disciplinary student teams. In: Proceedings of the ASME IDETC/CIE, DETC2011-48168
7. Umeda Y, Tomiyama T (1995) FBS modeling: modeling scheme of function for conceptual design. In: Proceedings of 9th international workshop on qualitative reasoning, pp 271–278
8. Ponn J, Lindemann U (2008) Konzeptentwicklung und Gestaltung technischer Produkte, Springer, Berlin
9. Friedenthal S, Moore A, Steiner R (2008) A practical guide to SysML: the systems modeling language. Morgan Kaufmann, Burlington
10. Jones JL (2006) Robots at the tipping point, the road to the iRobot Roomba. Robot Autom Mag IEEE 13(1):76–78
11. Cagan J, Vogel CM (2002) Creating breakthrough products: innovation form product planning to program approval, 1st edn. FT Press, Upper Saddle River, NJ 07458

A Design Inquiry into the Role of Analogy in Form Exploration: An Exploratory Study

Sharmila Sinha and B. K. Chakravarthy

Abstract Cross transfer of ideas from one target domain to another with analogies as triggers to generate new ideas is being studied in various fields. But the role of analogy in the creative process for both generating new ideas and exploring high degree of novelty in product form generation needs to be investigated. Using an analogy can help transcend the obvious to the unexpected by forming a confluence of two mediated thoughts, guided by creative interpretations. The important aspect of generating creative ideas is the ability to use the source analogy for a resultant design solution by interpreting it in terms of the design task at hand. The study analyses the creative ideas that emerges from the design solution, specifically focusing on the use of analogy for form exploration. By using the analogical inference, transition from one domain idea to another opens the exploration of novel viewpoints and numerous alternatives. Such a malleable approach of creative generation can yield novel ideas and forms. The paper explores how the use of analogy can facilitate idea generation and allow form exploration. This research examines idea generation issues of creativity by the use of multiple source analogies to help develop multiple domain concepts threw case study method. The study collects empirical data from observations and design outputs during a design session. The aim is to articulate the influencing effect of the use of analogy on factors of form exploration. The goal is to create a value proposition that designers can use to develop novel ideas as well as expressive form generation through radical exploration.

Keywords Analogy · Idea generation · Form exploration

S. Sinha (✉) · B. K. Chakravarthy
Industrial Design Centre, IIT Bombay, Mumbai, India
e-mail: sharmila.sinha@iitb.ac.in

B. K. Chakravarthy
e-mail: chakku@iitb.ac.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_14,

1 Introduction

Cross transfer of ideas from one target domain to another with analogies as triggers to generate new ideas is being studied in various fields. But the role of analogy in the creative process for both generating new ideas and exploring high degree of novelty in product form generation has scope for further investigation. Using an analogy can help transcend the obvious to the unexpected by forming a confluence of two mediated thoughts, guided by creative interpretations.

The important aspect of generating creative ideas is the ability to use the source analogy for a resultant design solution by interpreting it in terms of the design task at hand. The study analyses the creative ideas that emerges from the use of analogy towards the design solution in form exploration. The use of analogical inference, opens the exploration of different viewpoints and numerous alternatives. Thus allowing a malleable approach of creative generation that can yield novel ideas and forms.

The proposed study investigates how novice designers use analogy, to explore innovative product forms during the creative process, and how it can be a means to generate unique designs and help effective product representation. As the use of analogies is an associative process, it can lead to unique solutions by providing either direct or abstract triggers [1]. Koestler [2] explains the act of creation as combining process in 'the bisociation of unrelated matrices'.

The study has been built on the hypothesis, that use of analogy in idea generation can allow radical form exploration by novice designers. This research examines idea generation issues of creativity and the mental sourcing of ideas threw case study method. The study collected empirical data from observations and design outputs during the design session. The aim is to articulate the influencing effect of the use of analogy on factors of form exploration, and the representation of the expression on the product form. The effect of this approach has, scope of empirical investigation to establish certain key issues regarding its application as procedures in design practice. The study is undertaken during a design module, 'Studies in Form' for first year design students. It discusses the strengths and limitations of its outcome in generating ideas for innovative form exploration.

1.1 Aim of the Study

This study proposes to explore the possibilities of the varied, novel and expressive form exploration with the use of analogy. Csikszentmihalyi [3] has elaborated that one connects to objects through the feeling it emotes. The paper explores the effect on the representation of form of the product with the use of analogy for idea generation. It is hoped that the results can benefit student designers to train for novel idea exploration and expressive form design.

The process of exploration while designing is fundamental to finding new and creative ways to design a given object. The notion of idea generation has been explored in the field of psychology and in the field of management, computer sciences, engineering, linguistics etc. Significant work in the AI sector is exploring this phenomena to translate the functioning of the mind and simulate it as discussed by Holyoak and Thagard [4]. In neurosciences it is said that the structuring of perceptions gathered from various experiences help in problem solving by bringing them to the foreground as and when needed [5]. The role of analogy in this process of representation is visible, but very little structured approach is available. This paper is a part of a larger study that aims to build knowledge on the role of analogy in the process of idea generation for product design.

The intent of the study is to establish the role of analogy as an integral part of creative/disruptive idea generation and its utility in innovative product design. Thus exploring the relation of analogy to idea exploration and its influence on the form expression. This can be useful towards methodology development for pedagogical interventions, to enhance idea exploration and its manifestation in the product form and break fixations.

1.2 Analogy in Design

Analogies are used within the design context, it maps the causal structure between the source object in one domain to the target design task/problem by building a relation. A few formal methods have been developed to support design-by analogy such as Synectics [6], Word tree [7] and Random input [8]. Methods basing analogies on the natural world are seen in use in Biomimetic concept generation, using the powerful examples nature provides for design. Analogies are used to project a structural relation from one domain to another, revealing new information and insight, further catalysing new analogy, to move further out of the problem and help map radical new solutions. According to Gero [9], unexpected design solutions are a product of the confluence of two schemas mediated through an analogy.

As creativity is a stimulated aspect of human thinking, it is also associated with the capacity to look critically at reality, explore unconventional alternatives, and perceive situations from innovative perspective [10]. Design being an amalgamation of both creativity and rational functionality, analogy seems to fit into it quite easily. Analogies can support understanding by abstracting the important ideas from the mass of new information by using the power of analogical relationships that is said to be based in their potential to comprise an entire set of associative relationship between features of the concepts that are compared [11].

1.2.1 Analogy in Idea Generation

Analogies are used when we want to say that something is like something else (in some respects but not in others) making it a key feature of many approaches to creativity and proposed as an underlying mechanism [12]. It is extensively used in Bionics, which follows the systematic use of biological and botanical analogies to solve novel engineering problems.

Literature reveals that stimulation, fixation, time, parameters have subsequent effect on idea generation as a whole in positive as well as negative way. It is stated that to set the flow of ideas and start the process of ideation, external stimulation can be helpful and particularly more heterogeneous stimuli form multiple categories are found to facilitate the production of more diverse ideas [13]. But on the downside the stimulation can lead to a fixation of reproducing parts of the given example to the created design, which will be discussed in the later part of the paper.

2 Method

The study is conducted during a course module "Studies in Form" as a case for data collection. The method of document analysis is used. From the choice of analogy to breaking up of its attributes for idea exploration by mapping on to the target product and how it is relating to the form expression is analysed through documents of the process. The study uses an explorative approach to show how the exploration of ideas with the use of analogy, generates novel forms in a classroom experiment with 15 design students. This paper has tried to look at the relationship between analogies, its workings and influence on the idea generation process during form creation. The study is done as a precursor to the main research of measuring the various influences of use of analogy in idea generation.

2.1 Description of Research

The sample consists of 15 first semester M Des. students of product design and interaction design from various engineering and architecture background. There were 7 female and 7 male students. The mean age is 25 years. Their experience ranged from fresh graduates to 3–4 years industry experience. The Data was generated from documenting class activities, sketches and thought outline during the design exploration process (unstructured interviews to get personal info was also done). The investigation was in the natural environment of the studio/classroom during the module "Studies in form". Protocol was specifically ruled out as it was felt that it would hamper the flow of thinking as the samples were novices-thus emphasis was given on thought links and sketches.

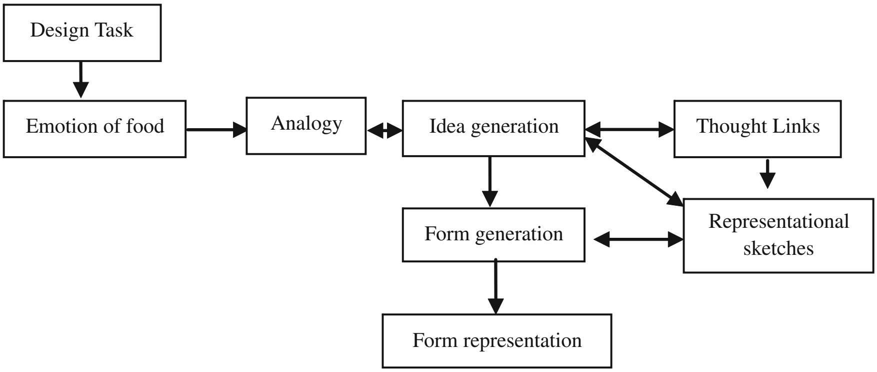


Fig. 1 The form exploration process using analogy

The task given was to design a 2 compartment plate connoting an expression with the use of analogy from nature. The study of the retrieval and representation of source data on the target form was done.

Values of plate: Experience plate. It had to be a 2 compartment plate with a minimum depth of 1 inch and maximum size 14 inches diameter, to be produced through a specific manufacturing process of vacuum forming.

A workshop on idea generation techniques with the use of analogy was conducted within the module. Students were taught to identify the source analogy and use the process of attribute mapping and transfer to the target, then translate it into the designing of the form (Fig. 1).

2.1.1 Procedure and Task

First of all, the teacher (i.e. researcher) provided the brief and the descriptions of the design task within the module "Studies in form: designing with analogy". The steps to be followed:

1. *Expression depiction*
2. *Take an analogy from nature and source visuals*
3. *Identify attributes of the source analogy*
4. *Representation of analogy to target plate design and its form*

3 Data Collection

This study draws from Cross's designerly way of thinking and idea generation by novice and professional designers [14], which investigated how designers can ideate through analogy. It is stated that the mind always looks for associative links to build ideas, through continually challenging abstract representations against visual representations during designing. This paper draws upon a single design case study, which is very limited in scope, in order to generalise the role of analogy in supporting ideating and development of novel product forms. Though the insights gained can be useful for further research.

The design problem given was to design a 2 compartment plate with the theme being any expression related to food with the use of analogy from nature, with size and process of manufacturing being specified. The study only focuses upon a subset of design activity the idea generation for exploring form.

The data in this paper is drawn from a 2 week long module with sessions on abstract form generation and sessions in idea generation with analogy, which the participants used to design the 2 compartment plate. Their thought flow and line representations were taken as document data for analysis. Students were asked to develop ideas by using analogy and develop line representation. They used river clay and prototyping materials for their 3D exploration of the ideas generated for form exploration and refinement.

3.1 Analysis

The technique of document analysis was used to identify typical ways in which analogy was used to support exploration (Fig. 2).

This exploratory approach of the study was used to help formulate an understanding of the thinking with analogy activity during the design process. This paper does not attempt to statistically proof any claims, because of the experiments small sample size. The design examples presented are the design outcomes of the experiment on which the data was collected as depicted in Table 1.

The levels of analogy used in the exploration process and the representations manifested in the product form was rated and plotted to observe the relationship that emerged (Fig. 3).

3.1.1 Findings and Discussions

The findings of the inquiry showed that idea exploration, with the use of analogy has a compelling effect in product designing. It gives physical representation to conceptual thought, and translates abstract emotions into tangible forms, by breaking predetermined perceptions and transcend to the next level of abstraction. It can be manipulated to have different association in differing contexts, as the same theme can be represented radically differently in the form with the use of different analogies.

Analogy from nature that was easily understood was adopted thus aiding and supporting ideation and novel form exploration. The use of direct analogy helped as an idea starter by offering a point of association. It helped to steer from direct to

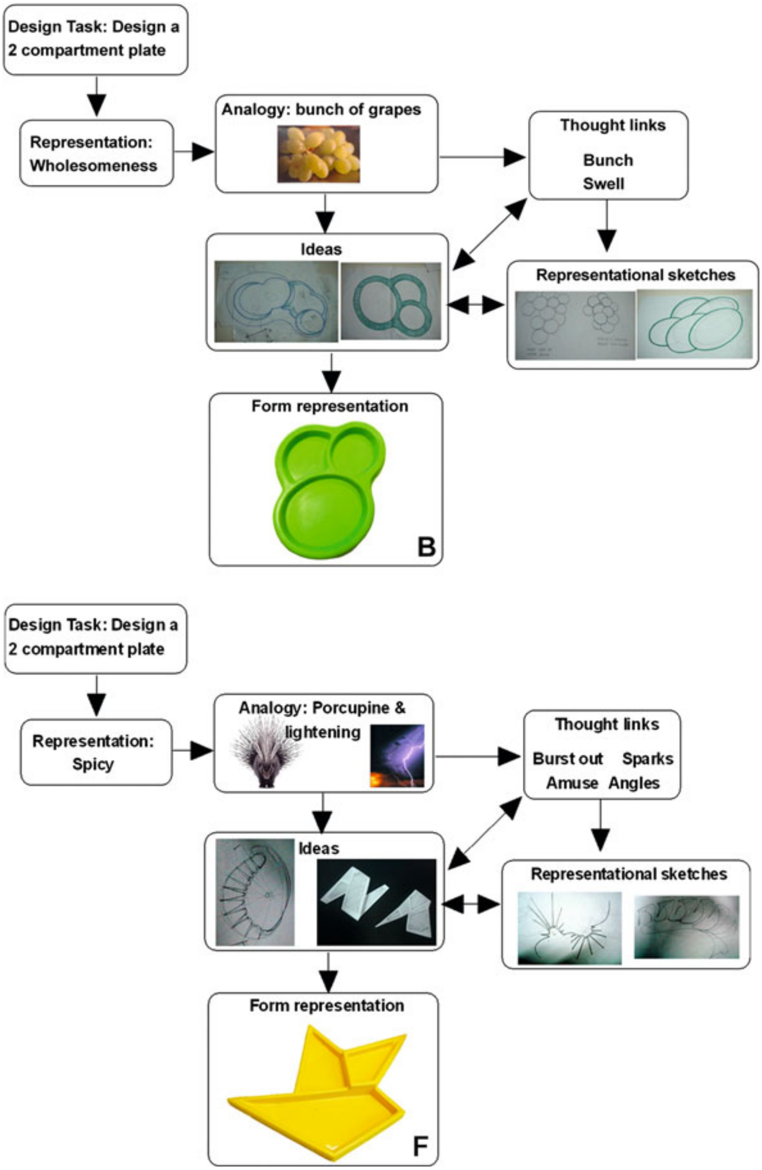
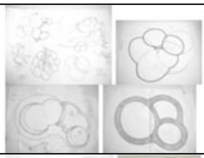
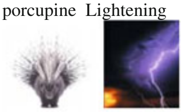
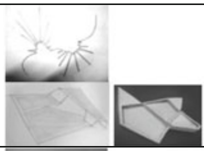


Fig. 2 The form exploration process using analogy (two examples)

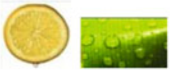
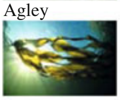
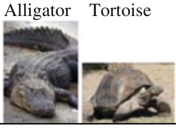
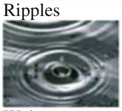
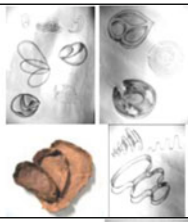
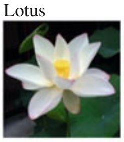
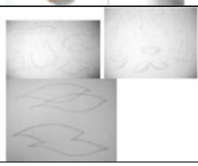
abstract thoughts, leading to radical representation through attribute mapping and help as a prop to idea exploration. Once the students were able to break out of their conditioned thinking by choosing an analogy from nature for the expression they wanted to represent in the plate design they were able to freely explore radical forms, where the analogy worked as a catalyst to trigger multiple thoughts and help in developing novel designs.

Table 1 Form exploration with use of analogy to represent an expression

Expression	Analogy	Thought links	Visual representation in form exploration	Final Form
Amusement Plate	Honey drip Surf 	Pleasure Exuberance Lush Curling		A 
Appetite Plate	Grapes bunch 	Wholesome Bunch Swell		 B
Healthy Plate	Pumpkin Elephant 	Bulge Volume Full whole		 C
Elegant plate	Pearl  Snake	Exotic Style Attractive Smooth Flow Balanced		D 
Happy plate	Flower & Bud 	Bloomed Bright Fresh		E 
Spicy plate	porcupine Lightening 	Amuse Excitement Burst Angles Open		F 
Aroma plate	Sprouting	Freshness Movement Upwards		G 

(continued)

Table 1 (continued)

Healthy plate	Apple Green leaves 	Bulgy Fullness Freshness Happy		H 
Fresh plate	Lemon Water 	Radiating Lively Splash		 I
Secure plate	Bud Peanut 	Enveloping Overlapping Compact Freshness Blooming		J 
Soft plate	Cloud Cotton 	Curvilinear Smooth light		 K
Poise plate	Swan  Agley 	Balance Slender Order Grace Style Elegant		L 
Strong plate	Alligator Tortoise 	Power Heavy Hard		 M
Musical plate	Ripples  Web 	Spread Resonance Repetition Harmony		N 
Crisp plate	Lotus 	Organized Symmetry Precise		O 

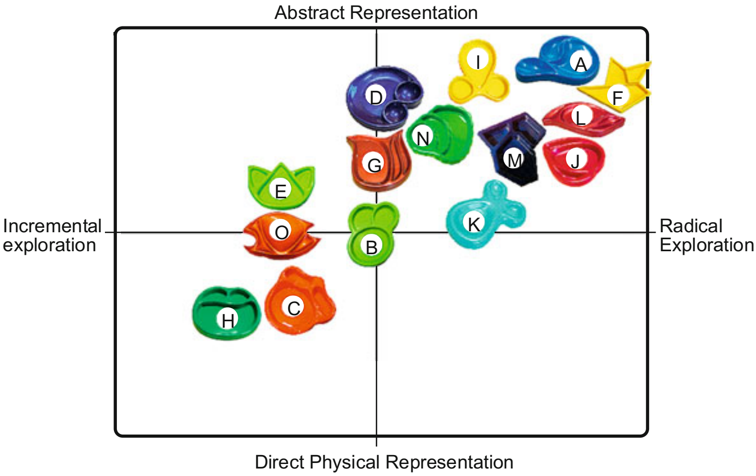


Fig. 3 Form exploration and levels of representation

Observing and mapping attributes from analogy allowed simple representation of abstract concepts as well as abstract representation of simple attributes and helped evolve unanticipated design solution and form generation. This can be seen specifically in forms A, F, L, J, G, M, I, N, D.

In a few cases the use of analogy were rather bounded to a physical representation only. In the case of forms H, O, E exploration remained in the realm singular physical attributes usage thus restricting next level of exploration. The contextual aspect of the use of analogy revealed various associative links to similar themes, allowing infinite possibilities of exploration. As seen in forms D and L where the theme is elegance but due to varied analogies the form exploration is diverse.

Use of analogy helped in integrating emotions to the physical qualities of the analogy to the form and bringing about a expressive representation. This helps to expand and extend the designers exploratory field. From the perspective of using analogy in form exploration it can be argued that the exploratory nature of analogies and its associative functions, significantly facilitates idea exploration and novel form generation. The use of multiple representations extracted from the analogies and its abstraction is seen to effect radical form generation in an encouraging way. Thus the assumption that radical form generation by novice designers can be enhanced with the use of analogy and can bring benefit to assignments in hand has been observed. By understanding how using analogy in the thinking process enhances form exploration, this study can help to identify the incremental to radical exploration of form and its relation to the abstraction of analogical attributes mapped.

The key role that analogies can play during the design exploration stage is in building sense through the process of representational transfer and facilitate the mind to think differently. Despite the apparent benefits that analogy provides for idea exploration, the possibility of fixation is an area that needs to be given considerable attention. Thus a structured guided pedagogical intervention can be useful. Further work in the area has to be done to formulate it.

4 Conclusion

This paper has articulated with examples, the role of analogy in idea exploration and in facilitating expressive form generation.

The fundamental findings of our inquiry are that:

1. The use of analogical representation in form generation is able to move the ideas to the next level. Design ideation can be stimulated with analogical inspirations to multiple directions, allowing a more versatile field of exploration of ideas and deliver novelty.
2. Using analogies to explore ideas and form generation helps students to break out of their trained perception of form generation and discover new expressions in form exploration.
3. The use of analogy as a training for associative thinking is useful for exploratory designing. As designers unconsciously source ideas analogously, but by understanding its deeper implication in the design representation can help them to enhance their practice of designing. This gives scope to further this study to way all the implications and develop a framework for creativity, and validate new methodology through more robust experiments. In the training process it is important to convey that the analogue is not meant to be a copy of all the features of the target [15], rather its value lies in the abstraction of the representation.

In today's competitive market the ability of analogies to produce novel forms by aiding idea exploration during the design process, can be considered as an important tool. This study focuses on use of analogical stimuli to evoke radical form generation, and shows that more abstract themes can be translated to novel form representation, through the use of multiple analogies. Thus reflecting a scope for further study to develop a structured pedagogical intervention for training idea exploration and form realisation from abstract themes and arrive at novel products.

Further, this practice can facilitate design at multiple levels of formulation, representation and implementation of ideas, leading to the form expression. Thus further examination of the specific types of analogy usage [6] and its specific implementation may help progress the use of analogy to show radical effect on original design outputs of novice designers.

Acknowledgments I'm grateful to my guide Prof. B K Chakravarthy for his guidance and for allowing me to conduct my experiment within the module, Studies in Form at IDC. The cases cited here are assignments of first semester MDes. students of the 2010 batch. I'm grateful to the students for sharing their work and cooperating with my data collection.

References

1. Boden MA (1994) Dimensions of creativity. MIT Press, Cambridge
2. Koestler A (1964) The art of creation. Hutchinson, London
3. Csikszentmihalyi M (1992) Flow: the psychology of happiness. Rider, London
4. Holyoak KJ, Thagard P (1995) Mental leaps: analogy in creative thought. MIT Press, Cambridge
5. Christoff K, Keramation K (2006) Abstraction of mental representations: theoretical considerations and neuroscientific evidence. Oxford University Press, Oxford
6. Gordon WJJ (1961) Synectics: the development of creative capacity, Harper & Row, Publishers, Incorporated, New York
7. Hey J, Linsey J, Agogino A, Wood K (2007) Analogies and metaphors in creative design. Proceedings of the mudd design workshop VI, Claremont
8. De Bono E (1970) Lateral thinking. Penguin Books, Harmondsworth
9. Gero JS (1992) Creativity, emergence and evolution in design In: Gero JS, Sudweeks F (eds) Preprints computational models of creative design, department of architectural and design science, University of Sydney, pp. 1–28
10. Csikszentmihalyi M (1997) Creativity: flow and the psychology of discovery and invention. Happer Perennial, New York
11. Glynn S (1991) Exploring science concepts: a teaching with—analogies model. The psychology of learning science. Erlbaum, New Jersy
12. Finke RA, Ward TB, Smith SM (1992) Creative cognition: theory, research and application. MIT Press, Cambridge
13. Howard-Jones PA, Murray S (2003) Ideation productivity, focus of attention, and context. Creativity J 15(2–3):153–166
14. Cross N (2006) Designerly ways of knowing. Springer, London
15. James M, Scharmann L (2007) Using analogies to improve the teaching performance of preservice teachers. J Res Sci Teaching, 44 (4):565–585

Supporting the Decision Process of Engineering Changes Through the Computational Process Synthesis

Florian Behncke, Stefan Mauler, Udo Lindemann, Sama Mbang, Manuel Holstein and Hansjörg Kalmbach

Abstract Engineering changes (ECs) are considered as cost and time-consuming. Based on the understanding of EC as a specific representative of cycles within development processes, the implementation of ECs is initiated by a target deviation, which leads to a decision over different alternatives of the implementation process of the particular EC. This decision is based according to literature and industrial practices within the field of process design methods on an expert discussion, without a formalized and explicit consideration of different change options. This paper presents computational process synthesis (CPS) as a support for the decision making of change options. The CPS is embedded within a procedural model for the decision process of ECs. Besides, this paper presents a case-study, which describes the application of the presented procedural model as well as the CPS.

Keywords Cycles · Changes · Process design · Design synthesis

F. Behncke (✉) · S. Mauler · U. Lindemann
Institute of Product Development München, Technische Universität München, Munich, Germany
e-mail: behncke@pe.mw.tum.de

S. Mauler
e-mail: stefan.mauler@mytum.de

U. Lindemann
e-mail: lindemann@pe.mw.tum.de

S. Mbang · M. Holstein · H. Kalmbach
Daimler AG, Sindelfingen, Germany
e-mail: sama.mbang@daimler.com

M. Holstein
e-mail: manuel.holstein@daimler.com

H. Kalmbach
e-mail: hansjoerg.kalmbach@daimler.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_15, © Springer India 2013

1 Introduction

1.1 Motivation

The development towards a worldwide buyer's market driven by globalization, leads to an intensified individualization of industrial goods [1, 2]. The results are a growing number of products and especially a growing variety of these products [3]. As a consequence development efforts combined with higher expectations on products increase, while market-induced development periods are reduced at the same time [2]. So cycles of development and innovation need to abbreviate at increasing frequency to keep the company competitive [4]. Therefore, it is inevitable to adapt a company's processes to these new requirements. Engineering changes and their implementation are a vital sign of this adaption. Reorganizing processes is very expensive and time-consuming. The outcome is a static process-map, which is unable to react on unplanned changes [3]. The effects of engineering changes on the process flow are difficult to evaluate. In particular external cycles, induced by changing customer preferences, technological or economic developments, are barely predictable [5]. Kleedörfer [6] suggests a better crosslinking between the sub-processes, which can be transferred to the implementation of engineering changes. Based on this, Heinzl et al. [7] developed a concept of defined process building blocks with standardized interfaces, in order to design a flexible development process.

At Daimler it was the objective to create a process which reacts flexibly on unpredicted engineering changes and can be adapted to new requirements. With "Computational Process Synthesis" (CPS) an approach was developed to answer the central research question of this paper: *How can computational process synthesis support the decision process of engineering changes*?

This paper describes the fundamentals of decision making (see Sect. 3.1) and of process design (see Sect. 3.2). Section 4 shows the development of the concept of CPS and Sect. 5 its implementation at the Daimler AG.

1.2 Background of Research

Complex products are characterized and influenced by a number of company-internal and external cycles. These cycles are objects of investigation of the Collaborative Research Centre (SFB 768)—'Managing cycles in innovation processes—Integrated development of product-service systems based on technical products'. Cycles are reoccurring patterns (temporal and structural), which are classified by phases. As a result, a cycle is always connected with repetition, phases, duration, triggers and effects. Moreover, cycles could include retroactive effects, interlockings, interdependencies (within cycles and between cycles), hierarchies and further influencing aspects [5, 8]. Engineering changes are, due to their reoccurring process, a specific occurrence of cycles in development, which are focused within the SFB 768 by a subproject on the cycle oriented planning and coordination of development processes. Triggers cause the repetition of a pattern and result of a deviation of the current and the intended status of an object. In order to resolve this deviation, changes are required. However, the characteristics of change options vary in terms of their effects, which emphasize the relevance of a systematic creation and decision on change options.

2 Research Methodology

The development of a procedure for the computational process synthesis is based on established literature of process design and decision making in complex systems considering the specific requirements of engineering changes. Through applied science the procedural model is refined iteratively and further developed by using real process examples of the tool-making department in the Mercedes-Benz factory Sindelfingen. The procedural model and its results in terms of evaluated change options (alternatives) were evaluated by expert interviews at Daimler AG and are in place for a validation within succeeding student project.

3 State of Technology

3.1 Decision Making

Roy [9] describes three basic kinds of decisions: decision by selection, decision by ranking and decision by classification and sortation. Decision by selection means to choose a group or a single alternative from all possible alternatives of action, while decision by ranking means to arrange the alternatives in sequence, in order to determine the ability for certain demands. Decision by classification and sortation corresponds to a common preselection. Decisions get more challenging when more objectives need to be matched with that decision. Still more effort is necessary if not all alternatives are known to the decision maker. In that case we talk about a multi-criteria decision problem, with an additional identification problem. These kinds of complex decision processes need to be supported methodically and conceptually [10].

3.2 Process Design

Process Design is a complex problem. Established procedures suggest a discussion-based process-mapping performed by project groups of experienced employees from the relevant process areas [11].

Together they document the current process of a change option using modeling methods like sign-posting. The group develops an ideal process as long-term objective, which the group's members expect to be perfect in the work-flow as well as in its results. Based on these two processes the target-process is mapped. It is a compromise between the perfect solutions of the ideal process and those solutions that are realizable under real conditions. They discuss the workflow step-by-step and determine the target-process with a sequence of decisions by selection. The number of alternatives is based on the solutions of the current process, the ideal process and the know-how of all involved experts, as well as their creativity. The criteria used for decisions aim mostly at local optimization, because the impact on the complete process cannot be evaluated with the given methods.

Methods like 'Program Evaluation Research Task' (PERT) or Critical Path Method (CPM) provide a procedure to derive an optimal process sequence out of given tasks, mainly focusing on the lead time. The process sequence is event-driven and considers uncertainties of single tasks [12]. However, multiple criteria are not used for the derivation of the process sequence. They are mandatory to consider optional tasks, which for example are performed to increase the quality of the output of specific tasks.

4 Computational Process Synthesis

CPS offers methodical support for the identification of change options as well as for the multi-criteria decision on the process-mapping of those change options. Conventional approaches use a sequence of local decisions for the selection, while CPS uses integrated decisions by ranking complete process-paths from the solution space. CPS is composed of three steps (Fig. 1). First, required input-data for the simulation is collected. All sub-processes with their inputs and outputs are determined and formalized. Afterwards, an excel-based tool spans the solution space, generating all possible process-paths through combinatorics. The third step is a two-stage assessment to choose the optimal solution from the solution space. Using defined K.O.-criteria, the number of solutions is reduced to a manageable amount. With a customized set of criteria the optimal process-path for the specific situation is determined.

4.1 Process-Mapping of Change Options

Objective is a process-map, which includes all process-paths for the implementation of the different change options. Like in the conventional approach a project group is established consisting of experts from all relevant areas [11]. The discussion is focused on the inputs of the sub-processes, as their performance and the quality of their results depend significantly on the quality of the process-inputs [13].

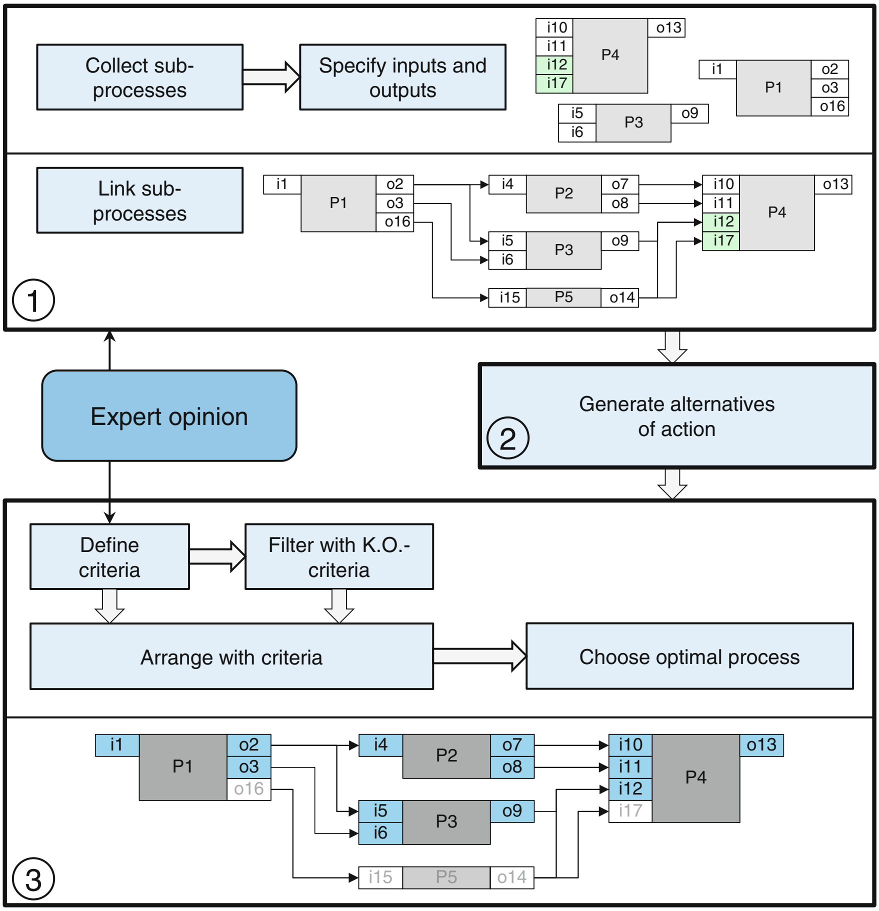


Fig. 1 Procedural model of CPS

The specification of the outputs results from linking inputs to their corresponding providers. This procedure avoids a deduction of unnecessary work results. Solely the processing time, needed from process-start to completion, is allocated to the outputs.

First all sub-processes are analyzed, according to their inputs, used in the current process. Here three kinds of inputs are distinguished: fixed, optional and alternative. Fixed inputs are those that are necessary to perform the sub-process at all, optional inputs complement the fixed ones, while alternative inputs replace other alternative parameters. Each input can be provided by several different suppliers.

In addition, new options and alternatives for the target-process are developed. This step holds high potential for innovation, however, it is very elaborate. Customer orientation is of high importance to prevent a misguided development [14]. When customers suggest additional input to raise the quality of their sub-process or its results, providers need to evaluate, whether or under which conditions they can deliver the demanded input. It is crucial, that the demand-pull on the customer side coincide with the technology push on the provider side [15]. The provider has to deliver what the customer needs, and vice versa. The previously documented sub-processes get expanded with this additional data. Using the defined links between inputs and outputs a process-map is drafted.

4.2 Spanning the Solution Space

This step determines the possible process-paths of change options by an automated excel-based tool. The characteristics (see Sect. 4.1) are available for the program in a formalized state. For sub-process holding *optional* or *alternative* inputs, the tool determines all variations of the sub-processes. Thereby a group of *optional* inputs can be interpreted as a binary number, where every input represents a digit that is either used '1' or it is not '0'. The number of variations V with n *optional* inputs in one sub-process is calculated after the rules of combinatorics, as shown in Eq. 1:

$$V = 2^n \tag{1}$$

A group of m alternative inputs expands the number of variations with a multiplication by the factor m as shown in Eq. 2:

$$V = 2^n \times m \tag{2}$$

Afterwards the path generation is performed, following the pull-principle just like in Sect. 4.1. Because of the focus on the inputs and the generation of variations using them, this approach is necessary to achieve an explicit set of relevant paths. The tool proceeds backwards, it starts with the last sub-process. Each sub-process requests those parameters from its predecessors, which are needed in its current variation. If a sub-process holds more than one variation, new paths are generated. The tool ends, as soon as all paths are determined. If a new path is applied, the attribute *open* is assigned. The path is attributed as *closed*, when it reaches the first (initial) sub-process and all its sub-processes are *closed*. The sub-processes on the other hand count as *closed,* as soon as all their inputs are linked to a predecessor. The final result is the whole solution space. It holds the entity of all paths through the process-map, which are able to achieve the requested outcome.

4.3 Two-Stage Assessment

The assessment occurs in two steps. It is based on substantial expert knowledge about the workflow and the individual operation steps. First the possible solutions are narrowed down using K.O.-criteria. In the second step the remaining paths are evaluated with a custom-designed set of criteria in a quantitative way. The set of criteria consists of quantified parameters, which allow making a statement about the capabilities of the process and the quality of its products. All criteria are derived from general requirements for the process. They indicate the degree of fulfillment of these requirements, which originate from the process owners themselves, from the management or from literature.

K.O.-criteria reduce the solution space to a manageable amount of relevant process-paths, either using a critical value or with Boolean statements about certain process properties. The second stage of assessment works with various criteria, set in weighted relation to each other. All criteria have to be quantified, to allow a computer-aided assessment. One possibility to use qualitative criteria as well, is score evaluation, or weighted score evaluation for higher significance.

For dynamic and flexible process design, critical values as well as the weighting of the criteria is to be defined specifically for each situation. As a result, the optimized process-paths for each situation can be found and implemented.

5 Case-Study

The tool-making department in the Mercedes-Benz factory Sindelfingen develops, constructs and produces dies and tools for deep-drawing operations of sheet metal parts for Mercedes-Benz cars. The increasing number of models and their variations, in addition to the market-induced shortening of development cycles, leads to severe deadline pressure and a shortage of resources. Out of this motivation an in-house-consulting project (IHC) was launched, performing a classical process optimization via sign-posting within a project group of experts. The following approach was developed in parallel to this project, to support the established approach. It was implemented in a pilot study, with which the specific actions are described in the following.

5.1 Process-Mapping of Change Options

The process-mapping took place within the project meetings of the IHC-project. The different variations of input compositions and alternative providers for the inputs resulted from discussions about the current, ideal and possible target-process. Figure 2 shows an example of an anonymized sub-process.

Inputs i1 and i2 are fixed parameters, which are required to perform the sub-process. i3 was provided sporadically in the past, to improve the quality. However, it is an *optional* input. i4 is requested by the process-owner, intending to improve his results. Another sub-process is identified as possible provider, whose owner agreed to provide the requested parameter under specific conditions. So i4 is charted and marked as *optional*. i5 and i6 serve the same purpose. Nevertheless, they show different characteristics. One of the two parameters is needed to perform

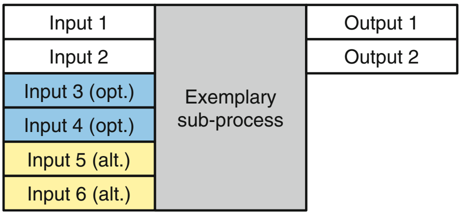


Fig. 2 Exemplary sub-process with inputs and outputs

the sub-process. That's why both are marked as *alternative*. Outputs o1 and o2 are requested by other sub-processes. The process-owner agreed to this request and defined processing times for both parameters. All sub-processes are connected, by linking their inputs and outputs. In the case-study 25 sub-processes are defined, holding 113 inputs and outputs. To keep clarity in the following a simplified exemplary process-map is used to describe further actions. Figure 3 shows this process-map. It consists of five sub-processes, with a total of 17 inputs and outputs. Two of them, i12 and i17 are *optional*.

The linking is conducted from input to output. Customers choose their providers. Every input needs at least one predecessor—except i1, which is an initial input—otherwise the process would stop at this point. Several predecessors for every input in the map are possible, if the customer considers more providers to be suitable. That way i12 for example can be provided over o9 by sub-process P3 or over o14 by P5. If one output has more than one successor, e.g. o2, which delivers to i4 and i5, it must be ensured, that the required goods are available in a sufficient amount. Such constellations in the case-study turned out to be unproblematic as most parameters were digital data like CAD-construction data, which are available.

5.2 *Generate Alternatives of Action*

The inputs and outputs' properties are formalized, documented in an excel-list and provided to the tool. Based on this, the tool derives all possible process-paths. In the exemplary process-map (Fig. 3) only P4 holds more than one variation (Fig. 4).

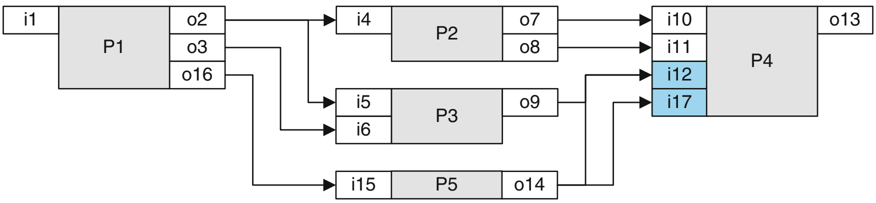


Fig. 3 Exemplary process-map

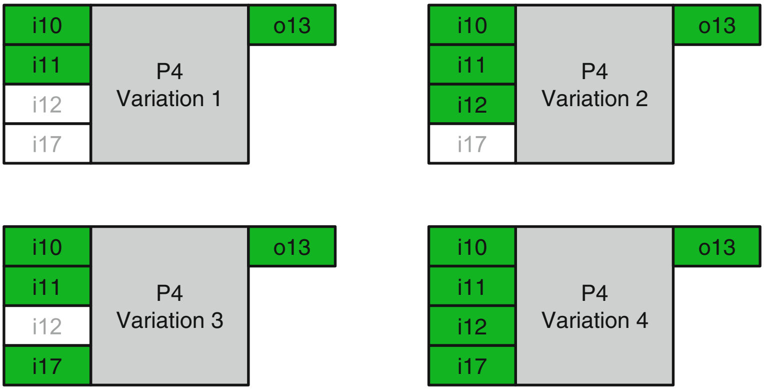


Fig. 4 Variations of sub-process P4

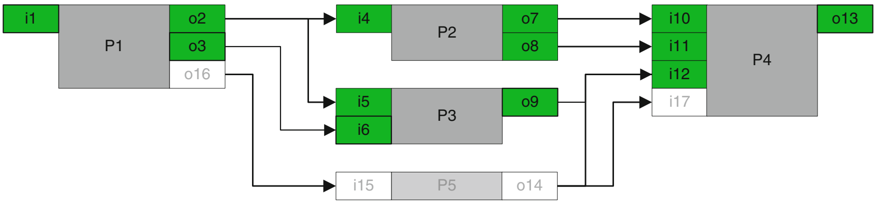


Fig. 5 Path no. 2 of the exemplary process-map

Following the earlier defined rules, two optional inputs cause an amount of $2^2 = 4$ different variations. The exemplary sub-process in Fig. 2 would double the amount because of the two additional alternative inputs to a total of $2^2 \times 2 = 8$. The path generation starts with o13, meaning at P4. Four paths originate here, caused by the four described variations of P4. As i12 holds two predecessors, every path containing i12 generates another path to display the additional alternative. This way for variation 2 and 4 there is one path providing i12 through o9 and one using o14.

Altogether there are six possible paths how to get through the exemplary process-map. Figure 5 shows path no. 2 of the exemplary process-map as a sample of the solution space. It contains P4's variation 2 and uses P3 to supply i12.

5.3 *Two-Stage Assessment*

The case-study's real process-map caused a total amount of 19,584 possible paths through the map. To handle this amount, the solution space was narrowed down using the two-stage assessment, described earlier.

Table 1 shows a selection of requirements for the process and the derived criteria for the process-assessment. As mentioned earlier the product-push in the

Table 1 Requirements and criteria for the assessment

Requirement	Criteria
Reduce processing time	Processing time (K.O.) T_p
Reduce processing cost	Operational hours (a.o.) T_o
Parallelize operations	Parallelism: T_o/T_p
…	…

automobile industry creates increasing deadline pressure. Therefore, one requirement was to reduce the entire processing time, to enable the workers to meet their deadlines. If deadlines cannot be kept, the process-path is not suitable. This shows, that processing time is a perfect K.O.-criterion. Process-paths that need less time than the critical value for this criterion are kept as possible solutions. The critical value in the case-study was set to 200[1] days, which lead to a reduction of the solution space to 2176[2] process-paths. However, the selection of the criterion and its critical value depends on the specific project.

All further criteria are assessment-criteria serving a decision by ranking, which have to be interpreted and weighted individually for every project by a group of experts. A basic requirement for all business processes is cost reduction. Among others, this is assessed with the operational hours for every cycle, which are equivalent to the labor costs of the process. So less operational hours are evidence for less labor cost or at least less tied-up working capacity. Simultaneous engineering claims parallelized operations. This can be assessed with the quotient of operational hours and processing time. This ratio, called parallelism, makes a statement about how much work is achieved during the processing time of the process. So a high ratio indicates a process, which performs several sub-processes in a short period of time. The connection between the first two criteria in the third one causes a conflict of objectives, which allows no process to achieve optimal values for every criterion. Weighting the criteria preforms a prioritization of the requirements according to their importance.

6 Results

Figure 5 demonstrates that all process-paths containing P5 are sorted out due to the K.O.-criterion. The processing time exceeded the critical value, because of the high processing time of P5. As o9 causes more operational hours than o7 and o8, P3 extends the complete processing time as well. However, its involvement improves the quality of the outcomes and the parallelism of the processes. As best

[1] Numbers were changed for this publication.

[2] Numbers were changed for this publication.

compromise between processing time and practicable work content, the shown second path is chosen from the solution space.

In the case-study the conventionally elaborated process was identified within the solution space and compared to other reasonable alternatives. As recommendation one path was determined, that has a shorter processing time and more operational hours at once. The parallelism rises from 1.36 to 1.62. This way the principles of simultaneous engineering are implemented consequently. Work content along the time-critical path is reduced as far as necessary, while parallel to this path validation content is performed, in order to use the available time effectively and to reduce critical changes during the stages of implemented hardware. Aspects like the time-critical path could not be considered, using the conventional approach, until the process planning was complete. Iterations for optimization are very elaborate. Using the approach of CPS, the results of the process organization can be improved, while the effort is reduced at the same time.

7 Summary and Outlook

This paper presents the CPS as procedure to support the decision making of engineering changes. Based on the fundamentals of decision making and process design, the procedure depicts the relevant sub-processes and their inputs and outputs for a specific change through structured interviews. The combinatorics of the sub-processes, using an excel-based tool, derives the different change options, which are fed to a two-step assessment method. First the change options are preselected by K.O.-criteria, before these options are assessed through a weighted evaluation method. Finally, the research results were evaluated within a case-study at the tool-making department in the Mercedes-Benz factory Sindelfingen and interviews with corresponding experts.

A first step of future work is the extension of the excel-based tool for the creation of change options, in order to improve its capabilities. Thereby, the processing speed and the graphic representation of the change options are focused. Moreover, checklists are to be prepared to support the user, while identifying K.O.-criteria as well as evaluation criteria. Based on the evaluation of the procedural model in a case-study at the tool-making department in the Mercedes-Benz factory Sindelfingen, we aim at a validation of the approach within a student project.

Acknowledgments We thank the German Research Foundation (Deutsche Forschungsgemeinschaft—DFG) for funding this project as part of the collaborative research centre "Sonderforschungsbereich 768—Managing cycles in innovation processes—Integrated development of product-service-systems based on technical products". Furthermore our thanks are given to Daimler AG, especially to the tool-making department BM of the Mercedes Benz factory Sindelfingen and all employees who supported this study.

References

1. Porter ME (1998) Competitive strategy: techniques for analyzing industries and competitors. The Free Press, New York
2. Cooper RG, Edgett SJ (2005) Lean, rapid, and profitable new product development. Basic Books, New York
3. Ehrlenspiel K (2009) Integrierte Produktentwicklung. Hanser, München
4. Griffin A (1993) Metrics for measuring product development cycle time. J Prod Innov Manag 10:112–125
5. Langer S, Lindemann U (2009) Managing cycles in development processes—analysis and classification of external factors. In: International conference on engineering design (ICED '09), vol 17. pp 539–550
6. Kleedörfer R (1998) Prozeß- und Änderungsmanagement der Integrierten Produktentwicklung. Dissertation, TU München
7. Heinzl J, Reichender J, Schiegg H (2001) Prozeß- und Änderungsmanagement der Integrierten Produktentwicklung. In: PMaktuell 2/2001
8. Langer SF, Knoblinger C, Lindemann U (2010) Analysis of dynamic changes and iterations in the development process of an electrically powered go-kart. In: International design conference (design'10), vol 11
9. Roy B (1996) Multicriteria methodology for decision aiding. Kluwer Academic Publishers, Dordrecht
10. Krishnan V, Ulrich KT (2001) product development decisions: a review of the literature. Manag Sci 47(1):1–21
11. Becker J (2005) Prozessmanagement. Springer, Berlin
12. Malcolm DG, Roseboom JH, Clark CE, Fazar W (1959) application of a technique for research and development program evaluation. Oper Res 7(5):646–669
13. Schöneberg U (2010) Prozessexcellence im HR-management. Springer, Heidelberg
14. Lukas BA, Ferrell OC (2000) The effect of market orientation on product innovation. J Acad Mark Sci 28(2):239–247
15. Hauschild J (2011) Innovationsmanagement. Vahle, München

Concept Generation Through Morphological and Options Matrices

Dani George, Rahul Renu and Gregory Mocko

Abstract The use of morphological analysis as a tool to aid concept generation is examined. Two principal limitations of the method are highlighted; (1) the lack of details generated for system concepts and (2) the explosion of combinatorial possibilities in the use of morphological matrices. The authors propose a method to support the generation of detailed conceptual ideas through functional combinations and use of options matrices, facilitating an intelligent exploration of the design space. In the options matrices, functions that are highly coupled are grouped together and idea generation is performed on the functional combinations based on identified innovation challenges. A subset of highly coupled functions are extracted from the morphological matrices and systematically integrated to form system level concepts. The resulting system concepts have greater design details compared to those generated through traditional morphological analysis techniques, allowing a designer to make informed decisions regarding their feasibility for the design purpose. An example of the proposed method is provided in the design of a seating chassis for automotive applications.

Keywords Concept generation · Morphological matrix · Options matrix · Innovation challenges · Functional coupling

D. George · R. Renu · G. Mocko (✉)
Department of Mechanical Engineering, Clemson University, Clemson,
South Carolina, U.S.A
e-mail: gmocko@clemson.edu

D. George
e-mail: dgeorge@g.clemson.edu

R. Renu
e-mail: rrenu@g.clemson.edu

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_16,

1 Introduction

Research in engineering design over the past few decades has resulted in the formulation of various theories, perspectives, models and methodologies for performing design activities [1–5]. Common to the various models and theories of design is the importance of creativity and the need for generation of good product concepts in order to satisfy customer needs, reflect their preferences and generate revenue. It is well understood that a poor design concept resulting from the product conceptualization process cannot be compensated for by 'bandaging' or quality of manufacturing [6]. Hence, it is paramount that designers focus time and effort in generating ideas, evaluating alternatives and performing concept selection appropriately.

Idea generation during product conceptualization can be roughly grouped into: methods to support the generation of ideas (means) to perform the individual functional requirements of the system and methods to support the combination of means to generate system level concepts [1, 2]. Several tools have been developed to support these idea generation activities [7]. The focus of our research is on the combinatorial aspects of concept generation.

Different combinatorial tools used to support concept generation can be classified as intuitive tools (such as storyboarding and affinity method) and systematic combination tools (such as check-listing and action-verbs) [7]. Morphological matrices may be used as a systematic combination or an intuitive combination tool. The concept of morphological thinking is essentially the method of systematic combination used to explore the complete set of possible relationships within any multi-dimensioned problem that can be decomposed into its' constituent sub-problems [8]. However, it also supports an intuitive approach to combination of means. A detailed review of the development and use of the morphological matrices is presented in [9].

Since the use of the morphological matrices is in the conceptual design stage, it typically contains means that are not detailed—the means may be high level working principles, non-dimensioned sketches, or vague ideas. Consequently, during combination of means into system concepts, it becomes difficult to identify which means are compatible with others to support their physical combinations. Therefore, simply choosing one means for each functional requirement may not yield a system concept if the means cannot physically be integrated into a working mechanism. Hence, the first limitation of the use of morphological matrices is the challenge of identifying compatible means to perform a system level combination.

Three techniques can be used to combine means into system concepts in a morphological matrix—a computational/quantitative technique, a qualitative technique and a fusion of the two. The computational technique is essentially based on calculating the estimated performance of the system that is generated as a result of combination of the means [6, 10–14]. The main challenge with this is that it requires the definition of performance parameters and a significant amount of design detail for each of the means, requiring a lot of time and effort from the designers, although the computations themselves may be automated in some cases.

The qualitative techniques [12, 15] and the mix of qualitative and computational technique [16] can be employed to generate concepts using three approaches—a systematic combination of all possible means (a full factorial approach), random combinations of means, and intelligent combinations of means.

The systematic combination approach systematically identifies all possible combinations, thus allowing the designer to choose the optimum system concept from the entire set. However, the major limitation of this approach is the number of combinatorial possibilities that must be explored. A small design task that is decomposed into 5 functions with 10 means identified to fulfill each function has 10^5 (100,000) combinatorial possibilities. In practise, may not be possible to explore all these combinations to identify the optimum system concept. The combinatorial possibilities become even larger for large complex design problems. The demonstrative example described in Sect. 3 had over 600,000 combinatorial possibilities despite having only four functions.

The approach of random combinations identifies one means from each row randomly to generate system concepts. This approach can result in the combination of unexpected means that force the designers to think deep into how the combinations can be achieved, thus leading to innovative system concepts. However, the challenge is that the randomness can also result in the exclusion of potentially good system concepts. Although the randomness can be biased toward good quality means to yield improved results, the adaptation may yet fail to identify the most complimentary sets of means to generate good system concepts.

The intelligent combination approach conceptually lies in between the previous two approaches. Some of methods using this approach are described in [12, 15, 16]. However, these methods still propose high level combinations of the means within the morphological matrices, without the generation of significant details to allow a designer to make informed decisions to explore the design space effectively.

In light of these limitations, this paper proposes a method of qualitative exploration of the design space with morphological matrices using a focused ideation technique based on identification of functional coupling and innovation challenges. The method proposes a strategic exploration of the design space and combinatorial possibilities are explored based on informed decisions that are influenced by the designers' domain knowledge, experience and technological challenges. The next sections explain the proposed method, demonstrate an application to design a seating chassis for an automotive application, outline our conclusions, discuss the limitations of the method and identify future work.

2 Proposed Method for Concept Generation

The proposed method for concept generation aims to reduce the number of combinations that need to be explored to identify good system concepts, generate detailed information on promising combinations of means, encourage the exploration of design alternatives, and facilitate innovation in design. As a prerequisite, the functional decomposition of the design task and the generation of individual means that achieve each function should be performed and listed in a morphological matrix. A summary of the proposed method is illustrated in Fig. 1.

Figure 1 illustrates the high level steps required to perform a focused detailed exploration of the design space. The means in the initial morphological matrix are grouped and filtered (Step 1) before identifying functional combinations to perform focused ideation using options matrices (Step 2). The crosses in the initial morphological matrix represent the filtered means. The specific combinations explored in the options matrices (Step 3) are carried forward to subsequent higher level morphological matrices that list the functional modules against the subsystem concepts. The sub-system concepts are subsequently combined again using pairwise combinations using options matrices and higher level morphological matrices to generate system concepts (Step 4). The process is repeated to generate alternate system concepts (Step 5—not shown in Fig. 1).

Options matrices are proposed for several reasons including: (1) not all functions are identified in the initial morphological matrix, (2) some sub-functions can only be identified when combining specific means and thus are not relevant to all the means in the morphological matrix, (3) there may be several different geometric and physical combinations of means within the morphological matrix, and (4) the combination of means in the morphological matrix are explored at a high level of detail.

Step 1: *Grouping and preliminary filtering of the individual means*

The individual means from the morphological matrix are organized and grouped according to their similarities based on similar working principles, similarity of components, or other explicit design specific criteria such as strength, reliability or complexity. Clustering the means into specific groups help to identify strategies for combining the means across functions and stimulate generation of additional means. Affinity diagramming is a useful technique that can be used to perform grouping of the means. The grouped means are then analyzed individually

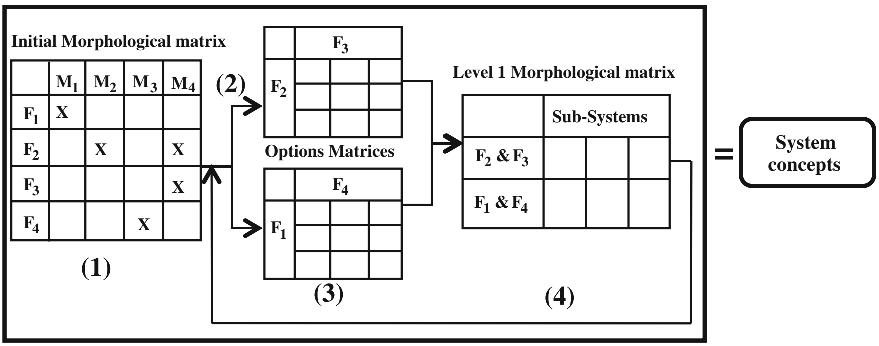


Fig. 1 System concept generation using morphological matrices and options matrices

and as a group with respect to feasibility to flag obviously infeasible ideas. The preliminary filtering helps to reduce the number of potential combinations to consider with minimal danger of losing feasible ideas. The result of this step is the generation of a morphological matrix with a reduced set of means that are grouped to identify similar working principles and design strategies.

Step 2: *Identification of functional combinations and innovative means for each function*

Subsets of the functions from the morphological matrix are extracted along with the means pertaining to those functions from the morphological matrix. Each subset consists of a pair of coupled/compatible/anti-functions that can be combined to form desirable or innovative sub-systems. These functions may be related to each other temporally, geometrically, or logically. Theory of Inventive Problem Solving (TRIZ) principles may also be used to identify function combinations representative of high level conflicts to identify the subsets [17]. The selection of functional combinations to form subsets may be subjective, i.e., designer specific, or design task or design focus specific.

Different functional combinations may be possible and desirable. However, an initial set of function subsets is chosen to specifically explore the possible ways in which the respective means can be combined, so that the functional coupling desired within each subset is physically realized. Different combinations of functions may be explored later during generation of alternative system concepts.

Innovative or promising means pertaining to each function are also chosen to carry forward for detailed exploration. The functional integration within each subset is explored through these means. The remaining means are not considered for further detailing at this point, although they are explored to generate alternative system concepts. The result of this step is the generation of functional combinations pertaining to possible design strategies and the identification of innovative/interesting ideas.

Step 3: *Generation of sub-system concepts*

The functional subsets and the promising means are exported to an options matrix, where focused idea generation based on explicit innovation challenges is performed on each subset, to understand how the various combinations of means can physically realize the functional integration. The innovation challenges are stimuli designed to provoke ideas for combining the means using different perspectives. They may be the result of provocative questions asked by the designer of the design task statement, requirement list, functional decomposition or the identified design space. TRIZ principles can serve as a basis to generate innovation challenges through forcing designers to consider different perspectives such as segmentation, merging, or mechanical inversion [17]. An options matrix is a two-dimensional matrix where means for one function are listed against the means for a second function. Every options matrix is constructed to explore the combinations of the means of two functions using a distinct, explicit innovation challenge.

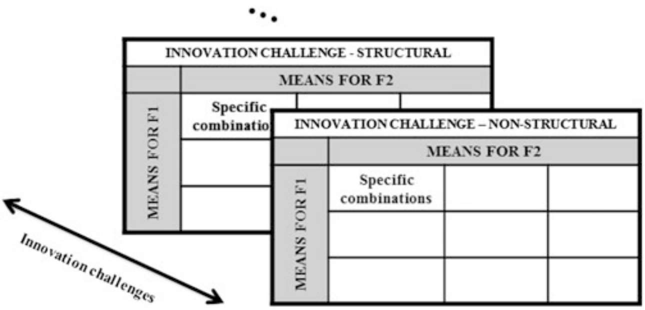


Fig. 2 Example representations of options matrices

A specific functional combination may be explored using different innovation challenges using independent options matrices as illustrated in Fig. 2.

Figure 2 illustrates the generation of distinct options matrices to explore the combinations of functions (F1 and F2) using two innovation challenges—structural and non-structural. For example, the two options matrices can be used to explore how the different means can be combined to create a mechanical sub-system where the components are (1) structural members or (2) non-structural members.

Each identified functional subset is explored in detail using the options matrices to generate sub-system concepts. The specific characteristics, positives, negatives and discussions regarding the sub-system concepts are explicitly captured in design documents.

Although the addition of the innovation challenges to the options matrices will result in additional combinatorial possibilities to explore, they are essential to push designers to explore non-obvious combinations, identify implicit assumptions, question the design space boundaries and facilitate innovation. The innovation challenges are generated from the information that is known about the system—design statement, list of requirements, function model and the design space. Innovation challenges may result in additional exploration of the solution space, necessitate a functional redefinition where an additional sub-function may be generated to support the combination of two functions, challenge the requirements thus questioning the implicit assumptions, question perceived design boundaries, identify functional combinations or stimulate exploration of additional configurations of combinations of means. The result of this step is the generation of small functional sub-systems that offer the designers a first glimpse of how the sub-system modules could be integrated into a complete system.

Step 4: *Generation of system concepts through sub-system combinations*

The functional modules and the sub-system concepts obtained through the options matrices are combined using a modified morphological matrix (Level 1 morphological matrix) as illustrated in Fig. 3.

Functional module pairs are extracted from the level 1 morphological matrix using a similar process as explained in Step 2. The sub-system concepts corresponding to the functional modules are then populated in level 2 options matrices to generate higher level sub-system concepts. These are fed back into the next level of morphological matrix and the process is continued until all the functions have been combined to form complete system concepts (Fig. 3).

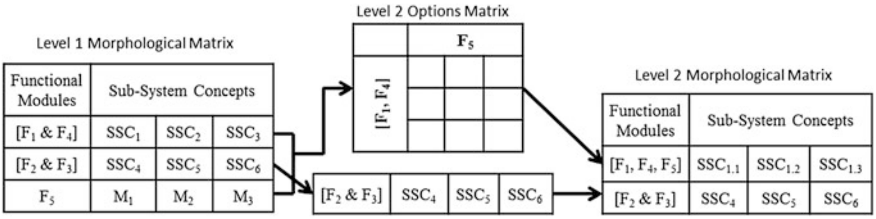


Fig. 3 Illustration of modified morphological matrices with functional modules

Additional levels of morphological matrices and options matrices are used depending on the size of the design task. A formal hierarchy of system decomposition needs to be established in order to apply the method to large design tasks so that the combinations formed at the various levels of the system may be appropriately termed. The decomposition described in [18] is particularly useful. The result of this step is the generation of complete system concepts and an understanding of the effects of specific functional combinations on the system characteristics.

Step 5: *Iteration to identify alternatives*

Once an initial set of system concepts are identified, alternative means and approaches to combinations are used to generate additional system concepts. Using the same method to generate system concepts, alternative designs can be created by altering functional combinations, using means that were previously unconsidered, and using different strategies for combinations. The result of this step is the generation of alternative system concepts based on solution characteristics resulting from functional combinations that affect the feasibility of the generated concepts.

3 Example Application of Proposed Method for Design of Automotive Seat

The proposed method was applied to the design of a seating chassis for the front driver/passenger of an automobile. The design task was decomposed into four functions and ideas were generated to perform each function. These were then populated in a morphological matrix as illustrated in Fig. 4.

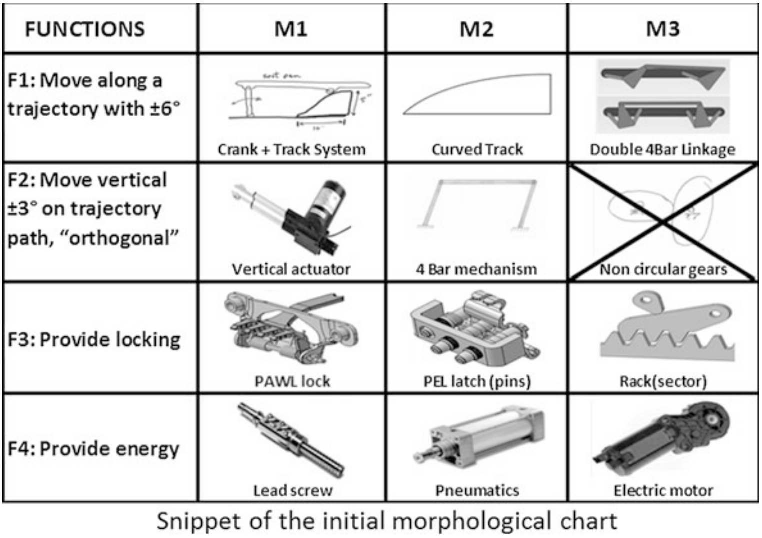


Fig. 4 Snippet of the filtered morphological matrix

Step 1: *Grouping and preliminary filtering of individual means*

Figure 4 illustrates a snippet of the initial morphological matrix and an example of one of the options matrices that was explored. The initial ideas in the morphological matrix were grouped according to the types of means that were generated for each function. For example, the means that were generated for providing the locking mechanisms were grouped according to the locking principles—positive interaction mechanisms, friction based mechanisms, geared mechanisms, and miscellaneous mechanisms. Once the groupings were complete, a preliminary filtering was performed on the generated ideas to discuss the individual means and ascertain their feasibility. Some clearly infeasible ideas such as use of tank tracks and complex gear trains (crossed out in the figure) were suspended from further detailing due to cost, manufacturability, and complexity concerns.

Step 2: *Identification of functional combinations and innovative means for each function*

The combination of functions 1 and 4 was one of the interesting functional combinations that was explored. The designers wanted to generate a unique and innovative power-assisted movement mechanism through integration of the two functions. Functions 2 and 3 were not combined initially because the designers wanted to focus on generating innovative power assisted movement mechanisms. The most promising ideas from the set of means for F1 and F4 were selected to carry forward to perform focused ideation, some of which are illustrated in the options matrix from Fig. 5.

Step 3: *Generation of sub-system concepts*

Functions 1 and 4 were paired in an options matrix with the selected means for each function as illustrated in Fig. 5.

Focused ideation was performed on the options matrix using the perspective of the innovation challenges—structural and non-structural, so that both structural and non-structural mechanisms could result from the combinations. After some geometric configurations of the paired mechanisms were identified and sketched, the designers were encouraged to generate more configurations using the perspectives of additional innovation challenges obtained using TRIZ principles (such as segmentation—instead of using one mechanism to achieve the movement along trajectory, a union of two mechanisms was explored, and mechanical inversion—designers were forced to consider how the physical combinations would be affected if the mechanisms switched positions in the sketch). This resulted in the generation of additional configurations, identification and discussion of the limitations of the means that had been identified for the locking function (F3), and a redefinition of the functional decomposition of the system.

Step 4: *Generation of system concepts through sub-system combinations*

The functional module consisting of functions 1 and 4 was then fed into a level 1 morphological matrix along with the separate functions 2 and 3. Subsequent

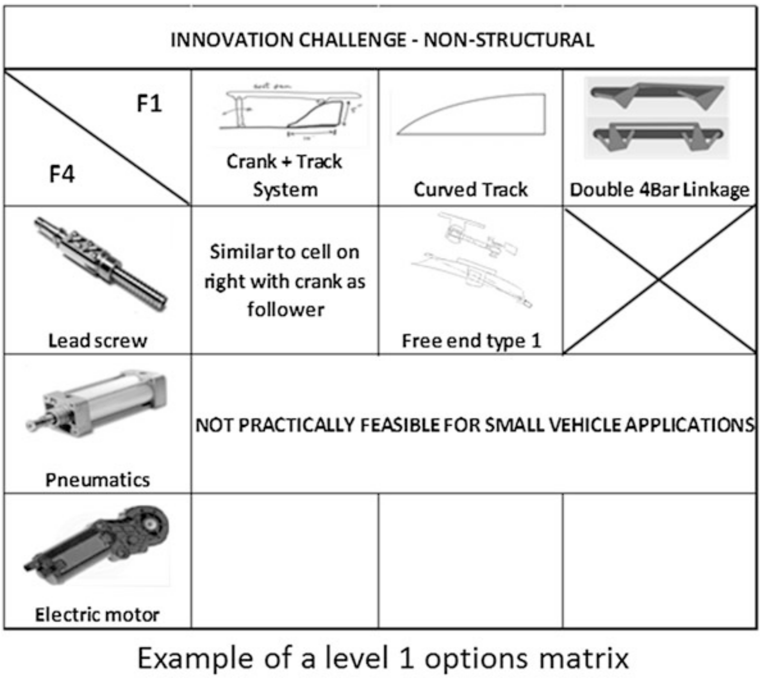


Fig. 5 Snippet of a level 1 options matrix for F1 and F4

options matrices saw the coupling of the locking mechanisms with the functional module of the power-assisted movement mechanism for the main trajectory and finally the overlay of the orthogonal movement mechanisms into the structure to generate complete system concepts.

Step 5: *Iteration to identify alternatives*

Additional system concepts were generated using different means, different innovation challenges and different order of functional combinations. For example, the movement mechanisms were coupled with the locking function, generating sub-system concepts that had a greater emphasis on managing the load paths through the structure to cater to crash load requirements. Other functional combinations and different orders of functional combinations were explored to generate additional system concepts.

4 Conclusions and Future Work

A method is proposed that provides detailed guidelines on how to efficiently generate system level concepts from individual functional solutions through focused detailed exploration of functional combinations using morphological and options matrices, and intelligently limiting the number of combinatorial possibilities explored. The method allows a designer to explore the specific characteristics of combinations of means or sub-systems, while generating detailed understanding of the design space, thereby enabling the generation of system concepts that better adhere to the design purpose and improving overall design feasibility. An example application of the method is provided in the design of a seating chassis for automotive application.

Further, research is currently underway to address the limitations of the method. First, the method implies some selection and filtering based on a high level understanding of the means. This may sometimes result in the inconsideration of potentially good means. Second, the individual means are filtered before consideration of their combinatorial effects. It is possible that two lower performing means are good in particular combinations. Also, the method proposes exploration of the design space through pairwise combinations. In other words, the order of identifying pairs and the pairs that are considered have an effect on the generated solutions. Finally, the method relies on the identification of explicit innovation challenges to perform innovative combinations of means. However, forcing the designers to identify the combinatorial perspectives (innovation challenges), questioning the design task and design boundaries, and looking to identify implicit assumptions will result in thorough understanding of the design task and help the detailed exploration of the design space.

Work is being done to refine the proposed method using feedback from practicing designers and to validate the steps of the method through user studies. The authors believe that the method is also complimentary to and capable of being coupled with the more recent utilization of design repositories [19–21], and ontological frameworks [22, 23] to support engineering design. A software tool is also being developed using ontological frameworks that supports the proposed approach while providing added functionality.

Acknowledgments This material is based upon work supported by Johnson Controls Incorporated (JCI). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of JCI.

References

1. Pahl G, Beitz W, Feldhusen J, Grote KH (2007) Engineering design a systematic approach. Springer, London
2. Ulrich KT, Eppinger SD (2008) Product design and development. McGraw Hill, New York
3. Ullman DG (1997) The mechanical design process. McGraw-Hill, New York
4. Buede DM (2000) The engineering design of systems: models and methods. Wiley, New York
5. Otto KN, Wood KL (2001) Product design—techniques in reverse engineering and new product development. Prentice-Hall Inc., New Jersey
6. Yan W, Chen C-H, Shieh M-D (2006) Product concept generation and selection using sorting technique and fuzzy c-means algorithm. Comput Ind Eng 50(3):273–285
7. Shah JJ (1998) Experimental investigation of progressive idea generation techniques in engineering design. In: Proceedings of DETC98 1998 ASME design engineering technical conference, Atlanta, GA
8. Zwicky F (1948) Morphological astronomy. Observatory 68:121–143
9. Ritchey T (2006) Problem structuring using computer-aided morphological analysis. J Operational Res Soc 57(7):792–801
10. Chen Y, Feng P, He B, Liz Z, Xie Y (2006) Automated conceptual design of mechanisms using improved morphological matrix. J Mech Des 128(3):516–526
11. Ölvander J, Lundén B, Gavel H (2009) A computerized optimization framework for the morphological matrix applied to aircraft conceptual design. Comput Aided Des 41(3):187–196
12. Huang GQ, Mak KL (1999) Web-based morphological charts for concept design in collaborative product development. J Intell Manuf 10(3–4):267–278
13. Tiwari S, Teegavarapu S, Summers J, Fadel G (2007) Automating morphological chart exploration: a multi-objective genetic algorithm to address compatibility and uncertainty. Int J Prod Dev 9:111–139
14. Matthews PC (2008) A Bayesian support tool for morphological design. Adv Eng Inform 22(2):236–253
15. Lin C-C, Luh D-B (2009) A vision oriented approach for innovative product design. Adv Eng Inform 23(2):191–200
16. Lo C-H, Tseng KC, Chu C-H (2010) One-step QFD based 3D morphological charts for concept generation of product variant design. Exper Syst Appl 37(11):7351–7363
17. Altshuller G (2005) TRIZ keys to technical innovation. Technical innovation center
18. Shishko R, Aster R (1995) NASA systems engineering handbook. In: Cassingham R (ed) NASA, Washington
19. Bohm MR, Stone RB, Simpson TW, Steva ED (2008) Introduction of a data schema to support a design repository. Comput Aided Des 40(7):801–811
20. Fenves SJ (2002) A core product model for representing design information. National Institute of Standards and Technology, NISTIR 6736

21. Schotborgh WO (2009) Knowledge engineering for design automation. Ph. d thesis, faculty of engineering technology, University of Twente
22. Darlington MJ, Culley SJ (2008) Investigating ontology development for engineering design support. Adv Eng Inform 22(1):112–134
23. Kitamura Y, Kashiwase M, Fuse M, Mizoguchi R (2004) Deployment of an ontological framework of functional design knowledge. Adv Eng Inform 18(2):115–127

Understanding Internal Analogies in Engineering Design: Observations from a Protocol Study

V. Srinivasan, Amaresh Chakrabarti and Udo Lindemann

Abstract The objective of this research is to understand the use of internal analogies in the early phases of engineering design. Empirical studies are used to identify the following: type and role of analogies in designing; levels of abstraction of search and transfer of analogies; role of experience of designers on using analogies; and, effect of analogies on quantity and quality of solution space. The following are the important results: analogies from natural and artificial domains are used to develop requirements and solutions in the early phases of engineering design; experience of designers and nature of design problem influence the usage of analogies; analogies are explored and unexplored at different levels of abstraction of the SAPPhIRE model, and; the quantity and quality of solution space depend on the number of analogies used.

Keywords Analogy · Novelty · Variety · SAPPhIRE model · Experience

V. Srinivasan (✉) · U. Lindemann
Institute of Product Development, Technische Universitat of Munich, Munich, Germany
e-mail: srinivasan.venkataraman@pe.mw.tum.de

U. Lindemann
e-mail: lindemann@pe.mw.tum.de

A. Chakrabarti
Centre for Product Design and Manufacturing, Indian Institute of Science, Bangalore, India
e-mail: ac123@cpdm.iisc.ernet.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_17, © Springer India 2013

1 Introduction

Design-by-analogy is used to produce creative solutions [1–3], in particular to enhance novelty and number of solutions [4, 5]. In designing, analogies aid [6] and inhibit fixation [7]. Design-by-analogy involves the transfer of analogous knowledge from a source domain to a target domain, to solve problems in the target domain. The following types of analogies are identified based on different criteria: domain of analogies: natural or biological and artificial analogies; apparent distance between the target and source domains: close domain and distant domain analogies; representation of analogy: verbal-, image- and video-based [3, 7]. In this paper, another category is identified based on development of analogies: internal and external analogies. An internal analogy is created using only the cognitive abilities of designers, mostly based on past experiences. An external analogy is created using an external source like a book, database, computer-based tool, etc. It could be argued that the external analogies also involve cognitive abilities of the designers; however, these kinds of analogies are created primarily due to the use of the external source. Current research on analogies in designing focuses only on understanding and supporting external analogies. As a precursor, it is important to understand the use of internal analogies. Further, this understanding should be the basis for understanding and supporting external analogies. Therefore, this research focuses on understanding internal analogies in designing.

2 Objective and Research Questions

The objective of this research is to understand the use of internal analogies in the early phases of engineering design. Specifically, the following research questions are posed:

1. What are the purposes and types of analogies used in the early phases of engineering design?
2. At what levels of abstraction are analogies searched for in the target domain, created in the source domain and, implemented in the target domain?
3. What is the role of experience of designers on the use of analogies?
4. What is the effect of analogies on the quantity and quality of solutions developed?

3 Research Methodology

Protocol studies of eight design sessions from earlier research [8, 9] are used to answer the research questions. Each design session consists of a designer, experienced (E1-E4) or novice (N1-N4), solving a design problem (P1 or P2),

Table 1 Design sessions (values available from [9])

	E1, P1	E2, P2	E3, P2	E4, P1	N1, P1	N2, P1	N3, P2	N4, P2
VCS	4.44	3.88	3.75	3	2.42	3.14	4.54	3.69
NCS	3.89	3.13	2.92	2.57	1.58	2.14	4	3.54
VIS	255	85	92	72	89	46	132	109
N_{ideas}	103	38	37	32	43	21	40	39

individually, by following a think-aloud protocol, under laboratory conditions (see Table 1). The objective of P1 is to develop solutions for a machine for making holes in any direction in three dimensions, subject to the following machine constraints: (a) change direction while making a hole; (b) make holes of different sizes; (c) make holes in metal, plastic, or wood; and (d) simple, small and portable. The objective of P2 is to develop solutions for a device to clean utensils subject to the following device constraints: (a) meant for urban middle-class family of maximum 10 members; (b) clean all kinds of utensils like tumbler, dining plate, pressure cooker, mixer-grinder, etc.; (c) clean utensils made of all general kinds of materials like stainless steel, porcelain, glass, plastic and aluminum. Before the commencement of designing, all the designers are instructed to develop requirements and as many solutions as possible. They are also instructed to explain on how solutions are developed, but are not told anything about analogies. The time for designing is unconstrained. The transcriptions and measures of solution space—variety of concept space (VCS), novelty of concept space (NCS), variety of idea space (VIS) and number of ideas (N_{ideas})—of these design sessions, available from [9] (see Table 1), are used for the following: (a) identify the analogies and, determine their domains and levels of abstraction, (b) identify the levels of abstraction in the target domain from which the search for analogies commenced and, (c) identify the levels of abstraction in the target domain at which the analogies are implemented. Since the SAPPhIRE model (see Sect. 4.2) can describe outcomes at several levels of abstraction in the early stages of engineering design, the levels of abstraction in the source and target domains are assessed using this model. To assess the effect of analogies on the solution space, Pearson's correlation, from Microsoft Excel™, is used to correlate novelty of concept space, variety of concept space, variety of idea space and number of ideas, with the number of analogies used to develop that solution space.

4 Literature Survey

In this section the relevant literature is organized according to the following topics.

4.1 Analogies

Several researchers studied the role of analogies in designing. The effect of experience of designers on the use of analogies, at the conceptual and detail design stages, is explored through empirical studies in an aerospace industry in [10]. The impact of the different kinds of representations of triggers on the representation and creative quality of design solutions inspired by those triggers in engineering design is studied in [3]. The effect of timing and similarity of analogies during idea generation is studied in [11]. The effect of the apparent distance between the source and target domains on the solutions developed is assessed in [7]. The effects of using no, biological- and engineering-based analogies in idea-generation are studied using an empirical study in [12].

4.2 SAPPhIRE Model

The *S*tate change, *A*ction, *P*art, *P*henomenon, *I*nput, *OR*gan, *E*ffect (SAPPhIRE) model is developed as a model of causality to explain the working of engineered and biological systems [13]. The model is observed to describe outcomes at several levels of abstraction in the early phases of engineering design [14]. Phenomenon is defined as an interaction between a system and its environment (e.g., displacement of an object over a surface). State change is defined as the change in property of the system due to the interaction (e.g., change in position of the object). Action is defined as the interpretation or high level abstraction of the interaction (e.g., movement of the object). Effect is the principle underlying the interaction (e.g., second equation of motion, $x = u \times t + 0.5 \times a \times t^2$). Input is a physical quantity, which comes from outside the system boundary, required for the interaction (e.g., acceleration on the object). Organ is a set of properties and conditions of the system and its environment, also required for the interaction (e.g., degree of freedom of the object in direction of acceleration, acceleration applied for a finite time, Newtonian properties of the object, etc.). Part is a set of components and interfaces that constitute the system and its environment (e.g., object lying on a surface).

4.3 Novelty and Variety

All the definitions and findings in this section are taken from [9]. A concept is defined as an overall solution which is intended to satisfy most of the identified requirements. An idea at a level of abstraction is defined as a constituent of a concept and is intended to satisfy only some requirements. Variety of a concept in a concept space is defined as a measure of a difference of that concept from the concepts developed earlier in that concept space. Variety of a concept space is defined as the average of the variety of all the concepts in that concept space. Novelty of a concept in a concept space is defined as a measure of the difference of that concept from: (a) concepts developed earlier in the same concept space, and

(b) concepts in the other existing concept spaces that satisfy the same overall function. Novelty of a concept space is the average of the novelty of all the concepts in that concept space. Both, variety and novelty of concept space are found to depend on the number of ideas explored at the different levels of abstraction; higher variety and novelty are observed when ideas at higher levels of abstraction are explored more. Variety of idea space is a measure of the difference of the ideas from each other in that idea space. It is also found that variety of idea space correlates well with the variety of concept space, which in turn correlates well with the novelty of concept space.

5 Results

The following observations are made from the analysis of the transcriptions and are supported with utterances from them. Even though the designers are not told anything about analogies, they are found to be used by both, novice and experienced designers. Since no external support is used during the designing, it could be reasoned that the analogies are based on the past experiences of the designers. This is supported by the utterances of E1: *It is a sort of electro-chemical erosion. I have read it somewhere in some manufacturing technology handbook. If you have a book…I do not remember erosion exactly. It is electrochemical erosion. There are other methods in this but that (electrochemical erosion) can be used. It has many limitations.* Here, the designer uses an analogy of electrochemical erosion for removing material and making a hole, and remembers reading about it. Table 2 shows the list of analogies used in all the design sessions. The fact that designers use analogies without being instructed to use them signifies that in studies involving the use of external analogies from a support, designers may be developing both, internal and external analogies. These analogies need to be distinguished, especially while studying the role of the support and experience of designers, on the use of analogies. It is also seen that solutions and requirements previously developed during the same session are also a source of analogies. This is epitomized by the utterances of E1, *That idea* (*laser*) *triggered the second idea of water jet because I felt laser might be little expensive. Water jet is, I think, a little cheaper and, I know that there is a process, so it was not very difficult correlating these two processes.* E1 develops a solution of water-jet machining by using the analogy of laser-jet, which is developed as a solution earlier.

Designers use analogies from both, natural and artificial domains (see Table 2). This observation is illustrated through the following utterances of E1 and N3 for natural and artificial, respectively. *It* (*tool head*) *can stick to any surface it wants to stick to locally, then why don't it have a have a, you know, lizards can stick upside down because of vacuum sort of, so why don't I use that principle here. I want to stick inside it* (work-piece). *It has some sort of vacuum pads it sticks wherever it wants.* Here, E1 uses the analogy of *vacuum principle of lizards* (natural domain) in the tool head, to enable it to fix itself. *So if we have to do that, why not dip the* *fresh utensil in a solution? This idea I got from Fevicol. When you apply Fevicol on the hand and after it gets dried, it comes out as a layer and we can peel off, comes with dirt or say everything.* N3 uses the analogy of Fevicol, a brand of adhesive, which after coming in contact with the hands, forms a layer after drying and can be easily peeled. This analogy can be used for cleaning utensils—utensils are dipped in a special solution, a layer of the material of the solution is formed on the utensils and the layer with the leftovers can be separated after the use of the utensils. A total of 12 and 36 analogies are used from the natural and artificial domains, respectively. All the designers, except N2, use more analogies from the artificial domain than natural domain. This is because all the designers have engineering or architecture backgrounds, and so their previous experiences are based more on the artificial rather than the natural domain. This signifies that, to exploit the rich and diverse knowledge of nature, designers with non-natural backgrounds need assistance.

It is observed that design problems also affect the use of analogies. All the designers solving problem, P1, use more analogies than those solving problem, P2. A total of 36 (11 natural and 25 artificial) analogies are used while solving P1, while an aggregate of 12 (1 natural and 11 artificial) analogies are used while solving P2 (see Table 2). Design problem, P1, is less conventional than problem, P2, therefore, P1 should be tougher to solve than P2. So, solving P1 should require more analogies than solving P2.

It is seen that analogies are used for developing both, requirements and solutions. Analogies for developing requirements is supported through the utterances of E1, *For example, you consider trees, trees grow in all directions in three dimensions, there is no fixed pattern as such and that's the kind of hole I am trying to achieve. So it is basically, there is an open space and, the branches and leaves are growing in different directions, so material is added into space. So, if I think of this problem in a different direction—it would be similar to adding material in open space and achieving my goal of creating cavity. In space I create the material from zero.* Here E1 uses the analogy of three-dimensional growth in tress to develop the requirement of adding material in space, instead of removing material from a given material. Out of a total of 48 analogies, only 4 are used for developing requirements while the rest are used for developing solutions (see Table 2). It has to be noted that the designers are instructed to only explain how the solutions are developed, not requirements. It is reported in literature that analogies can assist in the following: design problem search, identification, interpretation, elaboration, decomposition, and reformulation; solution refinement, evaluation; and evaluation criteria interpretation [2, 3, 15].

Experienced designers use more analogies than novice designers; on average, experienced and novice designers use 7.5 and 4.5 analogies, respectively (see Table 2). No experienced designer, except E1, uses any analogies from the natural domain, but prefer to use more analogies from the artificial domain. While the experienced designers use more analogies from the artificial domain, the novice designers distribute the analogies between the natural and artificial domains. These findings show that experienced designers need assistance for using analogies from

Table 2 Analogies created by designers and their domains, abstraction levels, purposes and implementation

Designer, problem	Analogy number	Analogy used	Domain	Abst. level	Req / sol	Imp. / unimp.
E1, P1	E1-1	Electrochemical erosion	Artificial	Ph	Sol	Imp
	E1-2	Arms of table lamp	Artificial	P	Sol	Imp
	E1-3	Decorative food items in exhibitions	Artificial	P	Sol	Imp
	E1-4	Beetles and insects	Natural	P	Sol	Imp
	E1-5	Rapid prototyping	Artificial	Ph	Req	Imp
	E1-6	Powder metallurgy	Artificial	Ph	Sol	Imp
	E1-7	Random 3-d growth in trees	Natural	A	Req	Imp
	E1-8	Casting	Artificial	Ph	Sol	Imp
	E1-9	Small creature	Natural	P	Sol	Imp
	E1-10	Light	Artificial	P	Sol	Imp
	E1-11	Cost, feasibility, laser jet	Artificial	P	Sol	Imp
	E1-12	Melting	Artificial	Ph	Sol	Imp
	E1-13	Injecting gadgets	Artificial	P	Sol	Imp
	E1-14	Rain water	Natural	P	Sol	Unimp
	E1-15	Cavities in cake	Artificial	P	Sol	Unimp
	E1-16	Chemical etching in PCBs	Artificial	Ph	Sol	Unimp
	E1-17	Complex shapes of human intestines	Natural	P	Sol	Unimp
	E1-18	Bull dozer	Artificial	P	Sol	Imp
	E1-19	Vacuum principle in legs of lizards	Natural	E	Sol	Imp
	E1-20	Globular creatures	Artificial	P	Sol	Imp
E2, P2	E2-1	Thread of bottle cap	Artificial	P	Sol	Imp
E3, P2	E3-1	Shoe polish	Artificial	P	Sol	Imp
	E3-2	Car wash	Artificial	Ph	Sol	Unimp
	E3-3	Washing toilet	Artificial	Ph	Sol	Imp
E4, P1	E4-1	Laser	Artificial	P	Sol	Imp
	E4-2	Flexible arm of robot	Artificial	P	Sol	Imp
	E4-3	Endoscopy	Artificial	Ph	Sol	Imp
	E4-4	Etching	Artificial	Ph	Sol	Imp
	E4-5	Tunnel digging	Artificial	Ph	Sol	Imp
	E4-6	CD burning	Artificial	Ph	Sol	Imp
N1, P1	N1-1	Drilling a tunnel	Artificial	Ph	Req	Imp
	N1-2	Earthworms	Natural	P	Sol	Imp
	N1-3	Insects	Natural	P	Sol	Unimp
	N1-4	Operating inside a human body using small robots	Artificial	A	Req	Imp
	N1-5	Giant-wheel with buckets attached on its periphery	Artificial	P	Sol	Imp
N2, P1	N2-1	Pneumatic guns and pneumatic actuators	Artificial	P	Sol	Imp

(continued)

Table 2 (continued)

Designer, problem	Analogy number	Analogy used	Domain	Abst. level	Req / sol	Imp. / unimp.
	N2-2	Earthworms and rats	Natural	P	Sol	Imp
	N2-3	Tunnel boring	Artificial	Ph	Sol	Imp
	N2-4	Penetration of roots of plants	Natural	Ph	Sol	Unimp
	N2-5	Growth in plants	Natural	Ph	Sol	Unimp
N3, P2	N3-1	Whirlpool	Artificial	Ph	Sol	Imp
	N3-2	Cats and dogs	Natural	P	Sol	Unimp
	N3-3	Fevicol (adhesive glue)	Artificial	P	Sol	Imp
	N3-4	Processes in beauty parlor	Artificial	Ph	Sol	Unimp
N4, P2	N4-1	Sweeping	Artificial	Ph	Sol	Unimp
	N4-2	Hairbrush	Artificial	P	Sol	Imp
	N4-3	Vacuum cleaners	Artificial	P	Sol	Unimp
	N4-4	Evaporators	Artificial	P	Sol	Unimp

the natural domain, while novice designers need assistance for using analogies from both, natural and artificial domains, to be on par with the experienced designers.

From Table 2 the following are observed. All the designers use analogies at the level of abstraction of *part* and, with the exception of E2, *phenomenon*. Analogies at no other levels of abstraction—*action, state change, input, effect* and *organ*—of the SAPPhIRE model are found to be used with the same intensity. This lack of exploration could be because designers do not understand these levels of abstraction as well as the other levels, to explore them with the same intensity. Another set of empirical studies shows that designers do not explore all the levels of abstraction of the SAPPhIRE model with the same intensity, but explore *part* of the SAPPhIRE model with greater intensity [14], although all the levels of abstraction contribute to variety and novelty [9]. This underlies the need for a support to assist creating analogies at the unexplored levels of abstraction.

Table 3 shows the contents in the target domain and their levels of abstraction with which the analogies in the source domain are searched. All the designers search for analogies at the level of abstraction of *action*. Less searching is done at the levels of abstraction of *phenomenon, organ* and *part*. No search is found at the other levels of abstraction of *state change*, *input* and *effect*. All the designers use analogies which are at the same or lower levels of abstraction than the contents in the target domain with which searching is done (see Tables 2 and 3). In other words, the transfer from the target domain to the source domain is always from a higher to the same or lower level of abstraction. The definition of analogous designs in [1] suggests that the search for analogies can happen at function-, behavior- and structure-levels. In the biomimetic design process in [16], search is performed using functions. In the biomimetic design process in [17], a problem is framed in biological terms, and this is used for searching analogies. Four classes of transfer in biomimetics based on the SAPPhIRE model are reported in [18]: copy parts, transfer organs, transfer attributes, and transfer state change.

Table 3 Search, abstraction level of search and implementation of analogies

Analogy number	What was searched	Abstraction level of search
E1-1	Make hole/remove material	A
E1-2	Flexibility	R
E1-3	Make hole	A
E1-4	Material removal	A
E1-5	Make cavity	A
E1-6	Lay material	A
E1-7	Lay material	A
E1-8	Lay material for metals	A
E1-9	Remove material	A
E1-10	Digging material	Ph
E1-11	Remove material	A
E1-12	Make material soft and remove material	A, A
E1-13	Remove material	A
E1-14	Make cavity	A
E1-15	Make cavity	A
E1-16	Remove material	A
E1-17	Make cavity	A
E1-18	Remove material	A
E1-19	Stick at a desired position	Ph
E1-20	Motion of insects	Ph
E2-1	To grip	A
E3-1	To sprinkle	Ph
E3-2	To clean	A
E3-3	To clean	A
E4-1	Material removal	A
E4-2	Flexibility	R
E4-3	Material cutting, removal, etc	A
E4-4	Material removal	A
E4-5	Material removal	A
E4-6	Material removal	A
N1-1	Drill hole	Ph
N1-2	Drill hole and change direction	Ph, A
N1-3	Remove material; size of hole and tool to make hole	A
N1-4	Drill hole and change direction	Ph, A
N1-5	Expanding and contracting tool diameter	Ph
N2-1	Flexibility and stiffness	R; R
N2-2	Make hole in desired direction	A
N2-3	Make hole in desired direction	A
N2-4	Make hole in desired direction	A
N2-5	Make hole in desired direction	A
N3-1	Relative motion between utensil and fluid in contact	A
N3-2	To clean	A
N3-3	To clean	A

(continued)

Table 3 (continued)

Analogy number	What was searched	Abstraction level of search
N3-4	To clean	A
N4-1	Cleaning	A
N4-2	Scrubber	P
N4-3	Cleaning	A
N4-4	Cleaning	A

Among all the analogies developed by the designers, some of them are not implemented into requirements or solutions in the target domain (see Table 2). For instance, designer, E1, uses an analogy of "cavities in cake" for "make cavity", but the designer finds that this analogy cannot be implemented because the direction of making cavity cannot be controlled for the given materials and so, this analogy is not implemented as a solution. Utterances to support are, *I thought cake, cake is porous and has cavities in random direction, but it is made out of baking process*, *so baking process creates the random cavities*, *I won't be able to bake metal*. In another instance, designer, N2 develops an analogy of "penetration of roots of plants underground" and "growth of plants in direction of sunlight" to make a hole in the desired direction—*I am thinking of the roots of the plants*, *it* (*root*) *penetrates and goes inside*. *But they do not have pre-defined path*. *They go in search of water in the ground*. and *Even the plant grows such that it gets maximum sunlight*. For experienced and novice designers, a total of 5 out of 30 analogies (17 %) and 8 out of 18 analogies (44 %) remain unimplemented. This shows the difficulties that the novice designers face while translating analogies from the source domain to the target domain. This shows that designers, in particular novice designers, need assistance in transferring analogies from the source domain to target domain.

To assess the effect of analogies on the variety and novelty of solutions, the variety and novelty of concept space, variety of idea space and number of ideas, all known from earlier research in [9] (see Table 1), are correlated individually, with the number of analogies, as shown in Table 4. The high correlation values between: (a) variety of idea space and number of analogies and, (b) number of ideas and number of analogies, indicate that the use of the internal analogies has positive effects on the quality and quantity of ideas. However, this positive effect is

Table 4 Correlation values

Correlating variables		Correlation value
Variety of concept space	Number of analogies	0.3201
Novelty of concept space	Number of analogies	0.3234
Variety of idea space	Number of analogies	0.8960
Number of ideas	Number of analogies	0.9067

not translated into concepts, as seen by the correlation values between: (a) variety of concept space and number of analogies and, (b) novelty of concept space and number of analogies. Nonetheless, all the correlation values are positive, which show the positive effect of the use of analogies on the quality and quantity of solutions. Analogies help build associations between the target and source domains, which are different from each other. These associations, not possible without the use of analogies, help develop solutions (ideas and concepts), which are different from the existing solutions including those developed earlier, thus enhancing the chances of variety and novelty.

6 Summary and Conclusions

This research helps understand the use of internal analogies in the early stages of engineering design through existing empirical studies. It is found that analogies from natural and artificial domains are used to develop both requirements and solutions in the early phases of engineering design. The experience of designers and nature of design problems influence the usage of analogies. Analogies are observed to be searched, developed and implemented at a few levels of abstraction of the SAPPhIRE model, while the other levels of abstraction are unexplored. The use of analogies has a positive effect on the variety of concept space, novelty of concept space, variety of idea space and number of developed ideas. This research gives directions for developing an assistance to support the use of analogies in the early phases of engineering design.

References

1. Qian L, Gero J (1996) Function-behaviour-structure paths and their role in analogy-based design. AIEDAM 10(4):289–312
2. Goel A (1997) Design, Analogy and Creativity. IEEE Expert Intell Syst Appl 12(3):62–70
3. Sarkar P, Chakrabarti A (2008) The effect of representation of triggers on design outcomes. AIEDAM 22(2):101–116
4. Young L (1987) The metaphor machine: a database method for creativity support. Decis Making Support Syst 3(4):309–317
5. Kletke M, Mackay J, Barr S, Jones B (2001) Creativity in the organization: the role of individual creative problem solving and computer support. Int J Human Comput Stud 55(3):217–237
6. Jansson D, Smith S (1991) Design fixation. Des Stud 12(1):3–11
7. Lopez R, Linsey J (2011) Characterizing the effect of domain distance in design-by-analogy. ASME IDETC/CIE design theory and methodology conference
8. Sarkar P, Chakrabarti A (2007) Understanding search in design. International conference on engineering design (ICED07)
9. Srinivasan V, Chakrabarti A (2010) Investigating novelty-outcome relationships in engineering design. AIEDAM 24(2):161–178

10. Ahmed-Kristensen S, Christensen B (2008) Use of analogies by novice and experienced design engineers. ASME IDETC/CIE, New York
11. Tseng I, Moss J, Cagan J, Kotovsky K (2008) The role of timing and analogical similarity in the stimulation of idea generation in design. Des Stud 29(3):203–221
12. Wilson J, Rosen D, Nelson B, Yen J (2010) The effects of biological examples in idea generation. Des Stud 31(2):169–186
13. Chakrabarti A, Sarkar P, Leelavathamma B, Nataraju BS (2005) A functional representation for aiding biomimetic and artificial inspiration of new ideas. AIEDAM 19(2):113–132
14. Srinivasan V, Chakrabarti A (2010) An integrated model of designing. JCISE 10(3)
15. Christensen B, Schunn C (2007) The relationship of analogical distance to analogical function and pre-inventive structure: The case of engineering design. Memory Cognit 35(1):29–38
16. Gramann J (2007) Problemmodelle und Bionik als Methode. Ph.d Thesis, Technical University Munich
17. Helms M, Vattam S, Goel A (2009) Biologically inspired design: process and products. Des Stud 30(5):606–622
18. Sartori J, Pal U, Chakrabarti A (2010) A methodology for supporting "transfer" in biomimetic design. AIEDAM 24(4):483–506

Craftsmen Versus Designers: The Difference of In-Depth Cognitive Levels at the Early Stage of Idea Generation

Deny W. Junaidy, Yukari Nagai and Muhammad Ihsan

Abstract This paper investigates the in-depth cognitive levels at the early stage of idea generation for craftsmen and designers. Examining this early stage may explain the fundamental thoughts in observing and defining design problems. We conducted an experiment using think-aloud protocol, where verbalized thoughts were analyzed using a concept network method based on associative concept analysis. Furthermore, we identified semantic relationships based on Factor Analysis. The findings showed that craftsmen tended to activate low-weighted associative concepts at in-depth cognitive level with a smaller number of polysemous features, thus explaining their concerns about tangible-related issues, such as proportion and shape. Designers, however, activated highly weighted associative concepts with more polysemous features, and they were typically concerned with intangible issues, such as surroundings context (i.e., eating culture) and users' affective preferences (i.e., companion, appeal).

Keywords In-depth cognitive level · Early stage of idea generation · Designers · Craftsmen

D. W. Junaidy (✉) · Y. Nagai
Japan Advanced Institute of Science and Technology, 1-1 Asahidai, Nomi, Ishikawa 923-1292, Japan
e-mail: denywilly@jaist.ac.jp

Y. Nagai
e-mail: ynagai@jaist.ac.jp

M. Ihsan
Institute of Technology Bandung, Jl. Ganesa 10, Bandung 40132, Indonesia
e-mail: ihsan@fsrd.itb.ac.id

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_18,

1 Introduction

This study focuses on the early stage of idea generation to capture the associative concepts at the in-depth cognitive levels of craftsmen and designers. Examining the early stage of idea generation may explain the fundamental thoughts in observing and reframing design problems. Many attempts have been made to capture users' affective preferences based on users as subjects. However, we examined the in-depth cognitive levels of the creators (craftsmen and designers), who attempt to grasp users' feelings when producing successful impressions of products [1, 2]. We conducted an experiment using think-aloud protocol, where verbalized thoughts were analyzed using a conceptual network based on associative concepts and semantic relation analysis.

1.1 Early Stage of Idea Generation

Idea generation, which consists of observation and ideation, is the essential step in the design thinking process. It is the interplay of cognitive and affective skills that lead to the resolution of a recognized difficulty [3]. Following are general steps of design thinking; the early stage of idea generation is the step mainly discussed:

1. Imagination (early stage of idea generation): the stage to observe and reframe the design problem.
2. Ideation (later stage of idea generation): the stage employing sketches, graphs, or paper models to generate ideas visually.
3. Prototyping: the stage of making a rough model to convey an idea concretely.
4. Evaluation: the stage to acquire user's feedback by evaluating affective preferences.

The next step after the design thinking process is realization or production for commercial purposes.

The early stage of idea generation is one of observation by craftsmen and designers through first-hand experiences. This stage is associated with greater diversity of ideas [4]; therefore, it is reasonable to assume that one's fundamental thoughts are captured fairly at this point.

1.2 In-Depth Cognitive Level

It is generally known that designers cannot express their thoughts explicitly; their latent sensitivity is widely researched in cognitive psychology. It is known as implicit cognition, which is understood to be that which is not explicitly

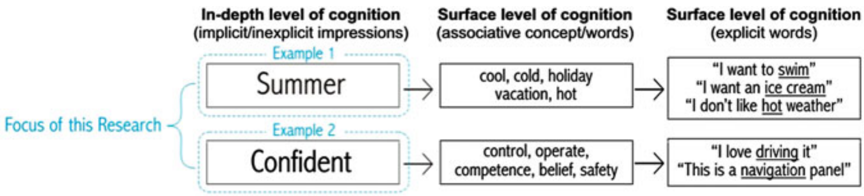


Fig. 1 Focus of this research: capturing the in-depth cognitive level

recognized or verbalized [5]. Explicit expression, which is presumably a shallow analysis, is referred to as surface-level cognition, and underlying cognition that is difficult to express is referred to as in-depth cognitive level (e.g., feeling, taste, impression) [2, 6, 7] (Fig. 1).

Taura et al. [7] explain that implicit impressions could exist in the feelings and are implied underneath explicit impressions that are related to deep impressions. Humans establish extremely rich metaphorical concepts (within in-depth impression) as key features of cognition in creative design; thus, a designer is able to capture a profound understanding of an object [2]. Previous studies have focused on capturing in-depth cognitive levels (impressions) of users based on created artifacts, but our study focuses on the creators of the artifacts (craftsmen and designers).

1.3 Verbalized Thoughts and Associative Concept Analysis

To examine the structure of thoughts from subjective experiences, a think-aloud, as a part of protocol analysis was employed to produce verbal reports of the thinking process [8]. Subjects were instructed to describe their thoughts and observations and reframe design problems through verbal expression. Verbalized thoughts reflect some aspects of the regular cognitive process [8]; for this study, they were reconstructed using a computational model to reproduce observable aspects of the in-depth cognitive level.

Associative concept analysis captures concepts of an expression associated with the individual's mental state. The associative concept is comprised of six subtypes: connotative, collocative, social, affective, reflected, and thematic [9]. It is latent within implicit cognition. Therefore, a conceptual network is suitable as an associative analysis tool for exploring the latent links among concepts. In the field of psychology, the conceptual networks depict human memory as an associative system, where a single idea can contain multiple meanings (polysemous). The concept dictionary utilized in conceptual network is from the University of South Florida Free Association Norms database (USF-FAN) [10, 11].

2 Aim

The aim of this research was to capture the differences in associative concepts at in-depth cognitive levels of craftsmen and designers at the early stage of idea generation in design thinking. Thus, we conducted an experimental study using think-aloud protocol, where designers and craftsmen freely expressed their ideas verbally.

3 Methodology

In this study, we used a concept network method based on the associative concept dictionary to extract verbalized thoughts. The framework of this research was comprised of the following steps (Fig. 2):

1. Two craftsmen and two product designers conducted a think-aloud protocol. They were instructed to imagine designing a fruit basket/container and freely express their ideas verbally without necessarily drawing or observing the object. Verbal data were recorded, and the sorted verbal expressions were then transcribed into English.
2. The verbal data, which consisted of explicit words, were transferred onto vector graphs (conceptual network on the basis of the USF norms database) to obtain extraction of highly weighted associative words indicated by the out-degree centrality score (ODC).
3. Differences in the concept network structures were identified by analyzing the following:

   a. Density of connection, which exhibits the property of idea within the associative concept network.
   b. Semantic relation, which finds the characteristics of the associative concepts at the in-depth cognitive levels using an orthogonal semantic map based on factor analysis.

4 Experiment

4.1 Subjects

Four subjects (two Indonesian craftsmen and two Indonesian designers in the age range of 27–51 years) participated in this experiment. The two designers were university graduates with experience in craft design and concern for natural material utilization. Each of the two craftsmen, known as master craftsmen, who

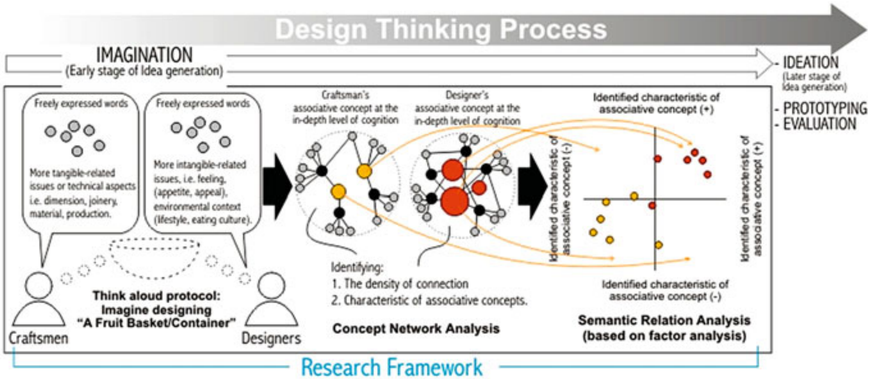


Fig. 2 Research framework: capturing craftsmen's and designers' associative concept at in-depth cognitive levels at the early stage of idea generation

has acquired special skills in artistry and apprehends design as an artistic or decorative creation. They gained their special expertise, passed down from one generation to another in the local village's traditional bamboo crafts.

4.2 *Procedure*

The experiment was set up simply; the subjects (craftsmen and designers) were not required to engage in specific activities, such as drawing or observing stimuli. They were deliberately conditioned with minimum instruction to be able to capture fundamental associative concepts. Rigid instructions about determining design theme, market segmentation, or design function were avoided since they might provide excessive information that would be unfair and misleading. Minimum instruction maintains a fair stage for noting craftsmen's and designers' first-hand experiences in observing and reframing design problems. There were no constraints on the subjects for expressing their ideas verbally and engaging in spontaneous thinking.

All procedures were recorded as verbal data and transcribed word by word. Grammatical rules were followed for connecting words, such as prepositions, a few general verbs, articles, and pronouns; also, other less relevant explanations were omitted [6]. Finally, the sorted verbal data consisting only of nouns, adjectives, adverbs, and verbs were translated into English and further analyzed according to the concept network method on the basis of the USF norms database (also visualized as graphs using Pajek 2.05 with the algorithm of Fruchterman Reingold) [12].

4.3 *Concept Network Analysis*

At the first stage of analysis, 107 sorted verbal expressions (nouns, adjectives, adverbs, and verbs) were obtained from craftsmen; 102 were sorted from

Table 1 Sorted verbal expressions

Category	List of sorted verbal expressions (partly shown)
Craftsmen	**Capacity, dimension, measure, standard, super, big, count, size, leg, height, thin, shape, square, position, part, head, stack, body, solid, base, width, top, long, oval, three-dimensional, thick, centimeter, box,** design, container, fruit, duck, salt, egg, adjust, buyer, function, capable, form, set, color, supply, bamboo, scar, spot, glue, mark, sandpaper, etc.
Designers	**Place, kitchen, pluck, tree, shop, sensation, reap, pick, preservation, tropical, rotten, fresh, delicious, interaction, inform, remind, children, invite, accommodate, people, way, salad, commercial, habit, crowd, appeal, appreciate, attractive, dignity, snack**, put, table, hang, fruit, wood, appear, stand, durian, banana, apple, orange, watermelon, grape, etc.

designers. Expressions of craftsmen tended to focus on tangible aspects, such as technique, material, and production (bold text). Designers, however, paid more attention to intangible-related issues, such as users' affective preferences and the environment (bold text) (Table 1).

The sorted verbal data were further visualized as graphs of conceptual network analysis (Fig. 3). Craftsmen's conceptual networks generated 1,941 vertices (nodes), and designers' networks generated 1,662 vertices (nodes). The networks were too dense and complex for analysis; therefore, it was necessary to simplify the created networks by a reduction method. Systematic reduction was based on considerations that not all the words from verbalized protocols contribute to an in-depth cognitive level, and surface-level cognition is overemphasized. The following indicate low scores associated with explicit words/surface-level cognition (bold).

- Craftsmen (total: 1,941 words): **0.000–0.010 = 1,462 words**; 0.020 = 352 words; 0.030 = 94 words; 0.040 = 27 words; 0.051 = 6 words.
- Designers (1,662 words): **0.000–0.010 = 1,259 words**; 0.021 = 293 words; 0.032 = 77 words; 0.043 = 23 words; 0.054 = 8 words; 0.065 = 1 word; 0.076 = 1 word.

5 Analysis and Results

5.1 Conceptual Network Analysis (After Reduction)

Application of the simplified concept reduced the words that were less important to the networks so that the extraction of the associative concept within the in-depth cognitive level was apprehensible (Fig. 4a, b). The reduction omitted <50 % words with lower ODC scores to get an observable network diameter [13] (i.e., craftsmen:

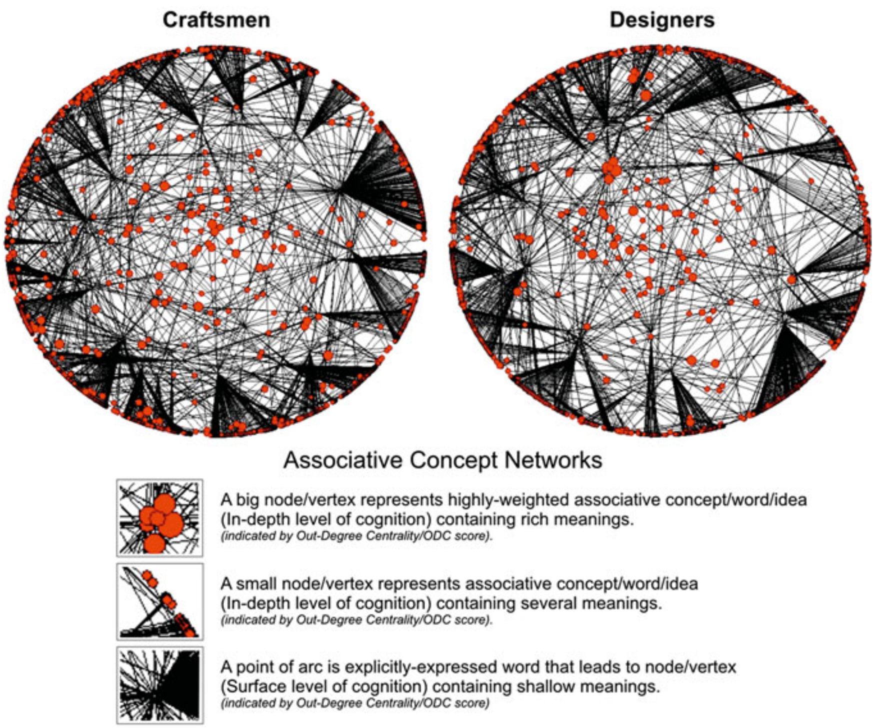


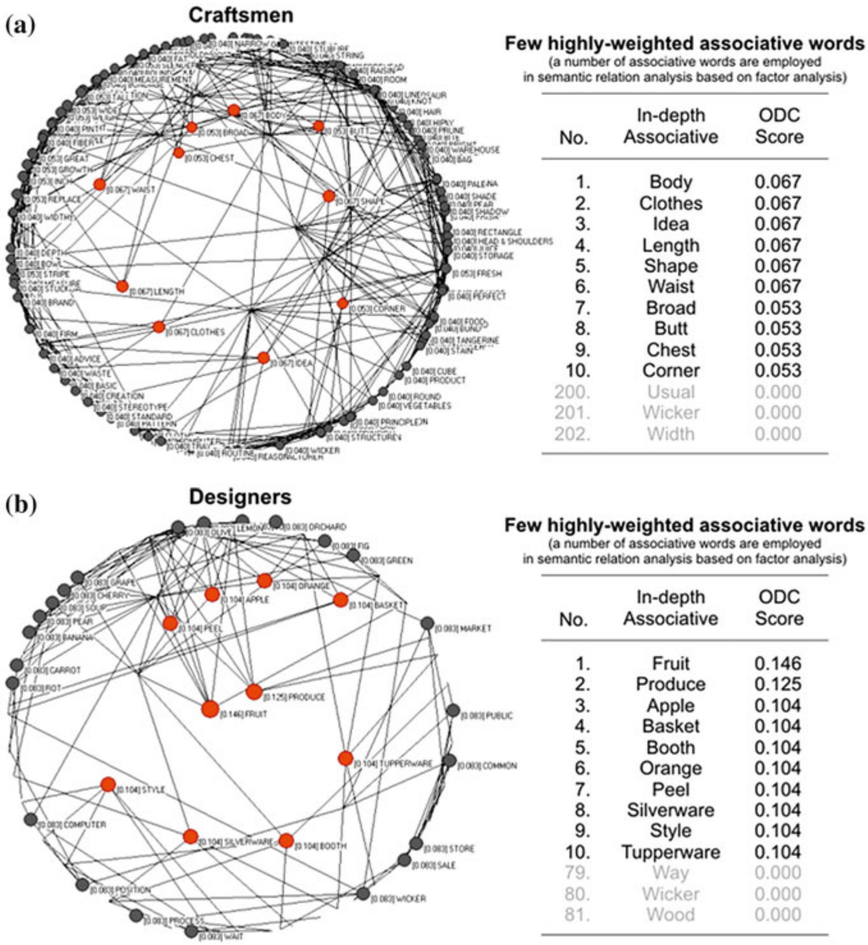
Fig. 3 Associative concept networks of craftsmen's and designers' before reduction (words and scores not shown due to complexity)

50 % × 0.051 ODC = > 0.025 ODC score; designers: 50 % × 0.076 ODC = > 0.038 ODC score).

The reduction was applied independently to each group where the highly weighted associative words were identified at the in-depth cognitive level with ODC scores as follows (bold text) (Table 2a, b):

- Craftsmen (total: 202 words): 0.000 = 75 words; 0.040 = 94 words; **0.053 = 27 words**; **0.067 = 6 words.**
- Designers (total: 81 words): 0.000 = 48 words; **0.083 = 23 words**; **0.104 = 8 words**; **0.125 = 1 word**; **0.146 = 1 word.**

Hereafter, we selected the top 10 highly weighted associative words from each group for further analysis.



(a) Few highly-weighted associative words
(a number of associative words are employed in semantic relation analysis based on factor analysis)

No.	In-depth Associative	ODC Score
1.	Body	0.067
2.	Clothes	0.067
3.	Idea	0.067
4.	Length	0.067
5.	Shape	0.067
6.	Waist	0.067
7.	Broad	0.053
8.	Butt	0.053
9.	Chest	0.053
10.	Corner	0.053
200.	Usual	0.000
201.	Wicker	0.000
202.	Width	0.000

(b) Few highly-weighted associative words
(a number of associative words are employed in semantic relation analysis based on factor analysis)

No.	In-depth Associative	ODC Score
1.	Fruit	0.146
2.	Produce	0.125
3.	Apple	0.104
4.	Basket	0.104
5.	Booth	0.104
6.	Orange	0.104
7.	Peel	0.104
8.	Silverware	0.104
9.	Style	0.104
10.	Tupperware	0.104
79.	Way	0.000
80.	Wicker	0.000
81.	Wood	0.000

Fig. 4 **a** Simplified concept networks of craftsmen's in-depth cognitive level. **b** Simplified concept networks of designers' in-depth cognitive level

Up to this stage, data extraction according to the associative model suggested that craftsmen tended to activate low-weighted associative concepts, as demonstrated by the surface-level cognitive score of 169/202 (83.6 %). Designers, however, activated more highly weighted associative concepts concerning issues linked to the presence of the fruit basket/container, as significantly demonstrated by a high ODC score and lower surface-level cognitive score of 48/81 (59.2 %). Following are identified characteristics of craftsmen's and designers' associative concepts after reduction.

5.2 Analysis of Semantic Relation Based on Factor Analysis

We distributed 120 associative words corresponding to identified characteristics of associative conceptual structures; ODC scores ranged from highest to lowest (Table 3). Identified characteristics were *proportion, shape, operation, companion,*

Table 2 Extracted verbal expressions of in-depth cognitive level (after reduction)

Category (a)	List of 202 extracted verbal expressions (ordered by the highest ODC score)
Craftsmen	**Body, clothes, idea, length, shape, waist, broad, butt, chest, corner**, creativity, exercise, fresh, great, grow, grown, growth, ideal, impression, inch, oval, plaid, portion, replace, sample, size, slender, stripe, suggestion, tall, tight, weigh, wide, advice, bag, etc.
Category (b)	List of 81 extracted verbal expressions (ordered by the highest ODC score)
Designers	**Fruit, produce, apple, basket, booth, orange, peel, silverware, style, Tupperware,** banana, carrot, cherry, common, computer, fig, grape, green, juice, lemon, market, olive, orchard, pear, position, process, public, rot, sale, soup, store, wait, etc.

Table 3 Identified characteristics of craftsmen's and designers' associative concepts

Category	List of identified characteristics
Craftsmen	(*Proportion*) length, inch, oval, portion, size, tall, tight, wide, centimeter, width, thin, thick, form, rectangle, measurement, narrow, weight, etc.
	(*Shape*) body, shape, waist, butt, chest, corner, round, leg, hip, giant, cube, prism, etc.
	(*Operation*) exercise, grow, replace, advice, bold, blend, bond, decision, firm, fit, perfect, stain, form, combine, cover, tie, trace, use, etc.
Designers	(*Companion*) fruit, apple, orange, peel, banana, carrot, cherry, fig, grape, green, lemon, olive, orchard, pear, etc.
	(*Appeal*) salad, peel, juice, soup, process, produce, display, method, rotten, put, save, buy, shop, stand, fresh, etc.
	(*Scene*) booth, silverware, tupperware, market, public, store, crowd, leaf, tree, wood, etc.

Table 4 Rotated factor matrix

Adjectives (+)	Adjectives (−)	F1	F2
Scene	Less scene	0.942	0.009
Appeal	Less appeal	0.932	0.193
Companion	Less companion	0.891	−0.199
Proportion	Less proportion	−0.757	0.613
Shape	Less shape	−0.722	0.636
Operation	Less operation	0.140	0.912
Eigenvalue (after rot):		3.66	1.6
KMO:		0.571	

appeal, and *scene*—six variables used in factor analysis. Furthermore, the correlation among variables was extracted into two factors; the KMO score of 0.571 was significant. The factor matrix and corresponding names are as follows: (Tables 4 and 5).

For Factor 1, *Scene*, *Appeal*, and *Companion*, hereafter referred to as *Surroundings*, were associated with the presence of the fruit basket/container. For Factor 2, *Less Proportion*, *Less Shape*, and *Operation*, hereafter referred to as *Object-Oriented*, concerned technical aspects of the fruit basket/container. Furthermore, factors were displayed on an orthogonal map to investigate the semantic relationships of the identified characteristics of craftsmen's and designers' associative concepts (Fig. 5).

Table 5 Corresponding name

Factor	Adjectives	Eigenvalue	Factor name
F1	Scene, appeal, companion	3.66	SURROUNDINGS
F2	Less proportion, less shape, operation	1.6	OBJECT-ORIENTED

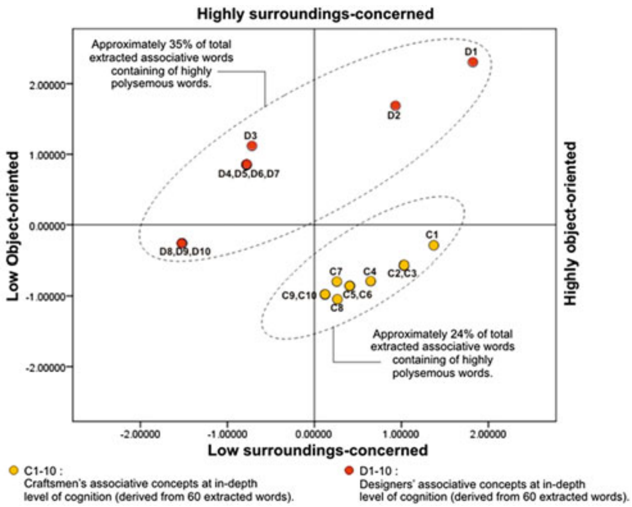


Fig. 5 Semantic relation map

6 Discussion

From the initial stage, the sorted verbal expressions showed that craftsmen paid attention to appearance and technical aspects of the fruit basket/container. They described such features as height, length, stack, capacity, standard, coating, and form (e.g., duck, heron). The extracted words obtained from concept network analysis were identified, as well as the characteristics of *proportion, shape*, and *operation.* In contrast, designers' sorted verbal expressions concerned issues pertaining to the presence of the fruit basket/container. Descriptive words included *place*, *kitchen*, *hang*, *pluck*, *tree*, *wood*, *inform*, *remind*, *children*, *salad*, and *dignity*. Some interesting comments were, "I don't want to put it on the table; I want to hang it," "I want it to be inviting so the children will reap its fruits," "How attractive to serve a salad in a fruit container," and "It's like a traditional banana-leaf container with prestige". The extracted words were identified along with the characteristics of *Companion, Appeal,* and *Scene.*

We identified that craftsmen tended to activate low-weighted associative concepts, as demonstrated by the high surface-level cognitive score of 169/202 (83.6 %). Designers activated more highly weighted associative concepts, as demonstrated by the high ODC score and lower surface-level cognitive score of 48/81 (59.2 %). We referred to the Associative Gradient Theory, which proposes that the more closely associated or "stereotypical" representations may lead to less creativity. The greater the number of associations, the greater the probability of reaching a creative solution, because remote associations (highly weighted associative concept) are best suited to such solutions [14–17]. We also found that approximately 24 % of 202 extracted words derived from craftsmen and 35 % derived from designers were highly polysemous. As Yamamoto et al. [18] argue, the polysemy of a design idea has significant correlation with its originality. It indicates that designers' in-depth cognitive levels have greater probability of reaching creative solutions.

The findings of this research suggest that the roles of closely and remotely associated concepts at the in-depth cognitive level during the early stage of idea generation are different for craftsmen and designers as they observe and define design problems. Craftsmen's in-depth cognitive levels, with fewer polysemous features, explain their concerns about tangible-related issues, such as proportion and shape. Designers' in-depth cognitive levels, with more polysemous features, concern intangible issues, such as surroundings context (i.e., eating culture) and users' affective preferences (i.e., companion, appeal). The semantic relation map confirms that craftsmen focus on the physical properties of an artifact instead of the surroundings and the user's affective preferences. Designers, on the contrary, are much more concerned about issues pertaining to the presence of the artifact and less attentive to physical properties.

7 Conclusion

In general, we can easily differentiate between artifacts created by craftsmen and designers by describing their appearance. However, it is difficult to describe the nature of creative cognition that influences the respective design thinking processes. This study has revealed the differences between in-depth cognitive levels of craftsmen and designers at the early stage of idea generation. Further, these findings can be developed as a reference for a co-created educational program (design training) that suits craftsmen's creative cognition.

References

1. Cross N (2006) Designerly ways of knowing. Birkhauser, Switzerland
2. Nagai Y, Georgiev GV, Zhou F (2011) A methodology to analyze in-depth impressions of design on the basis of concept networks. J Des Res 9(1):44–64
3. Houtz JC, Patricola C (1999) Imagery. In: Runco MA, Pritzker SR (eds) Encyclopedia of creativity, vol 2. Academic Press, Sand Diego, CA
4. Leijnen S, Gabora L (2010) An agent-based simulation of the effectiveness of creative leadership. In: Proceedings of the annual meeting of the cognitive science society, Portland, 5 Aug 11–14 2010
5. Reingold E, Colleen R (2003) Implicit cognition, in encyclopedia of cognitive science. Nature publishing group, London, pp 481–485
6. Georgiev GV, Nagai Y (2011) A conceptual network analysis of user impressions and meanings of product materials in design. Mater Des 32(8–9):4230–4242
7. Taura T, Yamamoto E, Fasiha MYN, Nagai Y (2010) Virtual impression networks for capturing deep impressions, design computing and cognition DCC'10. In: Gero JS (ed) pp xx–yy © Springer
8. Ericsson KA, Simon HA (1993) Protocol analysis: verbal reports as data. MIT Press, Cambridge
9. Mwihaki A (2004) Meaning as use: a functional view of semantics and pragmatics. Swahili Forum 11:127–139
10. Nelson DL, McEvoy CL, Schreiber TA (2004) The university of South Florida free association, rhyme, and word fragment norms. Behav Res Methods 36:402–407
11. Maki WS, Buchanan E (2008) Latent structure in measures of associative, semantic and thematic knowledge. Psychon Bull Rev 15(3):598–603
12. Batagelj V, Mrvar A (2003) Pajek—analysis and visualization of large networks. In: Jünger M, Mutzel P (eds) Graph drawing software. Springer, Berlin, pp 77–103
13. Leskovec J (2008) Dynamics of large networks. PhD thesis, Carnegie Mellon University, Pittsburgh
14. Mednick MT, Mednick SA, Jung CC (1964) Continual association as a function of level of creativity and type of verbal stimulus. J Abnorm Soci Psychol 69(5):511–515
15. Baer J (1993) Creativity and divergent thinking: a task specific approach. Lawrence Erlbaum Associates, Hillsdale, NJ
16. Eysenck HJ (1997) Creativity and personality. In: Runco MA (ed) Creativity research handbook vol 1. Hampton Press, Cresskill, NJ pp 41–66
17. Martindale C (1995) Creativity and connectionism. In: Steven SM, Ward TB, Finke RF (eds) The creative cognition approach. The MIT Press, Cambridge, MA, pp 249–268
18. Yamamoto E, Mukai F, Fasiha MYN, Taura T, Nagai, Y (2009) A method to generate and evaluate creative design idea by focusing on associative process. In: Proceedings of the ASME2009. California

Part III
Design Aesthetics, Semiotics, Semantics

A Comparative Study of Traditional Indian Jewellery Style of *Kundan* with European Master Jewellers, a Treatise on Form and Structure

Parag K. Vyas and V. P. Bapat

Abstract Jewellery has universal appeals that transcend borders of countries and cultures. There are examples of Indian jewellery being influenced by European tools, technology and in turn European jewellery drawing inspirations from Indian jewellery motifs and culture. Indian and European jewellery styles due to this mutually wholesome relationship have common grounds for a comparative study, observing similarities and understanding differences. A traditional Indian goldsmith works in anonymity, rarely seeking personal name or recognition. Therefore, in India a style begets a name that is not associated with a particular design house, yet has a distinctly different identity. *Kundan* is one such example that uses an intricate frame of gold for setting minimally polished diamonds. A European master jeweller on the other hand has a style synonymous with their design houses. Names such as Cartier, Van Cleef and Arpels and Tiffany are few such examples. They are identifiable from other comparable styles by use of distinctive motifs, treatment of form, usage of specific cuts of gemstones and types of setting. These characteristics give a logical basis for comparison and understanding features of form. Based upon these, Indian style of *Kundan* is compared with European contemporary styles. A treatise on the subject elucidates how a typical Indian jewellery style is analogous to European Master Jewellery styles. It draws parallels between these styles and provides a structure for studies pertaining to form in domain of jewellery. Such studies in domains of design are new, this subject gains importance by sharing deep insights from pioneering research in subject matter.

Keywords Traditional Indian jewellery · European master jewellers · Design · Studies in form

P. K. Vyas (✉) · V. P. Bapat
Industrial Design Centre, Indian Institute of Design Bombay, Powai, Mumbai, India
e-mail: paragvyas01@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_19, © Springer India 2013

1 Introduction

Kundan is traditional Indian jewellery style that is elaborately embellished with gemstones and colourful enamel. It has a character of its own that has remained unchanged over a period of time. Motifs [1, 2], often identifiable by their individual names are used in this particular style. Motifs are frequently mimicking nature, liberally adopting from flora and fauna [3, 4]. These smallest semantic units are the fundamental building blocks and used in combination with each other make a form cluster. In turn, these form clusters make patterns which are repetitive and appear through the body of jewellery as a coherent theme. There are manners of construction of these form clusters that are passed down from generation to generation, from master to an apprentice. An article of kundan jewellery is distinctly identifiable by its characteristic appearance [2] as shown in Fig. 1. This technique of setting, from which it derives its name does not belong to a particular design house but encompass different jewellers and their style of working in one coherent style. The features of form are use of specific shape of smallest semantic units [5] and the type of setting [6]. Practitioners spread across working in different locations independent of each other are joined by a common invisible link, making kundan distinctively identifiable.

A European master jeweller on the other hand has a style synonymous with their design houses. In comparison to kundan, the working style is limited to the house in terms of articles they specialise in and design themes. Names such as Cartier, Van Cleef and Arpels and Tiffany are few such examples. They are identifiable from other comparable styles by use of distinctive motifs, treatment of form, usage of specific cuts of gemstones and types of setting. For example a six prong tiffany setting, signature of this style is distinctively different from the Van cleef and Arpels mystery setting. Though both styles use formal brilliant cuts, their treatments have marked differences as reflects in following sections.

Fig. 1 An article of kundan jewellery, typical example

2 Observations and Articulation of Select Styles

For the purpose of understanding the selected styles are articulated briefly, so that at a glance the visual appreciation and comparison is plausible.

Cartier—though founded in America they in their manner of working is similar to European master jeweller and has a particular style that drew inspiration from animal forms, typically cheetah, birds and elephant [7, 8]. By virtue of their Geneva office, they do follow a European style and traditions. It is known for its exquisite craftsmanship and high quality of finish. This style is exemplified by pictures as in Fig. 2.

Van Cleef and Arpels—this house is specially known for 'invisible' setting where no metal is visible between two adjoining gemstone, this mysterious way of holding begets the name mystery setting [9, 10]. An additional cut under the girdle of the gemstones to be set makes this plausible. This style is their signature and is patented by them. This style is exemplified in Fig. 3.

Tiffany—is known for its six prong setting where the gemstone is set for maximum visibility and an effect is created by raising and supporting the stone in a manner where it appears levitating [11, 10]. This style is exemplified in Fig. 4.

Kundan—though it does not belong to a particular house, it is a distinct style that uses flush stone close setting [12] to hold minimally polished flat stones [13, 14]. The stones are set in an intricate framework of gold by compressing gold foils all around the stone to make a firm fit. This style is exemplified in Fig. 5.

They are identifiable from other comparable styles by use of distinctive motifs, treatment of form, usage of specific cuts of gemstones and types of setting, which constitute the characteristics or a visual identity. Characteristic of each style that are synonymous with a particular style are tabulated as under for Comparative

Fig. 2 Cartier as a style exemplified

Fig. 3 Van Cleef and Arples as a style exemplified

Fig. 4 Tiffany as a style exemplified

Fig. 5 Kundan as a style exemplified

study. This particular style of comparison is used by design houses for trend tracking as well as development of a storyboard for new trend style. It is readily adopted as a research tool and applied for this application.

The limitation of this style is that it does not follow a ruthless mathematical objectivity, however, design rarely demands that level of mathematical interpretation and often a gentle guidance in the direction is adequate [15]. This model can be adapted for such research.

Following is a tabulation of formal aspects that are taken into consideration while appreciating the products visually and articulating discussions and conclusions, as in Table 1.

3 Methodologies

In search for a suitable methodology for visual research, first inspiration was taken from visual research in domain of product form, [16] proposed a structure containing presentation plates, well suited for such purposes. For comparison of features of form products are arranged for visual comparison on plates providing a common frame of reference. This is in concurrence of views with [17, 18], where factor approach is propounded for dimensional classification and intercorrelation of items as shown in Fig. 6. Using this frame for reference articles from these master jewellers and jewellery tradition are visually appreciated and analysed. This approach is in tandem with evaluation approach by experts. The subsequent plates on following pages are schematically represented in the dimensionality model. The plates arranged in this manner create a frame of reference with respect to a datum. It is in light of this frame of references that form can be studied and interpretations can be made more objectively.

Table 1 Formal aspects taken into consideration for visual appreciation

Sr. No.	Feature/formal aspect	Comparison of master jewellers/tradition			
		Cartier	Van Cleef and Arpels	Tiffany	Kundan
1.	Motifs used	Leopard and elephant	Floral, post modern, art deco	Geometric	Flora and fauna/nature
2.	Treatment of form	High mechanical precision in metal.	Very high mechanical precision in metal and stones.	Geometric and precise forms.	Precision achieved visually using very irregular stones.
3.	Usage of specific cuts of gemstones	Round brilliants/other brilliant cuts	Square/nicked under girdle	Round brilliant/tear drops	As found/minimally faceted
4.	Type of setting	Pave/prong	Invisible or mystery setting	Six prong	Flush stone close setting
5.	Surface appearance	High lustre metal	More use of colour stones	Equitable amounts of metal/stones	Hand worked metal
6.	Geometric precision	High emphasis	Very high emphasis	Emphasis on type of prong settings	–
7.	Embellishment	–	–	–	Backside richly enamelled
8.	Representative picture	As in table	As in table	As in table	As in table

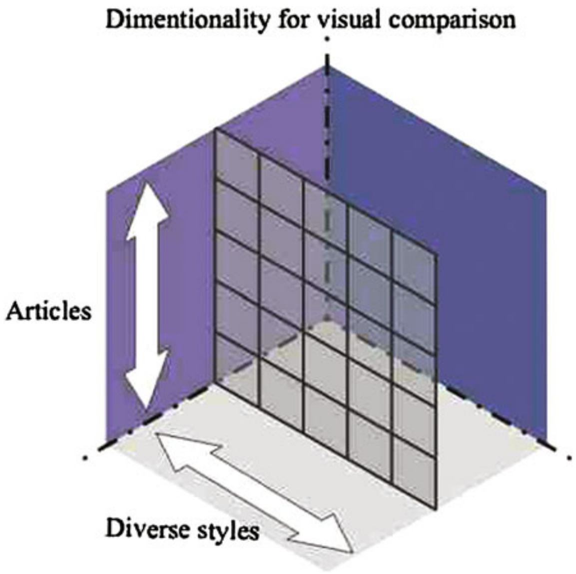


Fig. 6 Illustrated dimensionality of the comparative study

A mental model is created by observer in everyday life in order to understand everyday world. Perceptions and hence the observations on which a theory is based is shaped by interpretive structure of human brain. A model therefore is a help to understand a complex thing with relative ease. However, this simplification is by way of compromise, so proposed models have their applications and limitations.

The articles from four broad categories were selected namely, rings, earpieces, neck pieces and miscellaneous articles. These are tabulated and pertinent observations and comments were duly noted under each category for discussions and interpretation, as shown in Table 2. As methodical research are in their initial phases, they need validation by experts for checking argumentative fallacies and misinterpretation of terms. Study was presented to experts and practitioners. Their valid comments and point of views were incorporated in study.

4 Discussions

The European jewellery by master jewellers uses predominantly floral and butterfly as motifs in a very strong way. Both derive their form from nature and this is common factor with Indian jewellery too, drawing inspiration from nature. However, the significant difference is avoidance of dragonfly and butterfly as they are insects from the family of lepidoptera family, or insects that transform. Owing to a general aversion to the use of insect forms in indian jewellery, such occurrences rare in indian jewellery, unless they are bought abroad or made as an imitation of a particular article.

Table 2 Articles tabulated for visual appreciation and comparison

Sr. No.	Article	Tiffany	Van Cleef & Arpels	Cartier	Kundan
1	Rings				
					
					
					
					
2	Ear Rings				
					
					
					
					

(continued)

Table 2 (continued)

Sr. No.	Article	Tiffany	Van Cleef & Arpels	Cartier	Kundan
3	Pendents				
					
					
					
					
4	Misc. Accesories				
					
					
					
					

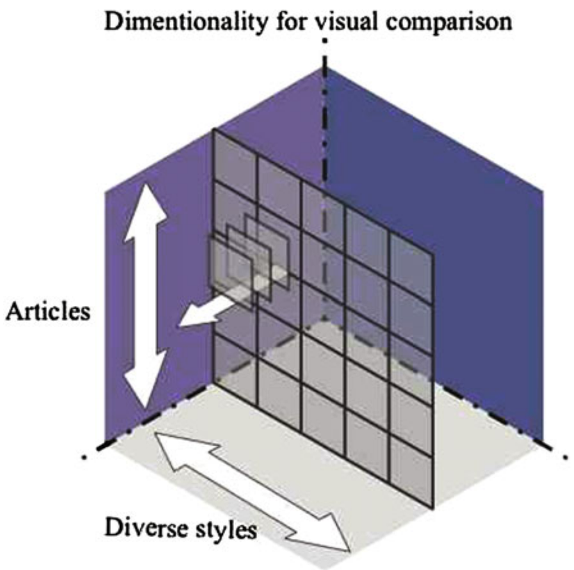


Fig. 7 Addition of new dimensionalities and parameters in the present study

The common element between western and Indian jewellery is use of lion head in some jewellery, with a minor change from leopard to lion in Indian jewellery. Sometimes in India the nails or the canine teeth of the animal used as an amulet with a belief to propitiate animal spirits or invoke divine protection. It is these belief system that govern the use of motifs in a particular article of jewellery [19]. For example, fish is a fertility motif and flowers depict blossoming, hence, find an adaptation in both eastern as well as western jewellery forms.

Geometric forms are common to both trends and freely adapted for use in Indian as well as western jewellery. The common frequently used forms are, tear drops, circle, oval and a variety of polygons both regular and irregular [20] and they appear consistently across diverse time and space in jewellery forms. This can be attributed to the simplicity and universal acceptance of polygons as readily adaptable forms for a variety of product forms. Familiarity with object, ease of definition and manufacturing are the factors that contribute to their universal usage and acceptability.

5 Conclusions

The conclusions are drawn under two heads drawing out similarities and dissimilarities. In general European inclination is towards a simple form that has a high level of precision, while Indian forms have a high level of detail per unit area with less emphasis on precision. There is a high level of symmetry and aesthetically pleasing appearance in Indian jewellery with minimal polishing, which clearly reflects in forms.

5.1 Similarities

1. Both European as well as Indian jewellery techniques draw inspiration from nature [3] often mimicking nature.
2. Polygons and familiar forms are common features, however, the overall treatment of form may be different on grounds of precision.
3. Diamond and its various cuts are preferred for its hard wearing quality in both Indian and European styles.
4. Indian styles prefer one of five major gemstones along with diamonds for setting and therefore are more colorful. On the other hand western styles are more liberal in trying out semi precious stones.
5. Emphasis on simple things done with perfection in European style, large details packed in a small unit area is the defining feature of Indian style.

5.2 Dissimilarities

1. Though adapted from nature, Insects are generally avoided in Indian styles while readily accepted in European.
2. Overall symmetry is preferred in Indian jewellery, while asymmetry and deliberate use of visual provocation is characteristic of European styles.
3. Use of stones in Indian style is minimally faceted stones retaining original form and weight while European styles go for formal and brilliant cuts compromising weight.
4. Emphasis on hand work in indian style demands acceptance of imperfections or individuality of a craftsman. While the mechanical precision of European style is independent of a person.
5. European craftsmanship heavily relies on technology, which to an extent dictates form. While *kundan* relies more on skill and creativity in use of material.
6. Conformance to original floral or animal motif is high in European jewellery while a high level of abstraction in form is characteristic of *kundan*.

6 Future Directions

1. New dimensions and dimensionalities can be added as shown in Fig. 7 to the proposed construct of the model and different parameters can be added either locally or following a grid approach [19].
2. A frame of reference can be extended in a parametric way and a ordinal scale can be incorporated for managerial as well as mathematical interpretation of things, that are visual in nature.

3. A tabulation is scalable in its construct and various columns containing styles and rows containing articles can be added to fortify the study.
4. An approach this way is better than an ad hoc approach, in the sense it gives a more rational approach comparatively.

7 Limitations

Study is a proposed model concept and there can be other ways to observe and compare styles, however, design is undemanding of mathematical precision and often only a gentle hint in the direction is good enough and serves the purpose. Hence, this model gains importance in quick market research and understanding things and bring in a level of objectively.

References

1. Balakrishnan UR, Kumar MS (2004) Dance of the peacock: jewellery traditions of India. India Book House Pvt. Ltd, India, pp 123–212
2. Untracht O (1997) Traditional jewellery of India. Thames & Hudson Ltd, London, pp 103–269
3. Adorno TW (2011) Aesthetic theory. University of Minnesota Press, USA, p 118
4. Sharma RD, and Varadarajan M (2008) Handcrafted Indian enamel jewellery. Lustre Press, Roli Books, India, p. 21–33
5. Vyas P, Bapat VP (2010) Identification and classification of semantic units used in formation of patterns in *kundan* jewellery, a methodical approach, design thoughts. IDC, IIT, Bombay
6. Untracht O (1985) Jewellery concepts and technology. Doubleday & Company, Inc., Garden City, p 580
7. Cartier "Jewellery" in http://www.cartier.co.uk/#/show-me/jewellery
8. Coleno N (2009) Amazing Cartier jewellery design since 1937. Published by Flammarion, Spain, p. 62
9. Van Cleef, Arpels "Jewellery" in http://www.vancleefarpels.com/ww/en/
10. Snowman AK (1990) The master jewellers. Thames & Hudson Ltd., London, p 215
11. Tiffany "Jewellery" in http://www.tiffany.com/Shopping/Default.aspx?mcat=148204
12. Balakrishnan UR, Kumar MS (2006) Jewels of the Nizams. India Book House Pvt. Ltd, India, pp 60–224
13. Tait T (2006) 7000 years of jewellery. The British Museum Press, London, p 174
14. Elgood R (2004) Hindu arms and ritual. Mapin Publishing, Ahmedabad, p 177
15. Kirsch I (2009) The Emperor's new drugs, exploding the antidepressant myth. The Bodley Head, Random House, London, p 51
16. Mokashi RP (2009) Study of user preferences for the visual domain of product form, IIT Guwahati
17. Shajahan S (2004) Research methods for management. Jaico Publishing House, India
18. Madhusudanan N, Chakrabarti A (2011) A model for visualizing mechanical assembly situations research into design. Research Publishing, India

19. Vyas P, Bapat VP (2011) Design approach to *kundan* jewellery-development of a tool to study preferential likeness of articles using mother grid and form clusters in a methodical manner, research into design. Research Publishing, India
20. Vyas P, Bapat VP (2011) investigation of form clusters made of smallest semantic units and patterns they create as building blocks of *kundan* jewellery, research into design. Research Publishing, India

A Structure for Classification and Comparative Study of Jewellery Forms

Parag K. Vyas and V. P. Bapat

Abstract Indian jewellery has a character of its own. It is rich in form and crafted in intricate details. Motifs often identifiable by their individual names are the fundamental building blocks. They are used in combination with each other to make a form cluster. These form clusters are repetitive and appear throughout the body of jewellery as a coherent theme. Complex Structures in gold, forms created using these motifs, are numerous and are made in a variety of ways. They track construction details to conform to body contours, for best presentation view they are often worn on a junction such as neck or wrist. An article therefore, is best understood in form with reference to anthropometric dimensions used as an underlying framework. The articles specifically chosen for study are neckpieces, as they are the largest in size and central part of a particular set. They are directly in line of sight for visual appreciation and therefore gain further importance as lead pieces in jewellery design. This study expounds on diverse types of forms and their characteristic features. A structure is presented by a comparative study that is expected to provide orientation, define key aspects of form and parameters. Outcome of this study is for benefit of jewellers as well as clients by better articulation of jewellery forms and thereby clear understanding of clients' expectations.

Keywords Form clusters · Complex structures · Jewellery design · Visual appreciation

P. K. Vyas (✉) · V. P. Bapat
Industrial Design Centre, Indian Institute of Design Bombay, Powai, Mumbai, India
e-mail: paragvyas01@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_20, © Springer India 2013

1 Introduction

Kundan is traditional Indian jewellery style that is elaborately embellished with gemstones and colourful enamel [1]. It has a character of its own that has remained unchanged over a period of time. Motifs, often identifiable by their individual names are used in this particular style. Motifs are frequently mimicking nature, liberally adopting from flora and fauna. [2]. These smallest semantic units are the fundamental building blocks and used in combination with each other make a form cluster. In turn, these form clusters make patterns which are repetitive and appear through the body of jewellery as a coherent theme. There are manners of construction of these form clusters that are passed down from generation to generation, from master to an apprentice. The knowledge is typically passed down verbally and little written material is available, typical of Indian traditions.

Our concepts of reality as Model dependent realism [3] makes it simple and comprehensible by having a structure for understanding things around us [4]. The beauty of a model is in its simplicity and how closely they agree with observations. Both of these are met by a way of partial fulfilment of objectives, or by finding a golden balance. One can use whichever model is more convenient in the situation under consideration. Model dependent realism applies to conscious and subconscious mental models we create in order to interpret and understand the everyday world.

In absence of well documented and dependable material it is difficult to have a structure for scientific studies in any domain, in particular area of form based studies in jewellery it becomes more severe as the field is very little explored [5, 6].

This primary objective of study is on providing a structure for comparative study of jewellery forms. The secondary objective is to articulate terms used in description of various aspects of jewellery. This is to provide a common standard vocabulary set for efficient and effective communication between client and designer.

2 Structure to Study Jewellery Form

Form of an article of jewellery which is the first visual interaction with a prospective client has a high influence on the client's decision in selection process [7]. It is one of the most important aspects that influence the preferential choice of the client. When it comes to study forms in a constructivist approach, literature is silent on the subject. It is of importance therefore to illuminate this potentially rich area of research.

A necklace is chosen for study as it is the largest article of jewellery amongst a collection, typically called 'a set' comprising of bangles or bracelets, necklace and ear pieces that follow a coherent theme. It is worn on the neck, in line of sight for

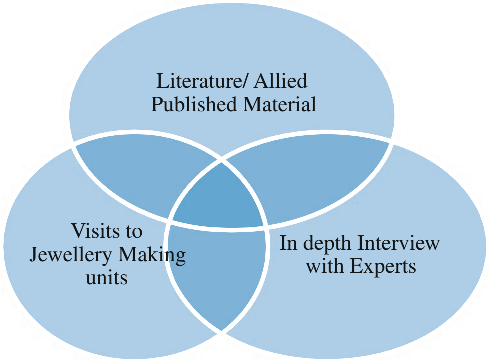


Fig. 1 Approach for study and validation by experts

visual appreciation and presents a good view, as compared to bangles which is worn on wrist and relatively small in size. The motifs are comparatively large and therefore it is dominant and most expensive article, ideally suited for such study. It was observed during visits to shops that the clients selects a neckpiece (or a design for the same first) and the jeweller makes the remaining articles of aforesaid set in line with this as a reference.

In search of a structure for a comparative study a three pronged (Fig. 1) approach was adopted firstly literature search, secondly visits to jewellery making units and thereafter informal in depth interview with experts for validation of findings. The proposed structure for classification evolved from observations on shop floor where a generating curve, often a circle of certain diameter is used as a reference to arrange form clusters.

3 Structure to Study Jewellery

There are varieties of forms existing in jewellery; the choice available to a potential buyer is enormous. With variants and creative embellishments *kundan* neckpieces present virtually limitless options to the observer [8]. A large variety of objects demand some classification for methodical study, for example the modern form of periodic table and its predecessors gave some sort of a structure for studying the elements. Despite their limitations and shortcomings they serve a purpose by providing a model for classification and cataloguing. This in turn makes it easy for us to comprehend large number of objects by compartmentalisation into similar groups and categories. A typical neckpiece is illustrated for its components in the following illustration.

In search for a rational for classification of jewellery articles, insights came from anthropometric studies [9] where the most basic differentiation can be made based on the manner in which they are worn. These can be broadly classified in two categories as follows:

Fig. 2 Neckpieces worn close to the body as chokers

1. Neckpieces Worn close to body as chokers that are conforming to the dimensions and contours of the neck and its proximity. As they are close fitting and worn tightly, gravity has little effect on their overall appearance. It has a slider and tassel that slides back and forth to facilitate the fit. As shown in Fig. 2.
2. Neckpieces Worn as chains or strings of a particular length. These are free hanging and the appearance is formed by weight and gravity. It has a hook and eye arrangement for opening that facilitates wearing. As shown in Fig. 3.

Both the types are made up of repetitive form clusters that appear throughout the body of the neckpiece. The free hangings do not necessarily conform to body form and dangle freely under gravity. The current trend is inclined towards the first type that is worn close to neck. This is due to two reasons; firstly they are worn against skin with a firm fit giving a neat appearance. They do not move as freely

Fig. 3 Neckpieces worn as chains or strings

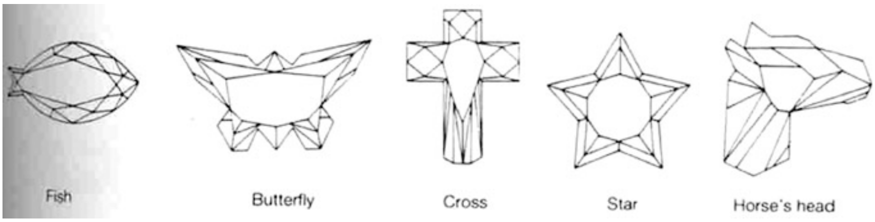


Fig. 4 Resemblance to a known object is used for Classification of fancy cut diamonds illustration adopted from Vyas and Bapat [6]

with movements and therefore can be worn both formally and casually. Secondly, their linear length is relatively small as compared to the free hanging ones, thereby making them less expensive and light. The design of a form cluster, however, for both the types may be same. Owing to this prevailing factor the first type is taken for further study and elaboration.

In search for further examples of classification structures that can be adopted for this purpose, reference was found in cataloguing of brilliant cut diamonds and other gemstones. Resemblance to a known object as a reference is used for Classification of fancy cut diamonds that come in a variety of shapes ranging from heart, butterfly, horse [10]. A similar approach is adapted for classification of necklaces that provides a frame of reference. Words used on shop floor are freely accepted and incorporated as they communicate that particular aspect most efficiently (Fig. 4).

These neckpieces can be classified in five categories based on composition of form clusters with respect to each other. Their characteristic features are summarised as follows:

1. Simple form clusters: these are the type of necklaces made up of form clusters that are same in size and appear repetitively through the body of the article at equal intervals or cluster pitch. These are easy to make as they have same sized smallest semantic units constituting them. They can be batch produced and subsequently assembled to form a necklace. As shown in Fig. 5.
2. Chhed Uttar: (or uniformly tapering form clusters) are the type of necklaces made up of form clusters that have a large form cluster at the centre and as the necklace progresses to either side the clusters decrease in size. This uniform gradient is called chhed uttar or a gradually decreasing cluster size. A variable cluster pitch is the typical characteristic of this style. This decrease in size, though appealing and interesting to eyes, requires each form cluster to be made using smallest semantic units that themselves are reducing in size from the previous adjoining cluster. This type of work therefore is far more intense in terms of time and money. Slowly the uniform sized clusters for its ease of manufacturing are replacing this type of work. As shown in Fig. 6.
3. Simple form clusters with pendent: these are the necklaces that have a simple form cluster, fixed cluster pitch as mentioned in first type. Besides this it has a

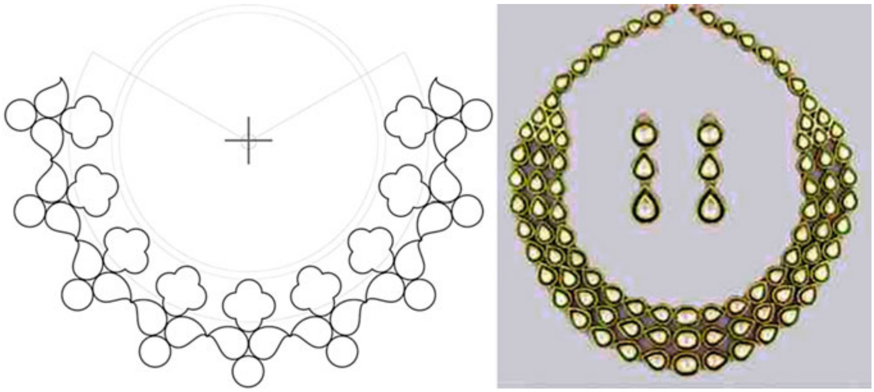


Fig. 5 Examples of simple form clusters, illustration and picture

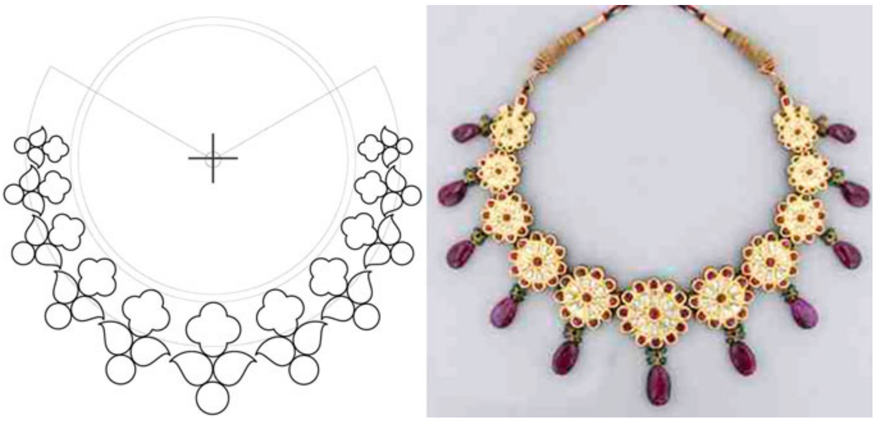


Fig. 6 Examples of *Chhed Uttar*, illustration and picture

pendent or 'padak' a typical form cluster hanging from the central unit. This cluster may have same combination of semantic units alternatively a different design that gels well with the rest of the structure may form this medallion. As shown in Fig. 7.

4. Chhed uttar with pendent: it follows same construction details as chhed utaar, but has a medallion similar to previous description. One typical variant of this type is where the pendent is integrated within body and rest of the clusters follow the gradient. As shown in Fig. 8.
5. Random paved: are the necklaces that appear as if paved with different shapes of smallest semantic units. Even though the sizes are random, yet an overall pleasing composition is achieved by carefully organising the adjoining units. As shown in Fig. 9.

Fig. 7 Examples of simple form clusters with pendent

Fig. 8 Example of Chhed uttar with pendent

A system diagram can therefore be formed for understanding at a glance (Fig. 10). With this structure it is possible to compare the forms of neckpieces inter group as well as intra group. An objective study therefore can be based on the articulated factors.

Proposed further is a conceptual structure for an inter group comparison of simple form clusters that takes into consideration three factors, number of semantic units constituting a form cluster, cluster pitch and number of form clusters constituting a necklace as in Fig. 11.

Fig. 9 Example of clusters randomly paved with shapes

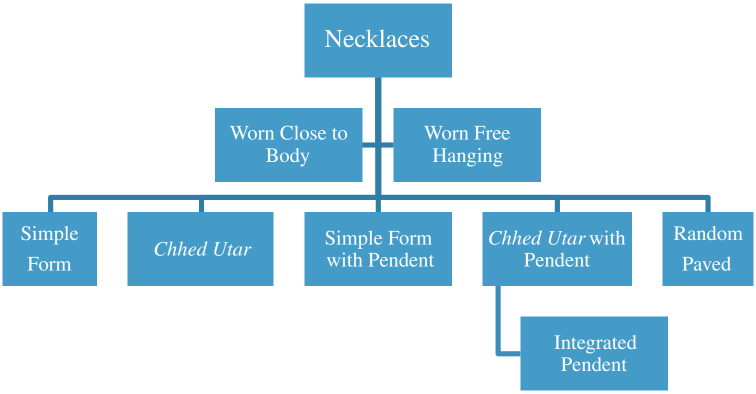


Fig. 10 Structure diagram of form cluster based classification of neckpieces

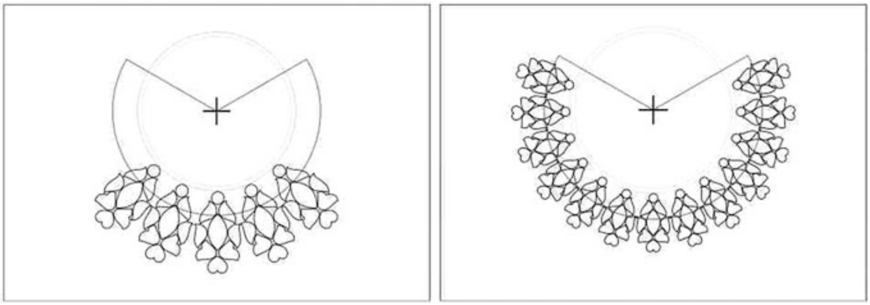


Fig. 11 Formation of form clusters for display and visual comparison

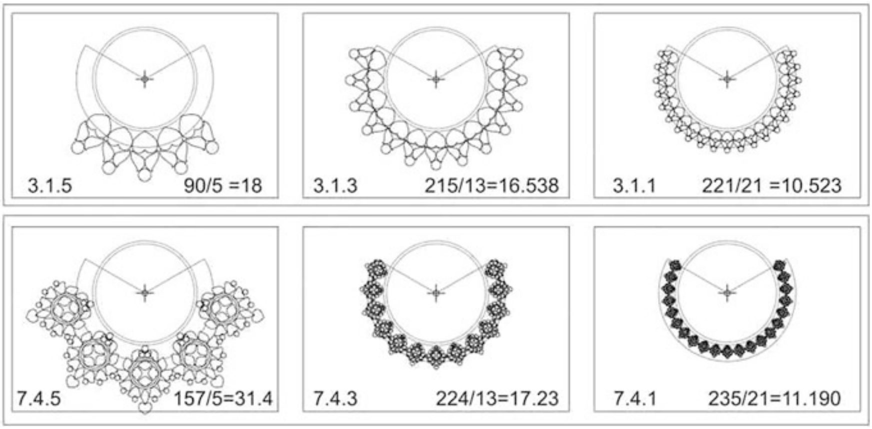


Fig. 12 Mathematical interpretation of cluster pitch

Arranged in form of a grid these can be used for mathematical interpretation of various parameters as shown in Fig. 12 as well as a three dimensional virtual model to assess preferential likeness of particular articles by using it in an adaptable appropriate form such as a display book or catalogue to have an insight into a clients choices and the inclinations.

This structure can also be used by designers for intra group comparison by two intra group grids being presented to a subject. Say for example, a simple form cluster can be compared with a chhed uttar type of form cluster with same number of clusters in each necklace.

4 Advantages

The beauty of a conceptual model is in its simplicity and adoptability. The proposed model structure can also be used for a variety of purposes like inter group and intra group comparisons. It can be used for assessing preferences of diverse and specific client profiles. As shown in the scalable construct in Fig. 13.

Assays sensitivity of the experiment being designed can be increased or decreased depending on the requirement [11]. Say for example for a quick survey a three by three grid can be used while for a fine survey a five by five grid can be used. The grid can only be increased in one particular dimension in case a fine measurement is needed for one particular aspect.

This model is minimalistic in its construct and has scalability in all desired dimensions. The model can also be used for trend tracking by making surveys time to time to observe changes that are taking place in preferential likeness of clients over time as shown in Fig. 14. This trend tracking, however, may include temporal

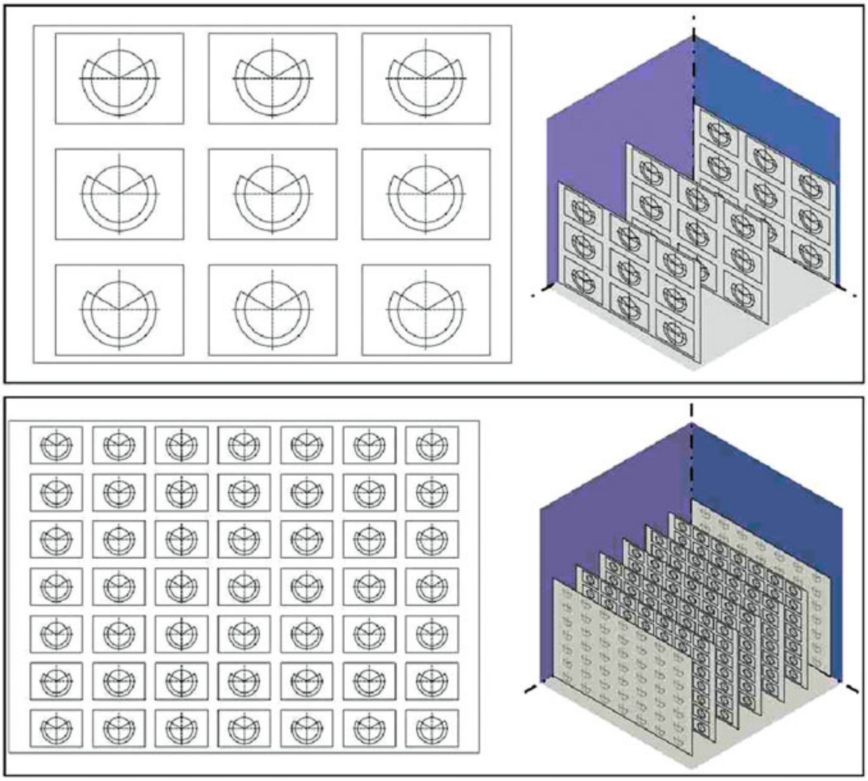


Fig. 13 A scalable construct of a virtual model

studies spread over a long time frame. The proposed model can accommodate other parameters to be tested in specific areas.

5 Limitations

The limitations can be best understood by quoting Hawking and Mlodinow [12], who propound that all models that we create will be off beam in some aspects. Nonetheless, as ground-breaking attempt this is a practicable structure. The success of a model is in how closely it matches to reality.

Also the field has vast potential for research and there may be more ways to classify and catalogue jewellery by presentation of different models which may be more effective in illuminating some other aspects.

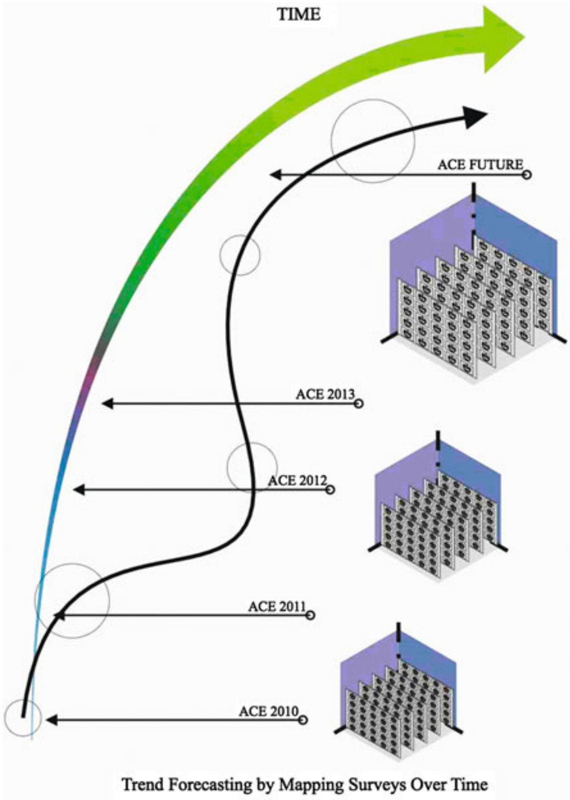


Fig. 14 Trend tracking across time

6 Future Directions

This study can be further extended to take into considerations other relevant factors such as cost, colour of gemstones being set, a combination of coloured gemstones for a particular article. Moreover, this study can be periodically administered to study trends and see if there are any emerging patterns.

Over a long period of time this data can be used for understanding changes that kundan designs are going through or if any transformation is happening in the basic design style itself.

Trend forecasting is a very critical aspect of jewellery design, as the survival of many jewellers depends on accurate assessments of potential needs of a future market. The tool with a good data base generated over years can be used to a limited extent to predict future behaviour; this can be based on mathematical parameters and not opinions as it happens in this domain presently.

The proposed model can be readily adapted for other types of jewellery and miniature products for paired comparisons and studies that require features of form to be compared.

Acknowledgments The authors greatfully acknowledge Vinay S. and Manu Panchal for illustration and photographs, Prof. G. V. Sreekumar and Nitin S. for valuable inputs on construct of trend tracking and forecasting model.

References

1. Untracht O (1985) Jewelry concepts and technology. Doubleday and Company, Inc., Garden City, New York, p 614
2. Sharma RD, Varadarajan M (2008) Handcrafted Indian enamel jewellery. Lustre Press, Roli Books, India, pp 36–41
3. Hawking S, Mlodinow L (2010) The grand design. Bantam Dell, London, p 46–51
4. Hawking S, Mlodinow L (2010) The grand design. Bantam Dell, London, p 117
5. Vyas P, Bapat VP (2011) Design approach to kundan jewellery—development of a tool to study preferential likeness of articles using mother grid and form clusters in a methodical manner. Research into design, Research Publishing, India, p 775–783
6. Vyas P, Bapat VP (2010) Identification and classification of semantic units used in formation of patterns in kundan jewellery, a methodical approach. Design Thoughts, IDC, IIT Bombay, p 59–72
7. Vyas P (2007) Understanding features of form in fine jewellery, by overt eyes. Dev Agric Ind Ergonomics 1:101–108
8. Balakrishnan UR, Kumar MS (2006) Jewels of the Nizams. India Book House Pvt. Ltd, India, p 81–203
9. Chakrabarti D (1997) Indian anthropometric dimensions, for ergonomic design practice. National Institute of Design, Ahmadabad
10. Pagel Theisen V (1993) Diamond grading ABC handbook for diamond grading. Rubin & Son Bvba, Antwerpen
11. Shajahan S (2004) Research methods for management. Jaico Publishing House, India
12. Hawking S, Mlodinow L (2005) A briefer history of time. Bantam Dell, New York, p 23

Product Design and the Indian Consumer: Role of Visual Aesthetics in the Decision Making Process

Naren Sridhar and Mark O'Brien

Abstract The research paper aims to examine the influence of 'Product design' on buying decision making in the Indian urban market sector, focussing on visual product aesthetics; the characteristics that create a product's appearance and have the capacity to affect observers and consumers [1]. Product design, specifically the 'Visual Aesthetic' [Visual Aesthetics (VA), for the purpose of this study, is defined to entail the colour, size and proportions, materials and design expression of the designed product] has been recognised as a key strategic variable in securing or defending a marketplace advantage. This question will be examined in the context of Indian social, cultural and economic systems and with regards to the relative position of visual aesthetics in the decision making process of young adults in the Indian urban consumer market.

Keywords Product design · Indian consumer · Social psychology

1 Introduction

'Aesthetics proper is a recent discipline, born of a real revolution in our perception of the phenomenon of beauty'—Ferry.

Ferry [2] comments in his article—'The Origins of aesthetics', specifically the visual aesthetics in the field of art, and this same understanding prevails in the

N. Sridhar (✉) · M. O'Brien
University of Huddersfield, Queensgate, Huddersfield HD1 3HD, UK
e-mail: naren_vasista@yahoo.com

M. O'Brien
e-mail: m.a.obrien@hud.ac.uk

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_21, © Springer India 2013

relatively younger creative areas such as Graphic design and Industrial design. This comment can be construed such that the understanding of beauty or the subjective perception of beauty and in a broader and more relevant context, general visual aesthetics is congenital in all humans and is then subject to recall.

The demands of today's consumer marketplace continuously influence how retail, wholesale, distribution and consumer product manufacturers operate. As a result, these organizations need to understand and anticipate customer needs in order to remain competitive and provide innovative, differentiated products.

Marketers realise now, that the reactions of the target consumer is foremost at the visual level, especially in the tangible consumer goods market and the measure of this as a factor in the success of the product is mostly in the marketer's domain of control. "It is important to understand and measure these individual differences relating to design for several reasons: First, individual differences in responsiveness to visual aesthetics may underlie a number of other well-established consumer behaviour variables such as product involvement, brand loyalty, materialism, innovativeness, self image congruence, choice, and usage behaviour" [3].

In such markets, developing a product image in a consumer's mind becomes an essential marketing tool; an image once in the consumer's long-term memory is more likely to be purchased when a need for that product arises [4]. However, this need is primarily addressed by the functional aspect of the product. The visual value of the product has been, in the recent past, given its due as the premier and most immediate reaction drawing factor in the cognitive and attention processes. The obvious shift in the paradigm of marketers is evident in the evolving role of product image, which includes the visual aesthetics, the packaging, branding and the communication methods in the ambit of marketing strategy.

A good product image may also increase the level of product equity (the value that consumers assign to a product above and beyond the functional characteristics of the product) [5]. This is where the design of the product comes into the fray. A well designed product brings with it an edge over the competing products that can be the defining criteria in the decision making process of the consumer.

With the market clustered with competing products that are very similar to each other in terms of technicalities and functionalities, the deciding factors for the consumer in choosing one product over another could dictate success or failure of a brand. This decision making has moved away from the basic variables such as pricing, performance to more intangible yet influential factors such as brand and product image, communication methods and product design. These factors independently or in groups become the stimulus inputs or cues for the consumers. In a lot of cases, these inputs impact sub consciously on the consumer. Wilkie [4] indicated that consumers translate stimulus inputs into mental identification. This process is called perceptual categorisation. For consumers, this process works extremely rapidly and is usually not perceived at a conscious level.

In this cluttered market, the key word for marketers and businesses becomes 'Differentiation', the process of creating an individual image to the product, distinct and attention grabbing, while confirming to the overall general perception of the product and hence not creating a dissonance with its unfamiliarity. "While manufacturing costs always decline with the use of commonality, the firm's overall profits may decline because of reduced differentiation" [6].

One such consumer market, India, has been steadily seeing this kind of consumerism and its associated effects and is predicted to grow at an ever increasing pace, with total domestic consumption growing from $370 to $1,500 billion by 2025 and with the Gross Domestic Product (GDP) growth of India on the rise and set to reach a high of 7.3 % increase by 2025, and with 'Thos macroeconomic forecast' indicating that the Indian economy which has till date been a developing economy is set to continue into a new stage of development in comparison with other Asian and world economies, it becomes imperative to understand this market. The socio-economic and cultural factors of the region present a unique opportunity and a necessity to examine it as an independent case study.

2 Economics of Product Design

The Indian consumer market has never had it better. Higher disposable incomes, the development of modern urban lifestyles and an increase in consumer awareness have affected buyer behaviour—in cities, towns and even rural areas. According to a 2007 report by McKinsey & Co., India is set to grow into the fifth largest consumer market in the world by 2025 [7].

In an excited market atmosphere such as this, stand out products were hard to come by for a long time, though it was a necessity. Products tended to resort to the comforts of tested and usually conservative market strategies with the intention of market survival overpowering market dominance. This was especially the case during the period of the initial years post globalisation or the opening of the economy to foreign businesses and investments in 1991, till when India had pursued an economic strategy based on import substitution [8]. The first decade or more after the economic liberalisation saw a number of market entrants, especially in the consumer market forum, but the product differentiation was not the primary focus of the marketers, the attention was more on the registration of the brand in the minds of a relatively infantile consumer market. There has, however, been a sustained shift towards underlining the individuality of the product since recent times and this required the understanding of Indian consumer psychology.

Products, which have been newcomers to the consumer market not long ago (e.g., mobile phones, laptop etc.) are now becoming mature products. Though the market has opened, the sales are not seeing the proportional increase. Quick model changes, technical updates or price reductions in order to improve the turnover have not been sufficient in terms of net sales per potential market increase. This new environment has created a situation where the consumers have more say in what they want and for what they pay. An increasing number of people want to express their individuality and even mass produced products have to be adaptable to individual demands regarding form, design and function [9].

However, in the present charged and turbulent international economic state, India has relatively resisted the meltdown but has still been measurably affected. The recommended and urged strategies to counter this crisis include departure from the dominant economic philosophies of neo-liberalism, dominant free market capitalism and shift from manufacturing to agriculture [10]. With such drastic expected potential changes, the value of 'Design' or more specifically 'Visual Aesthetics' (VA which incorporates under its brackets facets such as shape, colour, visual image, form and features) amongst the chosen market segment and the resulting shifts in paradigms needs to be monitored and interpreted.

3 Socio-Economic Factors

The process of demystification of the behaviour process of a consumer has to acknowledge the social and economic atmosphere surrounding the studied segment. Social psychology, vitally concerned with the behaviour of individuals and groups and the relationship between them, has been used in order to discover and recognise relationships between customers' attitudes, personality and motives, and the purchase decisions.

The effects of family, culture, peer groups, reference groups, subcultures, external cultural influences are all unique and respective to individual societies and countries.

The sociologist George Simmel felt that the deep changes occurring in man's psychic structure were a consequence of the socio-economic development of capitalism [11].

The developing countries are now under the system of consumer capitalism, which affects more and more people; the process of consumption and its related services has become the dominant social activity, even its philosophy. This has progressively led to the creation of its own: own characteristic and philosophical framework, social ranks and exclusivities; to the extent that membership and identification is gauged by the level of consumer participation. Richards [12] terms this 'Commodification' and defines it—'treating people and things only in terms of their market value—the degree of integration into this ritual of consumption being indicative of a person's social worth and his sense of social and individual responsibility'.

Marx's 'Commodity fetishism' describes this shift in social ideology as 'the fetishism of commodity is a definite social relation between men themselves' [13] or more vividly, 'to the producers… the social relations between the private labours appear… as material [*dinglich*] relations between persons and social relations between things'. According to Marx, this is the fetish associated with the products of labour as soon as they are produced as commodities, and is therefore inseparable from the production of commodities [14]. This sociological change is evident in the Indian consumer market.

India is the second most populous country in the world with an estimated population of more than 1.2 billion [15] and it may at the rate of growth, be the most populated country within a decade. As a developing country which saw economic liberalisation in the early 1990s and a recent economic growth surge, with rapid socio-economic changes taking place in India, the country is witnessing the creation of many new markets and a further expansion of the existing ones. With above 300 million people moving up from the category of rural poor to rural lower middle class between 2005 and 2025, rural consumption levels are expected to rise to current urban levels by 2017 [16]. India's market potential is greater than that of many countries in Western Europe with more than 150 million middleclass consumers earning more than $4,000 annually in local purchasing power [17].

Beginning in the late 1980s, the Indian government has taken a series of steps to liberalise the economy and ease restrictions on imported goods. As a result, the Indian market today is flooded with imported products from many countries. This has increased collaborations, indigenous brands and international brands all competing to grab the growing market opportunities. This process of globalisation has been an integral part of the recent economic progress made by India. Globalisation has played a major role in export-led growth, leading to the enlargement of the job market in India, especially in the urban centres such as Bangalore, Pune and Mumbai. However, with globalisation, corresponding social changes have developed in the country. This is primarily due to the lowering of the employed age group. This has a domino effect in the increase in disposable incomes, younger earners, nuclear families, younger consumer market, shift in consumption choices, and shift in spending patterns.

This assortment of at times congruous and at others conflicting agents in a dynamic socio-cultural zeitgeist makes for keen and necessary junctures of observation and recording. That Product Design is affected by and affecting many of the observed changes is crucial to be registered.

4 Psychology of Product Design

"Products are often instinctively perceived, and product choice is rarely just an exercise in logic"—Macdonald [18].

According to Macdonald [18], the buying behaviour of the consumer primarily and ultimately depends on how the product has been perceived by the individual and the reasoning behind this perception. Chapman [19] proposed that *"we are consumers of meaning, not matter and products provide a chassis that signify the meanings to be consumed"*. Between these two statements, the importance of 'meanings' and 'perceptions' in the buying behaviour process can be evaluated.

The visual appearance of products is a critical determinant of consumer response and product success. Judgements are often made on the elegance, functionality and social significance of products based largely on visual information [20]. These judgements relate to the *perceived* attributes of products and frequently centre on the satisfaction of consumer wants and desires, rather than their needs [21].

Previous research studies indicate that the relationship between cognitive response and product appearance can be classified into three elements: [22].

- Aesthetic impression—This is the emotional response resulting the aesthetic attractiveness of the product. This could be positive or negative responses.
- Semantic interpretation—This can be defined as what the product intends to describe about its function, performance and qualities. This can also be a response to function which the form is trying to underline.
- Symbolic association—This is the perception of social status and significance of the product, the design represents what the product says about its owner or user. The personal significance of the design might overcome the social significance.

However, these aspects of response are not exclusive to each other in most cases, they do not operate independently, but are highly inter-related; each one influences the others. For example, evaluation of the product and its features can be influential and modify judgements on the aesthetic response of the product and also the social value or symbols it may connote. The relative importance of the elements and the combinations may vary depending on the situation [22].

The decision making process with regards to the product design or visual value can be affected and influenced by visual references such as stereotypes, metaphors, clichés etc. [22]. The viewer makes sense of the visual information which the product presents based on these visual references [21]. Visual referencing may also influence the semantic interpretation allowing the viewer to categorise the product easily and associate it with familiar concepts and similarly can influence the symbolic value by allowing the viewer to connect them with products that already have associated social meanings [23].

Product design can be viewed from the perspective of psychoanalysis, especially the form of the product, which provides an ample area for subjective perceptions. We concentrate on the behavioural approach to marketing: Social psychology, vitally concerned with the behaviour of individuals and groups, has been used in order to discover relationships between customers' attitudes, personality and motives, and his or her purchase decisions.

"Nothing we can learn about an individual thing is of use unless we find generality in the particular. The endless spectacle of ever new particulars might stimulate but would not instruct us" [24].

The premise to begin with is that consumers are rational subjects, capable of governing their thoughts and actions by the principles of reason when faced with purchase decisions. According to the view that became dominant with the enlightenment, human nature is divided into a rational part, the faculty of reason, and a non-rational part comprised emotions, appetites and desires [25]. These two parts are distinct and opposed. Reason is disinterested, universal, objective and autonomous in its operation. The emotions and appetites, by contrast, are partial, particular and subjective. They are a force hostile to reason in human life [25].

All emotions are experienced and learnt in the interactions between self and society. Emotions exist only through reciprocal exchanges in social encounters. Emotions cannot be studied without paying attention to the "local moral order" and the existence of "those concepts (emotions) in the cognitive repertoire of the community" [26]. This suggests that the individual emotion is often affected by the collective expectations of society or as referred to previously, by the Subjective Norms. This is explained by Sabini and Silver [27] as the relationship of 'selves' to the 'moral objective universe'.

The essence of these arguments is the observation that emotions are necessarily crucial to the understanding of behaviour of most kinds, including the behaviour arising from the process of decision making. However, the occupying argument is the viewpoint that 'emotions' could stem from a collective or social sub-conscious and the standoff between the 'rational' and 'irrational' schools of thought in the understanding of 'emotions'.

Another paradigm which is pertinent to the overview of product design and consumer psychology is the dominance of the 'collective' sub-conscious in the social psychology. Jung divided Freud's 'Unconscious' into two very unequal levels: the more superficial 'Personal', and the deeper 'Collective'. Those mental contents that the ego or the conscious part of the psyche does not recognise fall into the 'Personal Unconscious', which is composed of many contents that vary from person to person and from time to time. But the significance of the contents lies in its partial personal and partial 'collective' nature. The unconscious contents are much more extensive than the conscious contents [28]. Everyone has their own 'Personal Unconscious'. The 'Collective Unconscious' in contrast is universal. It cannot be developed by the conscious observations and learning like one's personal unconscious is; rather, it predates and in most cases, is beyond the control of the individual. It is the repository of all the religious, spiritual, and mythological symbols and experiences. Its primary structures are the deep structures of the psyche, which were referred to by the term 'Archetypes' by Jung and Hull [29].

Jung says "we do not think of distrusting our motives or of asking ourselves how the inner man feels about the things we do on the outside" [29].

This can be utilised in the understanding of the visual communication of the products and its relationship with the human psyche; the visual archetypes are not questioned by the conscious human mind and thus the reasons for the associations and affects of the visuals is not consciously analysed.

Product design provides the consumer with this sense of metaphorical opposites, the sense of being a part of the collective infinite and also the individual identity. Thus, according intimacy and a connection to others which is the primary motivation in human beings is confirmed to and succeeding which, pleasure that is rather a secondary motivation derived from this more primary motivation [30].

Jung theorised that we are tied to a much greater archaic collective unconscious mind that emits universal symbols and processes we all share [31].

Therefore, the hypothesis is that this is the symbolic meaning associated with all products and their forms. These symbols can be deliberately controlled so that the association of the product to its intended buyer works in the collective sub-conscious strata of the mind, orchestrating the desired market behaviour. The process of the symbols communicating with its audience and the behavioural response towards these symbols happens at the unconscious level and this process is known as 'Symbolic interactionism'

The concept of symbolic interactionism is based on the premise that individuals interact with society at large and with reference groups, and this usually occurs at the sub-conscious levels of the human psyche, in determining the structure of the individual behaviour to determine. Individuals are, therefore, assumed to relate to objects or events based on their symbolic meaning given by society [32].

5 Summary

This study employs these theories of Social Psychology in its attempt to test the hypothesis that the VA in Product design is a 'Universal', 'Collective' and sub-conscious process between the designers and the consumers and is reciprocal and cyclic in nature. This is achieved through a systematic theoretical understanding of the various categories of influencing factors and their inter-relationships leading to a final developed theory that is grounded in the behaviour, words and actions of those under study [33].

This is aided by the employment of the Grounded Theory; method is usually used to generate theory in areas where little is already known, or to provide a fresh slant on existing knowledge about a particular social phenomenon.

This method allows the researcher to examine the various facets concerned such as Social, cultural and economic factors, Situational factors, Methods and channels of communication of design, Intention and reception of design in India. These were explored in the primary stage of the study, based on the philosophy of the chosen research paradigm 'Grounded Theory' along with the relationship between the different theoretical 'categories' such as Consumer Behaviour, Product Design and Social Psychology towards the direction of a 'core' theory.

The study is examining Product Design and its associated affecting components in the Indian context with a focus on its socio-psychological relationship with the consumer. The theories of psychology and sociology explored are the paradigms juxtaposed with India and Product Design to provide us the ability to intrinsically and critically analyse them in a fresh perspective.

The research study is currently in the second phase where working alongside the theory building and empirically complimenting it, will be an in-depth case study of 'Titan Industries' and specifically Titan wrist watches. It is envisaged that this study will contribute to the general understanding of the Indian consumer providing an insight into the consumer psyche and cognitive reactions to Product Design.

References

1. Lawson B (2006) How designers think: the design process demystified. Elsevier, Westefield
2. Ferry L (1990) The Origins of Aesthetics. Available: http://findarticles.com/p/articles/mi_m1310/is_1990_Dec/ai_9339050. Last accessed 12 Sep 2011
3. Bloch H, Brunel F, Arnold T (2003) Individual differences in the centrality of visual product aesthetics. J Consum Res 29:551–565 (Trice Award Winning Article, College of Business)
4. Wilkie WL (1994) Consumer behavior, 3rd edn. Wiley, New York
5. Hawkins DI, Best RJ, Coney KA (1998) Consumer behavior: building marketing strategy. McGraw-Hill, New York
6. Desai P, Kekre S, Radhakrishnan S, Srinivasan K (2001) Product differentiation and commonality in design: balancing revenue and cost drivers. Manage Sci 47(1):37
7. Ablett J, Baijal A, Beinhocker E, Bose A, Farrell D, Gersch U, Greenberg E, Gupta S (2007) The bird of gold: the rise of India's consumer market. The McKinsey quarterly: the online journal of McKinsey & Co, May 2007. Available: http://www.mckinsey.com/insights/mgi/research/asia/the_bird_of_gold/. Last accessed 04 Feb 2012
8. Kesavan KV (2003) Economic liberalization in India and Japan's wavering response. Ritsumeikan Annu Rev Int Stud 2003(2):129–142
9. Shimizu Y, Sadoyama T, Kamijo M, Hosoya S, Hashimoto M, Otani T, Yokoi K, Horiba Y, Takatera M, Honywood M, Inui S (2004) On-demand production system of apparel on basis of Kansei engineering. Int J Clothing Sci Technol 16:32–42
10. Bhatt RK (2011) Recent global recession and Indian economy: an analysis. Int J Trade Econ Finance 2(3):2011
11. Slattery M (2003) Key ideas in sociology. Nelson Thornes, Cheltenham
12. Richards B (1989) Crises of the Self. Free Association, London
13. Marx K, Mandel E, Fernbach D, Fowkes B (1991) Capital: a critique of political economy. Penguin Classics, London
14. Balibar E, Turner C (1995) Race, nation, class: ambiguous identities. Verso, London
15. Sala-i-Martin X (2006) The world distribution of income: falling poverty and convergence, period. The quarterly journal of economics, May 2006 121(2). Available: http://qje.oxfordjournals.org/. Last accessed 03 Dec 2011
16. Falk S (2009) Shift of power or multipolarity?. Zeitschrift für Politikberatung 2(4)
17. Kulkarni VG (1993) Marketing: the middle-class bulge. Far Eastern Econ Rev 156(2):44–46
18. Macdonald AS (1998) Developing a qualitative sense human factors in consumer products. Taylor & Francis Ltd, London
19. Chapman J (2005) Emotionally durable design. Earthscan, London
20. Coates D (2003) Watches tell more than time: product design, information and the quest for elegance. McGraw-Hill, New York
21. Lewalski ZM (1988) Product aesthetics: an interpretation for designers, design and development. Engineering Press, Carson
22. Crilly N, Moultrie J, Clarkson PJ (2004) Seeing things: consumer response to the visual domain in product design. Des Stud 25(6):547–577
23. Postrel VI (2003) The substance of style: how the rise of aesthetic value is remaking commerce, culture, and consciousness. Harper Collins, New York
24. Arnheim R (2004) Visual thinking. University of California Press, Berkeley
25. Damasio R (1994) Descartes' Error: Emotion, Reason and the Human Brain. Vintage Digital, London
26. Harré R (1986) The Social construction of emotions. Blackwell, Oxford
27. Sabini J, Silver M (1986) The social construction of emotions. Blackwell, Oxford
28. Mattoon MA (2005) Jung and the human psyche: an understandable introduction. Routledge, New York
29. Jung CG, Hull RFC (1959) The Archetypes and the collective unconscious. Routledge & Kegan Paul, London

30. Robbins BD (1999) A brief history of Psychanalytic thought—and related theories of human existence. Available: http://mythosandlogos.com/psychandbe.html. Last accessed 17 Nov 2011
31. Small J (1994) Embodying spirit: coming alive with meaning and purpose. HarperCollins, New York
32. Mead GH, Morris CW (1967) Mind, self, and society: from the standpoint of a social behaviorist. University of Chicago Press, Chicago
33. Goulding C (1999) Grounded theory: some reflections on paradigm, procedures and misconceptions. Working Paper Series WP006/99, University of Wolverhampton, Telford

Effective Logo Design

Sonam Oswal, Roohshad Mistry and Bhagyesh Deshmukh

Abstract Today's world is becoming increasingly visually oriented and logos have become a prime asset of companies. Logos are absolutely essential in branding and brand building and aims to facilitate cross-language marketing. The aim of this paper is to translate and expand the concept of logo effectiveness in the field of visual logo designs by identifying and understanding various factors that influence consumer perception of logos. The current research investigates numerous factors which influence the effectiveness of logo design including human perception factor. The study reveals that effective logo design adheres to seven elemental standards that all designers should be aware of. These principles may serve as key elements for judging whether the design and style systematically delivers the message to its potential audience. Degree of logo effectiveness is function of simplicity, versatility, memorability, relevance, timelessness, quality and appropriateness where as the psychological factor acts as multiplier of any one or more of the above factors. Logo design is an explicit function of shape factor (S) Color factor (C) and Font factor (F) and Human Perception Factor (P). The research includes case studies from different industrial backgrounds including automobile, sports, food products and beverages. The research classifies and studies different types of logos such as ones based on shapes, words, letters and Graphics. The work also addressed the issue of Good and bad logos. The study developed a set of guidelines for the effective logo design.

S. Oswal (✉) · R. Mistry · B. Deshmukh
Mechanical Engineering Department, Walchand Institute of Technology, Solapur, Maharashtra, India
e-mail: sonamoswal2907@gmail.com

R. Mistry
e-mail: roohshadmistry@gmail.com

B. Deshmukh
e-mail: dbhagyesh@rediffmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_22,

Keywords Logo effectiveness · Logo design factors · Good logos · Bad logos · Guidelines for effective logo design

1 Introduction: Need for Effective Logo Design

A logo conveys the entire essence of the owner or of the product represented and a good graphical realization. Effective logos successfully communicate a brand's style and personality. A logo is a distinct and recognizable identity of an organization.

A logo identifies a company or product via the use of a mark, flag, symbol or signature. Logo is basically a statement of business to all over the world. Logos give the first impression of a product or a company and hence play a very big role in the presentation of a company or an organization. A good logo can not only influence a customer's decision to buy a particular product but also attract the right kind of customers. Good logo expresses the organizations vision, its values and outlook.

Logos help in making a company more distinguishable and memorable because target audience easily gets connected with the organization through them. It creates an impact in consumers mind and represents the company's personality in most favorable manner. Logos are very effective in communicating a brand's message to consumers.

2 Objective of Study

1. Discuss factors affecting logo effectiveness.
2. To understand the relation of shape, color, and fonts on logo effectiveness.
3. To provide designer with a guidelines to select the optimum features including color, font and shape for logo design.

3 Literature Review

Chakrabarti and Kumari [1] studied the effect of structure sharing on logo design and to enhance the effectiveness of it. The degree of structure sharing and resource effectiveness on logo design was done. Kohli et al. [2] provided their thoughts on the two facets of logo design: content and style where content referred to the elements contained in the logo, including text and graphic representation and style referred to how these elements are presented in a graphical sense. Hem et al. [3] found that logo representativeness and design were important determinants of logo success. Bottomley et al. [4] investigated color appropriateness and showed the effects of colors and products on perceptions of brand logo appropriateness. Doyle et al. [5] studied the effect of font appropriateness on brand choice. It was found that brand presented in appropriate fonts was chosen more often than brands presented in inappropriate fonts. Saleh [6] has investigated the relationship between consumer's perceptions of a logo the organization it represents and the organization's performance. The relationship between the perceived image of the logo and organization perceptions was found to be positively significant. Fang et al. [7] studied the effect of a logo design on attitude toward the firm and the perception of the firms' modernness. They found that the respondents had a better attitude toward the firm for a round logo versus an angular logo. In terms of a logo change, Kohli et al. [2] provided some guidelines and stated that if a logo is changed, the change should be made in content. However, the changes to the logo should be kept to a minimum. Walsh et al. [8] has studied consumer's attitudes toward a logo change or redesign and investigated the effect of different degrees of redesigned logos on consumers brand attitude toward them, with the moderating effect of brand commitment.

It has been observed form the above literature survey that research has been done on factors such as logo content and style, logo appropriateness, logo redesign, color appropriateness, font appropriateness but not a so much on effectiveness.

4 Scope of the Study

The study covered logos from different business domains and comparative study was done on the basis of shape, font and color and was ranked on the basis of their effectiveness. Analysis of good and bad logos is carried out considering its simplicity, relevance, appropriateness and quality.

5 Methodology

5.1 Study of Various Logos for Understanding the Effectiveness

Various logos belonging to companies from various business domains were selected for evaluating effectiveness. The logos which scored high on effectiveness were considered for further analysis. After analyzing logos those parameters affecting the effectiveness are established. The methodology is to expand the concept of effective logo design. The study reveals that effective logo design adheres to seven elemental standards that all designers should be aware of.

Most logo designs can be broadly classified into three types: text, emblem, emblem and text, graphical or mascot type. In most cased the emblem or icon is accompanied with the company name. As a general rule icon or emblem based logos the following rules apply;

- Best visual appeal.
- Likely to appeal to a large and diverse audience. More memorable.
- Good for merchandising.
- Can serve as a trademark effectively.
- Lacks uniqueness and versatility especially if the business group is diverse (Fig. 1).

Fig. 1 Icon based logos (Google Chrome, Apple Computers and Nike)

Pure text logos are also the simplest but at the risk of becoming monotonous. The following features for text based logos have been noted:

- Most appropriate for companies who don't have a physical product viz. Banks, service sector companies, legal firms etc.
- Do not stand out.
- Esoteric appeal (Fig. 2).

Fig. 2 Text based logos (Walt Disney Entertainment Company and NASA)

Some logos contain a mascot or some graphical illustration. These are quite complex and require a skilled artist and designer. The points noted about these logos are:

- Must choose the character or mascot carefully.
- Suited for entertainment industry, food and beverages and toy manufacturers and service oriented companies.
- Can be memorable if designed properly.
- Not suited for manufacturing industry, legal firms and banks (Fig. 3).

Fig. 3 Graphic logo (Starbucks Coffee)

As a general rule icon or emblem based logos the following rules apply:

- Best visual appeal.
- Likely to appeal to a large and diverse audience. More memorable.
- Good for merchandising.
- Can serve as a trademark effectively.
- Lacks uniqueness and versatility especially if the business group is diverse.

In majority of cases icon and company name is used. The rules which apply for icon based and text based logos apply here as well (Fig. 4).

Fig. 4 Icon and text logos (Puma and Burger King)

Above logos were studied in detail and following 7 elemental standards [9, 10] are explained in detail related to logo design:

(a) *Simplicity* A logo must be simple and this is true especially when on an insignia or an emblem is used as a logo as in the case of Nike and Apple. Very intricate and geometrically complicated logos must be avoided. For example the flag of Japan depicting the land of the rising sun appropriately represents the nation. A logo must be simple and this is true especially when on an insignia is used as a logo as in the case of Nike and Apple. Often the simplest things are also timeless and memorable. This is the reason that most of the logos which are memorable and timeless are also simple.

(b) *Relevance* Logos must reflect clearly the company's message, values, beliefs and business domain. For example using the emblem of a Jaguar in Jaguar cars does qualify on the basis of relevance. The same is not be true for the logo Peugeot especially given the fact that Peugeots product lineup includes mainly low to medium budget cars where as the logo is that of a Lion.

(c) *Memorability* The memorability of logos can vary from person to person country to country and depends upon the individual's cultural political geographic background and his own experiences. Hence a rule of thumb is difficult to establish but can be generalized for a certain populous. For example the Apple has immense philosophical implications for western people but is just a fruit for most Asians. For a logo to be memorable it must be unique and also simple. Nike and Apple logos are the best examples. Coco Cola and McDonalds logos also fall in this category.

(d) *Quality* Quality can be very effectively expressed by use of certain shapes fonts and colors. Use of circles is preferred followed by ellipses and squares must be avoided. For example Honda, BMW and Mercedes Benz all make excellent quality cars. The Honda logo however does not reflect this as compared to the BMW and Mercedes logo. Quality is often best expressed in simple sharp fonts. Cursive fonts must be avoided.

(e) *Appropriateness* Logos must reflect the product business environment or company policy appropriately. For example the Burger King logo appropriately represents the product 'Burger'. Radio Mirchi logo represents the company name appropriately and so does the apple logo. But they do not represent the company product appropriately.

(f) *Versatility* Many large business houses operate different business and manufacturing different products. In such case it is better to have logo which reflects the group rather than the individual product. In such cases the logo must be versatile. Mitsubishi logo is effective representation for automobiles and manufacturing but is not so effective in representing the group which includes banking insurance etc. A good example of a versatile logo is TATA and GENERAL ELECTRIC.

(g) *Timelessness* This is a combined effect of the above factors and it is difficult to establish a rule of thumb for the same. Generally speaking logos exhibiting simplicity and memorability exhibit timelessness; the logos of Coco Cola, Nike and Apple for to speak.

5.2 Testing the '7 Elements of Logo Effectiveness'

These 7 elements are further tested for Color, Shape, and Font for the logo of Talk more. In 'Structure sharing in logo design' [1] the study was done on structure sharing and little work on effectiveness was done and structure sharing exist when there is more than one function fulfilled by the same structure at the same time. It also need FM tree to show structure sharing. The focus was more on structure sharing and least on effectiveness.

Logo of talk more as shown in Fig. 5; a telephone service from Kingston Communication is taken for analysis. Talkmore uses symbology in the form of quotation marks to replace the letters A and E, creating a clever image that gives a graphical representation of the words and meaning of the brand. The touch of color enhances this effect making the logo stand out. Simple and clean use of typography is observed to communicate professionally with the potential clients.

Fig. 5 The Talkmore logo

A 10 point scale was used to rate the Color, Shape, Cultural Impact and Human perception Factors as shown in Table 1.

A Tree structure of various factors of logo effectiveness is drawn as shown in Fig. 6.

An equation for logo design effectiveness is written as,

$$\text{Logo Design Effectiveness} = f(\text{Colour (C)} + \text{Font (F)} + \text{Shape (S)}). \quad (1)$$

Table 1 Analysis of various factors affecting logo effectiveness

Font (F)	Color (C)	Shape (S)	Cultural impact factor rating (point)	Human perception factor rating (point)
Sanserif	Grey	Constant (C)	10	9
Serif	Blue	Constant (C)	8	8
Handwritten	Black	Constant (C)	7	6

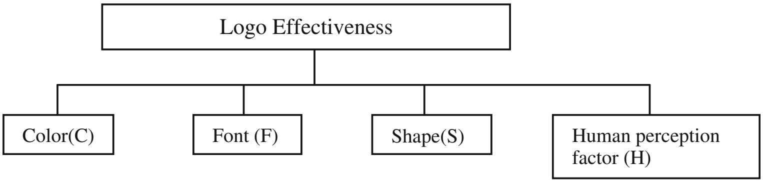


Fig. 6 Logo effectiveness factors

5.3 *Applying Shape, Font and Color Factors to the Logo of Various Sectors to Study Effectiveness*

On the basis of shape factor, color factor and font factor logos have been analyzed in for automobile, beverage and sports good industry. The ratings for shape, color and font will depend upon the Human perception factor. Keeping the variable shape factor (S) as constant. Effect of color on logo design is due to cultural Impact factor.

Case I *Automobile Industry logo*

Various automobile logos were studied as shown in Table 2, and given a rating from 1 to 10 on a ten point scale.

It is seen from the above ratings that the Circular shape, Simple font and blue or black and white color is the effective combination for the logo design.

Case II *Beverage industries logo*

Various beverage industries logos were studied and some of them are as shown in Table 3, and given a rating from 1 to 10 on a ten point scale.

It is seen from the above ratings that the Circular shape, Simple-Cursive font and red, blue and white color is the effective combination for this type of logo design.

Case III *Sports and Shoe Wear Industry logo*

Various Sports and Shoe Wear Industry logos were studied and some of them are as shown in Table 4 and given a rating from 1 to 10 on a ten point scale.

It is seen from the above ratings that the Distinguishing shape, Simple-Cursive font and black color is the effective combination for this type of logo design.

Case IV *Food Industry logo*

Various Food Industry logos were studied and some of them are as shown in Table 5 and given a rating from 1 to 10 on a ten point scale.

Table 2 Order of ranking of effectiveness for automobile Industry

Automobile industry	Shape	Font	Color	Rating (point)
1. BMW	Circle	Non-serif	Blue, black and white	10
2. Mercedes Benz	3 pointed star	Uncomplicated typeface	Metallic grey	09
3. Ford	Oval	Cursive style	Blue	08
4. Renault	Rhombus	Simple bold	Yellow	07
5. Mitsubishi Motors	3 equally shaped diamonds	Simple	Red	06
6. Fiat	Letter mark	Improper typography	Red	05

Table 3 Logo Effectives of beverage industries

Beverage industry	Shape	Font	Color	Rating (point)
1. Pepsi	3-Dimension globe	Simple, roman, italic	Red and blue	10
2. Coca Cola	Rectangular shape/ circular	Cursive style	Red and white	8

Table 4 Logo effectiveness in sports and shoe wear industry

Sports and shoe wear industry	Shape	Font	Color	Rating (point)
1. Nike	Swoosh icon	Simple	Strong black	10
2. Adidas	3 parallel lines	Simple bold	Black	8

Table 5 Logo effectiveness in food industry

Food Industry	Shape	Font	Color	Rating (point)
1. Mc Donald	2 golden arches	Simple font	Golden and red	10
2. KFC	Mascot	Simple bold	Red	8

It is seen from the above ratings that the Distinguishing shape, Simple font and Golden-Red color is the effective combination for this type of logo design.

5.4 Analysis of Good and Bad Logos

Rating among good and bad (which also includes complicated) logos on the basis of elemental standards and given rating from 1 to 20 point scale where simplicity, relevance Quality and Appropriateness contributes a maximum of 5 points each.

Good Logos

Automobile industry	Simplicity	Relevance	Quality	Appropriateness	Rating (point)
1. BMW	4	5	5	5	19
2. Mercedes	5	3	5	3	16
3. Jaguar	3	5	5	5	18

Bad Logos

Automobile industry	Simplicity	Relevance	Quality	Appropriateness	Rating (point)
1. Honda	4	2	2	1	09
2. Hyundai	4	1	2	1	08
3. Toyota	2	2	3	1	09
4. peugot	3	5	2	1	11
5. Porshe	1	2	4	1	07
6. Cadillac	1	2	3	2	07
7. Scania	2	1	3	1	07

(a) (IRS, London Olympics) **(b)** (Honda, Toyota, Hyundai, Subaru)

Fig. 7 Bad logos. **a** IRS, London Olympics. **b** Honda, Toyota, Hyundai, Subaru

Examples of bad logos (Fig. 7).
Bad logos are characterized in various shapes and font.

- Unable to recognize the logo as to which domain it belongs.
- The use of too many shapes used together makes logo very difficult to comprehend.

6 Set of Guidelines

(a) **Guidelines for selective most effective shapes for logo**

- Prefer circular or oval shape that can quickly and easily be seen.
- Tall and skinny or overly wide format may take longer for the human eye to see and recognize the information.
- Avoid controversial icons and shapes. For example Swastika is widely accepted in India but abhorred in the West. Use rectangles over squares.

(b) **Guidelines for selecting most effective fonts**

- The theme of your logo is important in deciding what font to be used.
- If it is a more futuristic logo, stick with sci-fi fonts.
- For legal firms and manufacturing industry choose simple neutral fonts like Arial, Sans, etc.
- Avoid using italics for manufacturing sector.
- Choose the size of the text such that it does not overwhelm the icon.
- Complicated fonts (like grunge or fancy fonts) either don't look good or are illegible when they are too small so consider the size of the text while choosing font.

(c) **Guidelines for choosing most appropriate color**

- Universal use of green, yellow/amber, and red to label safety status.
- Avoid using green for automobiles and manufacturing.
- Blue is the best color for automobiles followed by red.
- Do not use more than two colors.
- The contrast between text and its background shall be sufficiently high to ensure readability of the text.
- In all cases the luminance contrast and/or color differences between all symbols, characters, lines, or all backgrounds shall be sufficient to preclude confusion or ambiguity as to information content of any displayed information.

(d) **Guidelines for effective logo design**

- Identify what kind of product the logo is for and its area.
- Benchmark the competitors, 'project budget' for the logo.
- Identify the most important thing the potential customers should think of while looking at the logo.
- Find out all potential implementations of the logo design letterhead design, business card design.
- Choose the right shape, font and color based on the respective guide lines.

7 Conclusion

The study reveals that effective logo design adheres to seven elemental standards that all designers should be aware of. These principles may serve as key elements for judging whether the design and style systematically delivers the message to its potential audience. Degree of logo effectiveness is based on its simplicity, versatility, memorability, relevance, timelessness and quality. For a Logo design to be effective shape factor (S) Color factor (C) and Font factor (F) and Human Perception Factor (P) must be considered while designing. Also a set of guidelines for effective logo design have been developed.

References

1. Chakrabarti A, Kumari MC (2011) Structure sharing on logo design ICoRD 2011 international conference, Indian Institute of Science, Bangalore, pp 838 ISBN: 978-981-08-7721-7
2. Kohli C, Suri R, Thakor M (2002) Creating effective logos: insights from theory and practice. Bus Horiz 45(3):58–64
3. Hem LE, Iversen NM (2004) How to develop a destination brand logo: a qualitative and quantitative approach. Scand J Hospitality Tourism 4(2):83–106
4. Bottomley PA, Doyle JR (2006) The Interactive Effects of Colors and Products on Perceptions of Brand Logo Appropriateness. Mark Theory 6(1):63–83
5. Doyle JR, Bottomley PA (2004) Font appropriateness and brand choice. J Bus Res 57(8):873–880
6. Abdulaziz S Consumers perception of rebranding: case of logo changes. Ph.D Thesis
7. Fang X, Mowen JC (2005) Exploring factors influencing logo effectiveness: an experimental inquiry. Adv Consum Res 32:161
8. Walsh MF, Page KL, Mittal Vikas (2006) Logo Redesign and Brand Attitude: The Effect of Brand Commitment ACR 2006 Conference. September Orlando, Florida
9. http://www.logobird.com/the-principles-of-good-logo-design/
10. http://www.johnnyflash.net/creative-and-effective-logo-designs/

Effect of Historical Narrative Based Approach in Designing Secondary School Science Content on Students' Memory Recall Performance in a School in Mumbai

Sachin Datt and Ravi Poovaiah

Abstract Use of Narratives for teaching science and technology at secondary school level has gained strength in recent years. Many approaches and explorations have been done by researchers like Arthur Stinner, Aaron Isabelle, Stephan Klassen and Yannis Hadzigeorgiou. With the spirit of extending existing work in domain of teaching science using narratives, a General Narrative Schema, (also known as Epistemological Narrative Schema or ENS) for describing a scientific inquiry event in context of cultural tradition of science was developed to assist secondary school science content writers in designing narratives to be used for explaining science concepts. Control group experiments were conducted with secondary school students in Mumbai to test the effect of ENS on certain aspect of science concept learning. The control group was taught using lesson from their existing text book while the Experimental group was taught the same content but modified and delivered in the Form of a Narrative designed using the Epistemological Narrative Schema. The posttest for evaluating difference in short term memory recall of students of the delivered lesson showed significant difference in the mean score of Experimental group versus the Control group. The experimental group scored significantly better than the Control group in Posttest results. This experiment strengthens the case for introducing narrative based approaches for designing science lessons at secondary school level.

Keywords Narrative · Epistemology · Science curriculum · Content design · Independent sample t-test

S. Datt (✉) · R. Poovaiah
Industrial Design Center, Indian Institute of Technology, 400076 Powai, Mumbai, India
e-mail: sachindatt9@gmail.com

R. Poovaiah
e-mail: ravi@iitb.ac.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_23, © Springer India 2013

1 Epistemological Narrative Schema and a Brief Justification for Its Development

In order to find the relation between Narrative structure and scientific inquiry event, a search into literature on Theory of Knowledge, Theory of Learning and Theory of Narratives was commenced. The final outcome of the search was the development of the Epistemological Narrative Schema. This framework is meant to assist content developers in designing science lessons in a Narrative format by having a better understanding of the scientific process of knowledge creation. The final outcome of this research was development of the Epistemological Narrative Schema.

A search into theory of knowledge and specifically the work of John Dewey revealed that Science is a narrative process with certain discrete events distributed in the five step general narrative structure defined by Existing Situation, Doubt, Reasoning, Suggestion, and New situation. It was realized through further search into Theory of Knowledge, that the components given above are linked with some other components associated with a scientific Inquiry.

The basic five steps in Narrative schema of science have further divisions and the overall components of a scientific inquiry process are believed to have the following constituents (Fig. 1):

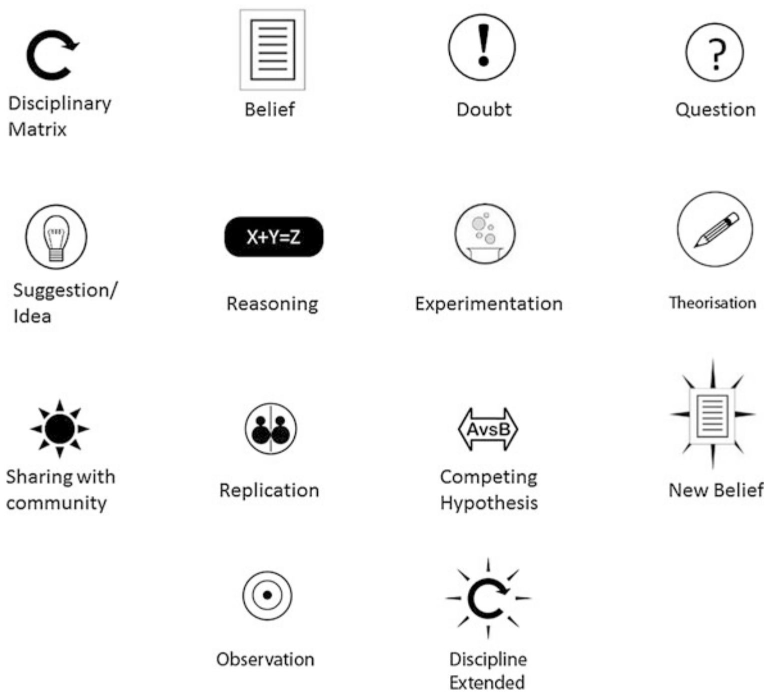


Fig. 1 Components of a scientific inquiry event in context of a scientific community

The first point of justification is supported from John Dewey's explanation of the Narrative nature of a scientific inquiry event. The narrative schema presented in Fig. 2 is an extension of the Narrative process of a scientific inquiry presented by John Dewey. Dewey's schema of a scientific inquiry is given in Fig. 2.

> John Dewey went as far as to believe that the 'reality' itself which philosophers and scientist have been attempting to understand (since birth of cognitive abilities in the human mind in prehistoric ages), is essentially Narrative in nature. Dewey believed that something appearing as permanent and rigid as a mountain, in a geologist's reality, is a scene of a drama of birth, decay and ultimate death. A flash of lightening to a layman may appear as a single event but for a scientist has a prolonged narrative history, with the growth of science, the tale of why lightening happens, becomes longer [1].

The second justification for believing in the truth of Epistemological Narrative Schema presented in Fig. 1 comes from the picture of a scientific community painted by Thomas Kuhn in his papers on *The Structure of Scientific Revolutions.* Kuhn explained that the compilation of a theory is not one person's work. Development of scientific ideas is directly related to the organization of the scientific community as a whole with its tradition of common language for knowledge sharing among members of a community within the context of a particular paradigm or disciplinary matrix [2].

The two ideas of the role of individual research and the role of a social community in advancement of science can be seen from another point of view which is presented in literature on Theory of Learning. Piaget's Constructivist theory of learning can be compared with an individual's process of acquiring knowledge in the four step process of Existing Schema (Assimilation), Expectation breaking event, Adjustment of new information into existing schema through Accommodation and the establishment of New Schema [3]. However, constructivist theory is limited to an individual's learning process. This limitation is rectified in Vygotsky's theory of social constructivism where learning is also a function of the socio-cultural environment in which the student learns which not only includes the teacher but, friends and family background [4]. For these reasons, the cultural aspect of science and its routine ways of sharing knowledge through community presentations and publications are part of the Epistemological Narrative Schema.

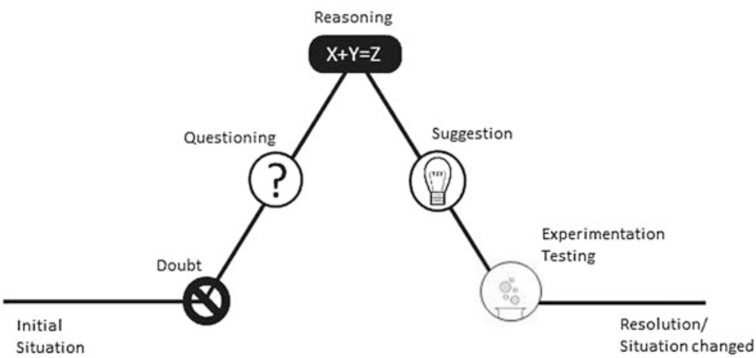


Fig. 2 John Dewey's narrative process of a scientific inquiry (Dewey, 1955, p. 105)

2 Existing Literature on Experiments Conducted for Testing Story Based Teaching Methods in Science Learning

Kokkotas et al. [5] conducted experiments in teaching the concept of Electricity and Electromagnetism with sixth grade primary school students to test the impact of a narrative based teaching intervention. The authors believe that telling a coherent story may be best way of learning, remembering and re-telling of science. They conducted a study in which the objective was to access impact of storytelling on student learning of Electricity and Magnetism. Within this, they wanted to study the impact on three factors (a) Importance of evidence and creative thought in the development of scientific theories (b) Consider how scientific knowledge and understanding need to be supported by empirical evidence and (c) Relate social and historical contexts to scientific ideas by studying how a scientific idea has changed over time. Their experiment result showed significant effect on student's learning on these factors after the narrative based teaching intervention.

In another study Casey, et al. studied the impact of story telling technique in teaching geometry skills to kindergarten students. Their experiment result showed a significant improvement in the performance of student. They also found that the impact of story intervention was greater on girls compared to boys [6]. A comparative study was done between the experimental group which was given story telling context and geometry component intervention and the control group which was only given the geometry component intervention. Their results showed significant improvement in the learning of students of the experimental group.

Cunningham set up an experimental design to test the hypothesis that narrative text structure would be more interesting than expository text structure and would motivate in learning. It was conducted on five secondary school classes with a lesson from history textbook. The results did not show any significant difference in the students' level of performance among the control and experimental group however they showed positive attitude towards the narrative text over the expository text [7].

3 Design of Experiment for Testing Effectiveness of ENS on Short Term Memory Recall: Experiment No. 1

The experiment was mainly centered on testing recall of chapter content after lesson delivery. We would like to differentiate between recall and rote memorization. In rote memorization, repeated exposure to material to be memorized is given. While short term memory is a cognitive process, which does not include repeated exposure. The recall in these experiments confirms a cognitive process rather than rote memorization as the students have to answer questions within a few seconds after only one recitation of the lesson. According to Bloom, 'remembering' is at level one of bloom's taxonomy of cognitive domains [8]. Hence, one can say that whatever the students recall after the lesson, it is due to some degree of cognition of content rather than rote memorization.

3.1 Experiment: Aims and Objectives

Objective of experiment was to find the difference in short-term memory recall of students who were taught with chapter designed using the ENS approach against those taught with current NCERT textbook approach. A study was conducted on class VII students from Powai English Medium School at Powai, Mumbai. Two sections of the same class very selected. One section was treated as the Control group, the other as the Intervention or experiment group. The control group had 52 students and Experiment group had 50. The experiment was performed in the natural classroom setup during the regular school hours. The experiment was conducted by a third person, the researcher collected data in the form of response to achievement test.

3.2 Design

The study was a between group design comparing two types of lesson delivery approach namely Current NCERT Textbook versus Chapter designed using Epistemological Narrative Schema. The science content to be taught was chapter on electricity taken from class VII NCERT book. A single variable design was adopted for this experiment where effect of one independent variable was tested on the dependent variable Fig. 3.

Following is the description of the variables.

Teaching Method (Textbook Based TB or Story Based) = Independent Variable

Achievement Score = Dependent Variable

Operational definition of each variable is as follows:

Teaching method is the way a lesson is delivered to a group of students. Textbook based (TB) teaching method means that a chapter from current NCERT textbook is taken as it is and is read out to the students. The Textbook based independent variable constitutes the control group. Story based (SB) teaching method means that the lesson was delivered in the form of a narrative. The significance of difference in the mean score of both achievement tests groups was calculated using independent sample t-test, which is the index used to find the same [9]. The test is called independent because there is no relationship between the control and experimental groups.

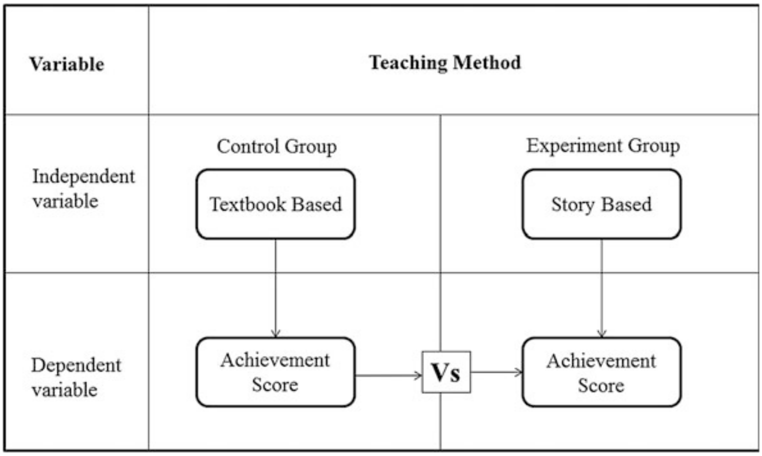


Fig. 3 Pretest-posttest nonequivalent control group design

3.3 Material and Procedure

Each group was delivered a lesson from a class VII NCERT textbook on electricity and how the Voltaic cell came into being. The layout and font size of both the chapters were kept the same. The lesson was taught to each group from their respective booklets. The same instructor read out the chapter to the groups on two consecutive days. The group which was chosen for experimentation had no prior exposure to the contents of the chapter. This was ensured through a screening test. The achievement test was evaluated by giving scores to students on each correct answer.

3.4 Instrument: Achievement Test

An achievement test in the form of a set of long and short essay type questions was given to both the groups before and after the lesson delivery. The achievement test was meant to measure the difference in mean performance of Control versus Experiment group. To find if the difference was significant, an Independent sample t-test was conducted with the help of SPSS software. The long essay type question simply asked the students to write the summary of chapter on Electricity in their own words in the case of Control group while the Experiment group was asked to write the story of Volta and the Voltaic cell in their own words. The short essay type question were a total three in number the first question asked the structure of Voltaic cell and What a Voltaic cell is made of? The second question was, What is the use of a Voltaic cell. The third question was to cross check with the second question whether the response was result of understanding. So it was the reversed form of second question which is how electricity could be generated. Same questions were given before and after the test to know the difference in response. The pre-test was meant to check their prior knowledge of subject which was supposed to be none as the chapter on electricity is taught to class 8th student and the test was given to class 7th. So the pre-test confirmed that they had almost no prior knowledge of the subject matter. So we can assume that the difference in post test would be because of the lesson delivery alone. The Subjective essay test questions prepared were from the list of 16 types of questions in textbooks of science outlined by Francis D. Curtis [10].

3.5 Results

The independent sample t-test was performed two times to know about two different aspects of the experiment outcomes. These two type are:

1. Score difference in mean of all Short essay type questions taken together.
2. Score difference in Long essay type question
1. The mean score for Short summary type for NCERT was 3.2 (out of 15) while for Experimental (Story group) was 6.3 and the difference is significant at $p < 0.001$ with confidence level of 95 %. The data is shown in Table 1.
2. The mean score for Long summary type for NCERT was 0.54 (out of 8) while for Experimental (Story group) was 3.88 and the difference is significant at $p < 0.001$ with confidence level of 95 %. The data is shown in Table 2.

3.6 Interpretation and Discussion

Since the achievement score on recall is significantly higher in the Experimental group, it can be concluded that the effect on student's recall because of story intervention is significantly higher than the control group. This implies that students were better able to remember the concepts in STORY group as against the NCERT group. This is not only true for Short answer essay type, but also for long answer essay type question. Within short essay type question, the question about the structure of voltaic cell has received almost equal response from both the groups that is because there is no significant difference in this case between the groups. The score of short answer type questions is significantly higher for STORY group because of significant mean difference of question two and three.

Table 1 Mean difference is significant at $p < 0.0005$ for short essay type test with Powai school

Group	N	Mean	Std. deviation	t-test Sig. (two tailed)
NCERT (control group)	52	3.201	2.751	0.000
STORY (experimental group)	50	6.300	3.157	

Table 2 Mean difference is significant at $p < 0.000$. Long essay type test for Powai English medium school

Group	N	Mean	Std. deviation	t-test Sig. (two tailed)
NCERT (control group)	52	0.538	0.821	0.000
STORY (experimental group)	50	3.880	2.791	

The mean of Story group is significantly higher than the NCERT or control group. However since the std. deviation is also positive, the curve seems to slide towards the higher side of mean. This means that a higher mean may be caused by few students scoring exceptionally well. The reason of this could be that students with good writing ability may be in a better position to write the answers while those with poor writing abilities may be at a disadvantage in answering the questions. Even in the story group, students with poor writing abilities may have scored low. An additional oral test might give a better picture of overall student performance.

4 Conclusion

A significantly increased performance in short term memory recall does not absolutely validate that narratives designed using Epistemological Narrative Schema enhance overall cognitive development of students, however it does indicate that Narrative approach to lesson design may be enhancing some level of cognitive development. Separate set of experiments need to be designed to test whether student's other cognitive skills like reasoning and understanding are also effected in the same way as short term memory recall. Testing of such skills can be done by allowing students to design Narrative to explain evolution of a concept using the constituents of scientific inquiry event as presented in the Epistemological Narrative Schema. The content of narratives designed by students can reveal their level of reasoning and understanding of a science concept. The experiment strengthens the case for organizing secondary school science lessons in the form of narratives of evolution of scientific concepts.

References

1. Dewey J (1955) Logic: The theory of Inquiry. George Allen & Unwin Ltd., London
2. Kuhn TS (1962) The Structure of Scientific Revolutions. In: Kuhn TS (ed) International Encyclopedia of Unified Science Vol 2. The University of Chicago Press,Chicago
3. Leonard DC (2002) Learning theories, A to Z. Greenwood publishing group, Westport
4. Ivic I, Vygotsky LS (1994) UNESCO: International Bureau of Education, vol 24(3/4), pp 471–485

5. Kokkotas P, Rizaki A, Malamitsa K (2010) Storytelling as a strategy for understanding concepts of electricity and electromagnetism. Interchange 41(4):379–405
6. Casey B, Erkut S, Ceder I, Young JM (2008) Use of a storytelling context to improve girl's and boys' geometry skills in kindergarten. J Appl Dev Psychol 29(1):29–48
7. Cunningham LJ, Gall M (1990) The effects of expository and narrative prose on student achievement and attitudes toward textbooks. J Exp Educ 58(3):165–175
8. Bloom B (1956) Taxonomy of educational objectives, Handbook I: the cognitive domain. McKay Co Inc., New York
9. Ary D, Jacobs LC, Razavieh A (1972) Introduction to research in education. Holt, Rinehart and Winston, Inc., New York
10. Ebel RL (1966) Measuring educational achievement. Prentice-Hall of India Private Ltd., New Delhi

The Home as an Experience: Studies in the Design of a Developer-Built Apartment Residence

P. K. Neelakantan

Abstract The developer-built apartments in Mumbai are advertized as ultimate symbols of iconic lifestyles. Referred to by evocative names, these are self-sufficient, gated microcosms. These advertisements claim uniqueness in terms of amenities; each attempting to outdo the other by projecting a more exclusive lifestyle. They declare: Purchase houses, acquire lifestyles. This paper intends to examine the relationship between lifestyle conception and house composition. A case-study of the design process of an apartment-housing project in Mumbai offers insights into this lifestyle-architecture combination at the moment of conception. The assumption here is that the space and moment of design allow unselfconscious forms to become apparent and be subjected to interrogation. Also, design itself might offer critical positions to view the relationship between *where we live* and *how we live*. The results of the case-study analysis point to how *new* lifestyles require the incorporation of *other* diverse spaces usually never associated with urban residences. The shape of this lifestyle emerges in the form of the super-built-up space, beyond the individual dwelling unit; the *value-addition* space that belongs to all and none in particular. A particular lifestyle-architecture configuration also seems to posit specific relations between the individual dwelling unit, the collective apartment and the urban neighborhood. Also brought forth is the underlying assumption of aesthetic congruence between lifestyle and house design.

Keywords Housing · Architecture · Experience · Lifestyle

P. K. Neelakantan (✉)
Industrial Design Centre, Indian Institute of Technology Bombay Powai, Mumbai, India
e-mail: neel.blu@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_24,

1 The Apartment-Block

As a type, the apartment-block is a single 'house' belonging to a community of dwellers. This house is further divided into smaller dwelling compartments called flats. It can also be thought of in terms of a vertical stack of a series of peculiarly interior 'houses' called flats having different owners. The type is an interior structure of a form/principle. It is capable of shared meaning and infinite variation. Therefore the tension between invention and form would be evident in the manifestation of any type.

What role does the house play in the apartment-type? This question also pertains to the relationship between the house-space and the home-space. The house-space is part of the material-spatial realm, in comparison to which the home-space is the more amorphous socio-politico-economic realm. Various relations have been posited between the house and the home: the house as a register of socio-cultural changes in the home-notions/practices [1]; as a place-bound aspect, the house acts like a geographic centre for the inhabitants [2]. The household in the form of the fusion of the house and the home, has been considered a socio-political unit [3]. The house has been also seen as a container of deep structures of the home [4]. If territory is the critical distance between two beings of the same species [5], the house also maintains territory through a number of elements like floors, walls, gaps, stairs, passages, etc. The act of housing is thus a complex act, and it depends upon how it decides/intends to receive the home-space. This would also mean imagining the home-space in advance.

The background for the question is this: In urban India, for instance in Mumbai, the phenomenon called apartment-block, predominantly involves someone else (the developer) in building the house. This house is purchased and then made into/called home. In Urban India, especially metropolises like Mumbai, the notion of the home cannot be thought of without bringing to mind images of both the vertical stack of compartments called the apartment-block and the horizontally dense slums. Mumbai in the recent times has witnessed a spate of developer-built housing. Referred to by evocative names, these are usually either a single or group of tall residential buildings. While the slums have been discussed extensively with respect to their development, homelessness, etc., there is dearth of literature on the home in relation to the apartment-block itself.

2 Designing Housing

Architecture brings into being types of dwelling [6] —an ordering and diagramming of the social. The architect's role is to transform this ideal diagram into a physical model. Design is an intentional, strategic and calculative practice. It is a moment of conceiving and assembling. It would thus offer an insight into the vectors that would actualize the house. The designing of housing would allow unselfconscious forms to become apparent and be subjected to interrogation. Design practice requires that the forms of sociality and home be mobilized, thought about, reinforced, altered, articulated, translated, and reflected upon. This paper wishes to study the 'designing' of housing which would allow the house to be seen as an aggregate of multiple parts. It would bring forth the concerns associated with each part. The biggest challenge is the home as an affair of prospective inhabitants. It's personal, intimate and unique nature poses a challenge to the mass-housing nature of developer-built apartment residences.

3 Apartment Layout: A Case

The negotiate tactics of 'housing' are examined, through the case-study of the design process of an apartment-housing project in the city of Mumbai. A reputed architectural firm in the city, offering design solutions in areas of architecture, urban design and interior design, had been invited to compete, by one of the well-known construction companies and developers, for the design of a residential apartment-complex in a central suburb of Mumbai. This of course limits the case to the conceptual, master-plan level, at the cost of detailing the individual unit.

The developer's brief to the architects, other than providing details of the location, land and amenities to be provided, also highlights the development philosophy and theme. It discusses the historic aspects of the site, highlighting its intention to restore and integrate some of the existing architectural elements. Also attempted is a profile outline of prospective inhabitants. The brief describes the immediate surroundings as being 'not up market and having small towns look', devoid of 'high' structures and planned development. What is expected is a spatial remedy for this place. To compensate for the mundane surroundings, therefore, they demand an 'iconic' architecture and landscape to produce a 'feel of being in a different world' to attract prospective inhabitants.

The project site of approximately 25 acres is a redundant textile mill compound, located in a suburb of Mumbai. The amenities comprise of common facilities for Health, Sports and Leisure, which include Olympic size swimming pools, gymnasiums, skating, amphitheatre, etc. The project components include residential, substantial built-to-suit offices, convenience retail, school and auditorium. The residential mix consists of 2, 2.5, 3 and 3.5 bhk, (the unit areas are extremely well-defined—the external areas are not so well-defined). The time period allotted to them was about three weeks. The firm put four senior architects on the job. They produced one alternative each for the project (see Fig. 1). All the designs went through a process of iterative refinement and detailing. This happened through the team's discussions with and guidance from the chief architect. All the important design decisions were taken through a discursive process where every one of the team members was present. The researcher had access to all the formal discussions. He had a contact person in the architectural firm, a senior architect engaged in the project. It was at his behest that the researcher was

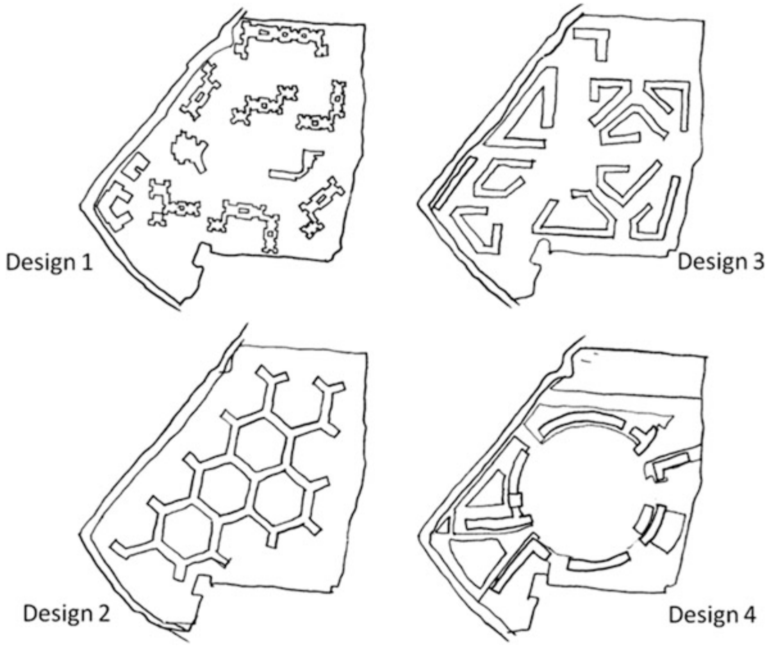


Fig. 1 Diagrams showing the four alternative schematic plans for the apartment-complex. *Source* Author

permitted into the meetings, to make notes of the discussions and access the work being prepared for the presentation.

These discussions were studied for how the 'role of the house' was being thought about. In the design-process, since the house is being thought about in the multiple, the discussions on the role of each of these parts were also examined. The analysis of the material provides us with the following three themes: Spacing's, which deal with the distributions of architectural space, especially between the individual dwelling-unit and the collective housing. Placings are about the entexturing of the spatial distribution through place-making. Ambiences engage with the quality of immersion in the space of architectural containment.

4 Spacings

The design team's conceptual framework involves categorizing space into micro-meso-macro scales. It ranges from the individual dwelling unit (micro) to the apartment-complex (macro) respectively. This scaling shows the interior-flat's intimate relationship with the flat-collective and of the project to the city. For instance, through the 'views', the individual unit possesses the vast community space laid out ahead. The view has to be 'housed' in the apartment-block. The view is a linkage between the individual dwelling unit and the community space constituted by the super-built-up. The tension between the two brings out the dialectical nature of privacy and the necessity of articulating it differently for different contexts.

Conventional practices are not only employed in evaluating the design alternatives, but are themselves questioned and redefined. For instance, 'is the balcony private or semi-private?'—this was the subject of a significantly intense debate. The argument for privacy was based on the point that the dwelling unit was private space. The argument for 'semi-privacy' claimed that the balcony looked onto the public space because of which it wasn't really private. The glass-house was the highlight of the above discussions. One member of the design team, as part of the public versus private argument, wondered aloud: Is a glass-house private or public? This was posed as a hypothetical, designerly manner of questioning in order to grasp architecturally, the terms of the private–public dialectic and territorial interface. The glass house question is posed as a special, exaggerated scenario emerging from the private autonomy of the individual flat-house. It pits the 'one' against the collective. The tension between the one and the collective, is brought into play through this question. Emerging from the practices of spacing as against that of locality/place, the absurd glass-house question interrogates place-based conventions. The hypothetical glass-house question, by challenging the inside-outside, private–public dialectic, challenges the apartment-block typology itself.

The concern for 'active' streets or 'streets for interaction' emerges from the desire to house a community. The notion of an average occupant is at work when the community is discussed. The attempt is to discuss specificities in terms of an average, or a group of people who for instance, "celebrate festivals like Ganesh Chaturthi" or "spend time in coffee shops". The design discussions reveal that the architects not only work with a certain notion of the average inhabitant ('people in Mumbai, 'people in India', 'people here', etc.), but also with that of the stereotype ('Mr. Tendulkar', 'Mr. Shah', etc.) employed in terms of its 'difference' with the average. This housing can be thought of at two levels: one at the more form-based, affordance-level, generic aspect, and the other which is more culturally nuanced. Much of the discussions refer more to the anthropomorphic figure than the cultural figure. This use of the anthropomorphic figure, allows certain architectural 'aesthetic' of form relatively autonomous of the milieu. It is an abstraction not colored by culture. This concern regarding the apartment's belongingness is also evident in their intention to move away from depicting inhabitants in the manner in which they are depicted in the developer's brochure—as slim, fit, young, foreign-looking couples. They wanted to put 'real people'; people from 'here' in the images. They referred to a free online repository of Indian, non-model-like, ordinary-looking people to characterize the residents.

5 Placings

Since place is something that happens through inhabiting, here it is employed as a semantic device. It fleshes out the spatial structure. It creates ‘effects’ of place. These places are meaning-chunks. They contribute in creating atmospheres. The effort by the group was to create the effect of place in/on the apartment-block. The intention was to bring ‘places’ into and contain it within the home-world. Actual non-residential places (like Kala Ghoda, Azad Maidan, etc.) are referred to depict the quality of spaces to be included in the housing design. According to Tuan, architects discuss space and place interchangeably [7]. The attempt seems to be to incorporate the attributes of these places, like a patchwork of places. The apartment-typological aspect of design is more space-based. The domestic aspects dealing with the home-notion are dealt with at the level of place. The spatial organization could question, innovate and also threaten place-based practices. Boundaries also were the subject of heated debates. The arguments around the decision to allow a public shopping street right through the private residential area are an example. In this sense, the technical-spatial aspect of the place and the private home-nature, especially in apartments might be at odds with each other [8]. For instance, lamenting on the market-based neutrality and loss of identity that discourages place-bound architecture in Mumbai, one of the participant architects critiqued the ‘placeless’ nature of the apartment-complex.

By describing/naming space in terms of the ‘look and feel of a mohalla’ or a ‘mohalla-like space’, or the typologies of ‘here’, associations with certain patterns, places, activities, practices, people are evoked, providing meaning to the abstract geometrical aspect of organizing space. The historical architectural remnants of the factory and warehouses on mill land, were made part of the common public space and lifestyle and ‘shared’ amongst hundreds of dwelling units. As a fragment, it is not only a spectacle but also points to another place—like collectively owning a piece of history.

This focus on the outside is extended in the design team’s discussion with an environmental designer. When shown the site-plan on Google Earth, he asked for a zoomed out view so as to gauge the surroundings of the site. His proposal was to develop the space around the site. The fact that the environmental designer considers the surrounding area beyond the site for development makes it seem like the super-built-up would go one-notch to become a *super* super-built-up area!

6 Atmospheres

Different ways of organizing/distributing the dwelling-units lead to different shapes of super-built-up area. The intention of the team was to present a ‘menu card’ of spaces corresponding to distinctive ‘spatial qualities’ and multiple lifestyle options. As a mark of spatial distinctiveness, they refer to American Architect

Steven Holl's work in Netherlands and the residential project 'Amanora' of the Dutch firm MVRDV in Pune. The chief architect hints at the fact that the 'extra' value-addition in the form of amenities in the super-built-up space would help in differentiating from other such projects in the market. Given most interior-flat layouts across various residential projects are the same (2, 3 bhk), he suggests that the real space of distinction would be the super-built-up, and the corresponding lifestyle offered.

The current trend of separation and hiding of the service space (plumbing, electrical, etc.) and its disadvantages were discussed. The service-space as being squeezed out of the visible sphere and relegated to the infra-structure (the structure which is not seen). They also observed a shift in the trend from 'Hafeez-like frills' (Hafeez Contractor is a very popular architect in India known once for his very ornate style of architecture) to amenities—from a visual to an experiential aesthetic; from an ornamental to a more diffuse, subtle effect. This directly points to the shifts in what has to be 'housed' for a particular lifestyle. The image ability of the project rests on capturing this aesthetic. According to a team-member, a 'walk-through', for instance, simulates the quality of space—the 'inter-building' and the 'intra-building' spaces—revealed through strategic positioning of 'camera angles'. Three-dimensional walk-throughs with 'some music' would act as an experiential substitute for the spatial surround.

The architectural solution tucks in the infrastructural services like plumbing and electricity. But it also attempts to incorporate services which manage the household. This service space is integral to generating a truly leisurely, conflict free, smooth space. This structural sorting, frees up interior space from the technicalities of territory. It opens it up to various ambient expressions. Towards the more expressive aspects of atmospheric manipulation, opens it up to all kinds of ambient expressions. Sightlines and views strategically constitute the relationship between the landscape and the interior as that of foreground-inside thus interiorizing the scenic outside. Owned interior-out, since the foreground is an extended interior, the apartment-complex induces in each individual unit, a sense of possessing more than its share of super-built-up space. Township developments are ways of interiorizing the city/urbanity.

The advertisements attempt to depict this ambient aspect. The image has to convey or rather perform this ambience. Lifestyles are a certain way of being immersed in that space. Therefore, the lifestyles, part of the placings ultimately are a performance of this ambience. The discussion on the 'complexion of space', the 'quality of space', and the 'richness of space' point to the experiential dimension of space. The richness of space means that the multiple employment of the same space is possible. The complexion of space also points to these multiple elements. The larger complexes, the more the collective space and the more the thought that can be given to the atmosphere.

7 Spacings, Placings and Atmosphere

An underlying assumption seems to be at work in the above discussion—that of the ‘everyday’ being too close and too normal to be considered spectacular. The home’s association with the everyday would also make it seem non-spectacular. Special experiences are not usually identified with the everyday. An attempt is made to bring this special feeling into the everyday. So, one doesn’t have to ‘seek out’ an experience. The experience could be simply had at home. The intention of the housing seems to be to offer a ‘new’ place, and thus a ‘new’ lifestyle; the exciting possibility of new habit-formations, along with the maintenance of some old ones. The aim is to provide an ‘out-of-the-world’ experience—the conception of a self-sufficient and complete world, everything within convenient reach. The housing thus attempts to bring the new experience indoors. The home as much as it is a place for possessions, is also a space that is possessed. In this case, the house-composition allows for the possession of new experiences. So the apartment-complex has to project the containment of a world of experiences.

The case-study discussions also engage with the shifting formal stylistics—the fact that the experiential aspect is more contemporaneous than the surface decoration on the façade of the built-form. The packaging of cities as commodities produces the city as a set of scenographic sites, a ‘non-place urban realm’—a sovereign space of atmospheric effects [9]. The apartment is a similar scenographic site promising intense experiences. The space of being together is articulated in terms of ‘new’ experiences of hyper-leisure. The housing thus assembles new experiences pieced together from various fragments and place-effects. The dweller is encouraged to incorporate the spectacular ‘other’ spaces and programs into how he lives and discover ‘out-of-the-world’ experiences in his own home. This ingesting of the extra-ordinary within the ordinary space of the everyday life is intensified in the space-choked urbanity of Mumbai. Through the common space and all the amenities (‘no need to go out during the holidays’ says a developer’s hoarding), the city is also interiorized, domesticated, made ‘homely’.

Bhartiya Group, DLF, and a host of other developers are planning townships which are ‘integrated’, ‘futuristic’ and ‘well-managed’ across the country. These developments claim to have dedicated green spaces. There are many manicured urban villages sprouting across the country in the outskirts of the city. These are fashionably gentrified enclaves. They are projected as idyllic. They are marketed furiously. They assure a variety of lifestyles. The individual gated community property developments (single apartment-blocks), unlike the township, lack the infrastructure to provide the ‘experience’ of lifestyle. The larger the common collective spaces, the greater the possibility of ambient, immersive modes of housing.

Acknowledgments I would like to acknowledge Uday Athavankar, under whose able supervision this study was conducted. I would also like to thank Nina Sabnani, Ramesh Bairy, Sharmila Sreekumar and Kushal Deb for having contributed significantly to the development of this study.

References

1. Srinivas T (2002) Flush with success: Bathing, defecation, worship and social change in south India. Space and Culture 5(4): 368–386 http://sac.sagepub.com/content/5/4/368.full.pdf+html
2. Dovey K (1985) Home and homelessness: introduction. In: Altman I, Werner CM (eds) Home environments, human behaviour and environment: advances in theory and research, vol 8. Plenum Press, New York
3. Saunders P, Williams P (1988) The constitution of the home: towards a research agenda. Hous Stud 3(2):81–93
4. Hillier B, Hanson J (1989) The social logic of space, Cambridge University Press, Cambridge
5. De Landa M (1995) Homes: meshwork or heirarchy? Mediamatic http://www.mediamatic.net/page/5914
6. Nesbitt K (1996) Theorizing a new agenda for architecture: an anthology of architectural theory 1965–1995, Princeton Architectural Press, New York
7. Tuan Y (1977) Space and place: the perspective of experience, University of Minnesota, Minneapolis, pp 1–10
8. Kaika M (2004) Interrogating the geographies of the familiar: domesticating nature and constructing the autonomy of the modern home. Int J Urban Reg Res 28(2):265–286
9. Ruthesier C (1996) Imageneering atlanta: making place in the non-place urban realm, Verso, London

Meta-Design Catalogs for Cognitive Products

Torsten Metzler, Michael Mosch and Udo Lindemann

Abstract This paper presents a concept of meta-design catalogs for cognitive products. Mechatronic and cognitive products usually demand multidisciplinary hardware and software solutions and while catalogs exist to support domain specific-design, to date there is no support for finding non-obvious and alternative solutions for cognitive products. The meta-design catalogs for cognitive functions proposed in this paper provide a link between abstract functions and hardware/software making it possible to find non-obvious and alternative solutions. They also make re-use of existing solutions possible by abstracting from the specific to an abstract pattern.

Keywords Design catalog · Design pattern · Cognitive product · Cognitive product development

1 Introduction

Design catalogs and catalogs of design patterns, such as [1–3] were created to support engineers in finding non-obvious solutions, alternative solutions and to avoid inapplicable solutions or repeated solutions. They exist for different domains but address mainly domain-specific problems.

T. Metzler (✉) · M. Mosch · U. Lindemann
Institute of Product Development, Technische Universität München, Munich, Germany
e-mail: metzler@pe.mw.tum.de

U. Lindemann
e-mail: lindemann@pe.mw.tum.de

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_25, © Springer India 2013

This paper presents a concept of meta-design catalogs for cognitive products that is appropriate to classify all types of solution patterns and thereby helps to transfer cognitive functions, e.g. *perceive, learn, plan,* etc., into cognitive products enabling them to act in an increasingly intelligent and human like manner. Meta-design catalogs for cognitive products are necessary because cognitive functions currently are realized only through interdisciplinary solutions and can not be realized by domain-specific solutions alone. A complete decomposition of cognitive functions into elementary functions is not possible yet due to a lack of understanding of cognitive processes. Instead, solution patterns systematically stored in design catalogs provide the possibility to include knowledge of different domains and support the conceptual design of cognitive products because they can be re-used. By directly addressing cognitive functions a further decomposition into elementary functions is usually unnecessary.

After a brief definition of terminology, domain-specific patterns are compared with the aim to identify how design catalogs from different domains are structured, what they have in common and how they differ. Based on this, a holistic framework of meta-design catalogs for mechatronic and cognitive products and systems is derived. This structure includes different meta-design catalogs differentiated by the type of design catalogs, complexity and granularity. They are appropriate to classify all types of solution patterns and thereby help to transfer cognitive functions into cognitive products. To demonstrate how solution patterns can be identified in existing cognitive products and generalized for re-use in conceptual design of future cognitive products an example is presented. One solution pattern is explained at different levels of abstraction and allocated to the framework of meta-design catalogs for cognitive products.

2 Background

Design catalogs and catalogs of design patterns are information sources supporting the conceptual design process by re-using solutions. They help to find patterns that realize certain functions used in function structures and models describing a system- or product-concept. They exist in several domains and vary mainly by the functions they provide patterns for and their level of abstraction. Alexander et al. [1] say that "each pattern describes a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice".

In mechanical engineering, design catalogs are tailored to systematically support the conceptual product development process and have to fulfill the following requirements: quick accessibility of information, ease of use, customizability, integrity within given boundaries, validity, upgradeability and consistency [4]. They are subdivided in three categories according to [2–4]: object catalogs, process catalogs and solution catalogs. Object catalogs contain available objects, e.g. bearings and screws, and are independent from specific design problems. They do not contain all principle solutions for a design problem but describe objects and their characteristics generically. Process catalogs contain processes, rules and process steps and are related to objects. Each solution catalog contains a variety of patterns for specific design problems and constitutes a source for alternative solutions [2]. Obviously, the three catalog types are related to each other, e.g. objects of an object catalog can help to generate new patterns for a solution catalog according to a process described in a process catalog. However, one object may be included in several patterns in different solution catalogs and adaption may be possible using different processes.

Design catalogs in mechanical engineering have mainly been developed for elementary functions, e.g. to convert, to increase/decrease, to mix/separate, etc. because it is assumed that all functions can be decomposed into them [2, 3]. However, they also include frequently re-appearing functions [3]. Homogeneous internal catalog structures are important with respect to convenience and clarity [1]. Therefore, most catalogs are structured in a similar way. They consist of an index structuring the content, a main part describing the solutions and an access part explaining the properties of the solutions. Recent research extends the access part by adding disturbances and robustness ratios to physical effect catalogs in order to consider them in the conceptual design phase of a product while avoiding additional effort and cost [5].

The development of electric and electronic systems and products is, when compared to mechanical engineering, more object-oriented. In electronic systems, objects, e.g. resistors, transistors and integrated circuits, are stored in object catalogs. Solution catalogs in this domain contain for example adaptable circuit diagrams for operational amplifiers that amplify a differential input voltage to a much higher output voltage. General circuit diagrams in solution catalogs are adapted according to the particular problem by defining properties of basic hardware components, e.g. resistors and capacitors. According to design rules and processes that are stored in process catalogs (or even computer tools), for example the width of conductor lines or the spacing between lines can be calculated. These rules, processes and especially the tools allow inexperienced electrical engineers to design electronic components, for example "Very-Large Scale Integration Systems", because the design methodology is based on the electrical behavior of circuit elements [6] and universal design rules. It is assumed that design catalogs for electrical engineering can be structured like those for mechanical engineering due to the above mentioned characteristics even though only object catalogs were found.

In computer science, design patterns are considered re-usable elements of software supporting the conceptual software design. Patterns in object-oriented software provide generic solutions in terms of objects and interfaces. They vary in granularity and level of abstraction. Similar to design catalogs design patterns are characterized by the "pattern name", the "problem" they address, the "solution" they provide and the "consequences" of their application. Further, they are classified by their purpose and their scope and grouped in families of related patterns [7].

Experts re-use successful solutions and base new designs on prior experience without having to re-discover the whole problem [7]. Design patterns help inexperienced software developers to do the same based on the experts sharing their knowledge.

Looking at the status-quo of design catalogs and catalogs of design patterns several limitations exist. First, design catalogs in [3] are still mainly paper-based even though Derhake [8] proposed a system to computationally create and represent design catalogs. Computational search for patterns is limited and synthesis is not adequately supported. For this reason, the ease of use is low and the speed of search is slow. The authors assume a negative impact for existing paper-based design catalogs regarding the acceptability and usability due to these issues. In addition, design catalogs in the mechanical engineering domain are predominantly available in German language hindering broad usage. Koller et al. [2], Roth [3] and VDI 2222 [4] demand a consistent and conceptually accurate catalog structure. This demand must be extended to design catalogs and catalogs of design patterns of all domains in mechatronics to enable a search for multidisciplinary patterns. The use of solution patterns was already proposed for mechatronic systems in [9].

3 Terminology

In this section the terms used throughout the paper are explained. This is important since every domain uses their own terminology with respect to re-usable solutions and the paper intends to be understandable for interdisciplinary product development teams.

A *design catalog* contains knowledge about engineering design. It is systematically developed and makes knowledge available for everyone, independent of the experience and knowledge of individuals [3]. A difference between a collection of solutions and a design catalog is drawn regarding the level of completeness, the systematic structure and the accessibility within the design process, all of which are more restrictive for design catalogs [2, 3]. The term design catalog is predominantly used in the electro-mechanical domain with a strong focus on mechanical design.

Design patterns describe general design problems and their solutions [1, 7]. According to Gamma et al. [7] a design pattern "names, abstracts, and identifies the key aspects of a common design structure". They can vary in granularity and the level of abstraction that is influencing the reuse of every design pattern. Design patterns with a high level of abstraction are likelier to be reused. The term design pattern is mainly used in the domains of computer science and architecture with increasing interest in mechatronic design.

Catalogs of design patterns organize design patterns to make systematic and efficient retrieval possible. They correspond to design catalogs in the electro-mechanical domain.

The term *solution patterns* is used in this paper to describe a generic solution of a problem that is solved in a domain-spanning way and is appropriate for re-use. Typically, the implementation of cognitive functions requires a domain-spanning solution. The new term “solution pattern” is introduced to avoid confusion with terms that have different meanings in different domains and to point out when solution patterns for cognitive functions are discussed. Solution patterns can vary in complexity, granularity and type of solution.

Solution patterns are stored in *meta-design catalogs for cognitive products*. The meta-design catalogs provide a framework for all solution patterns, similar to design catalogs and catalogs for design patterns. In addition they are linked with domain-specific design catalogs and catalogs for design patterns allowing a breakdown into domain-specific subfunctions. In contrast to all types of above mentioned patterns a *solution* is one problem-specific occurrence of a pattern. The terms *cognitive product* and *cognitive function* are defined in Sect. 4.2.

4 Meta-Design Catalogs for Cognitive Products

This section first compares design catalogs available in engineering disciplines and catalogs of design patterns from architecture and software design. Based on this comparison, functions in meta-design catalogs are described. Finally the framework of meta-design catalogs for cognitive products is presented.

4.1 Comparison of Design Catalogs and Catalogs of Design Patterns

A comparison of design catalogs and catalogs of design patterns from different domains leads to the following assumptions. They all serve one main purpose: to find solutions for general design problems and avoid repeating the same work. In general, they use a semi-formal description of the initial situation, e.g. elementary functions in [2], electrical behavior in [6] or pattern name in combination with problem description in [7]. The solution pattern usually is broken down into a description including elements like name, problem, solution and consequences.

The common goal of design catalogs and catalogs of design patterns is to make the re-use of successful designs and architectures easier and so help designers to find design alternatives quickly [2, 7].

Graphical notations solely are not sufficient to represent solution patterns; neither in engineering design nor in object-oriented software design [2, 7]. Nevertheless, they are important and useful to foster understanding of an abstract textual description in all domains and can provide concrete examples.

4.2 Functions in Design Catalogs

To date, design catalogs and catalogs of design patterns address mainly design problems related to single domains. Nevertheless, element design and system design are inseparable [6] and systems engineers manage the development process of complex engineering projects. This paper is about meta-design catalogs for cognitive products. *Cognitive products* are tangible and durable things consisting of a physical carrier system with embedded mechanics, electronics, microprocessors and software [10]. The surplus value is created through cognitive functions, e.g. to perceive, to learn and to act [11], enabled by flexible control loops and cognitive algorithms. *Cognitive functions* are the elementary functions enabling cognition as a whole and heavily rely on a software component but nevertheless are regularly realized through the combination of solution-elements from different domains. This already indicates that common, domain-specific design catalogs and catalogs of design patterns are not appropriate to search for high-level solution patterns of cognitive functions. First order cognitive functions, e.g. perceive, learn and think, are very abstract and neither support a straightforward search for solution patterns nor allow an easy decomposition into subfunctions with known solution patterns. Nevertheless, solution patterns are needed for each cognitive function that can be adapted to specific design problems in the conceptual design of cognitive products.

Koller et al. [2] and Gausemeier et al. [9] show that product functions can be decomposed into elementary functions, e.g. according to Pahl et al. [12]. Is it possible to similarly decompose cognitive functions into elementary functions? If so do these correlate with common elementary functions that can be found in existing design catalogs of different domains? If such a decomposition is possible, it is not intuitive and even cognitive scientists or neuroscientists can not precisely tell what the elementary functions are that are involved in cognitive processes in human beings. For example, Rees [13] says that "seeing is not perceiving" but can not name the extra "bit" required for perception. The authors assume that a full decomposition of human cognition into elementary functions is, with the current knowledge of human cognitive processes, not possible and for this reason not realized in a cognitive technical system to the same extent yet. However, cognitive functions are imitated and realized in CTSs and cognitive products.

Functional decomposition of imitated cognitive functions always points to solution patterns in catalogs of different domains without considering interrelations among them. By developing meta-design catalogs for cognitive functions interrelations can be considered among corresponding sections of the catalogs. It is also expected that, in future, objects will be available off the shelf that conduct cognitive functions instead of elementary functions. Therefore new object catalogs are required, capable of linking abstract solution patterns to real solutions.

4.3 Framework of Meta-Design Catalogs for Cognitive Functions

In this paper a pragmatic way to support the design of cognitive products is proposed. The approach is to develop a framework of meta-design catalogs for cognitive products that links generic solutions to related subsets of solutions in domain-specific design catalogs and catalogs for design patterns. Relating the meta-design catalog to domain-specific design catalogs is important because it allows product developers to use design catalogs they are familiar with, they do not have to be updated independent from the domain-specific catalogs and it is less demanding computationally.

The catalog types used in mechanical engineering already provide a meaningful catalog classification for design catalogs of cognitive products as well as other domains. The above mentioned catalog types constitute the first dimension of Fig. 1: type of catalog. Process catalogs for cognitive products contain processes, rules and process steps describing for example how to develop a cognitive product, how to connect cognitive functions or how to decompose cognitive functions into cognitive subfunctions. Object catalogs for cognitive products are empty at the moment because integral objects accomplishing cognitive functions independent from specific design problems are not available. For this reason process catalogs are not yet linked to object catalogs targeted at cognitive products. In the future, integral objects accomplishing cognitive functions may exist and will be integrated in the object catalogs. Solution catalogs for cognitive products contain solution patterns for specific design problems related to artificial cognition and constitute a source for alternative solution patterns. The authors currently work on a modeling approach for cognitive products using the systems modeling language (SysML) and expect the identification of patterns realizing different cognitive functions. Instead of linking process catalogs and solution catalogs for cognitive products with empty object catalogs directly, they are linked to domain-specific design catalogs including object catalogs.

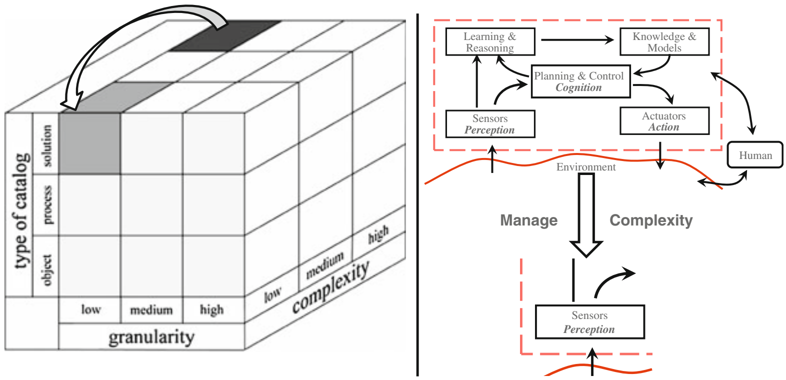


Fig. 1 Framework of all design catalogs for cognitive products (*left*) and the management of complexity (*right*)

Further, [3] and [4] distinguish design catalogs regarding their complexity whereas [7] use the term granularity. The authors consider both differentiations important for the following reasons. Roth [3] and [4] determine complexity by the number of relations among elements in a system or product. This means that a cognitive product with several interlinked cognitive functions is usually more complex than a system with an isolated cognitive function. Granularity describes how detailed a system is broken down or decomposed into subfunctions and therefore a higher granularity is characterized by an increase of interlinked functions in the model. In conclusion it is assumed that a higher granularity increases the model complexity but not the inherent system complexity because only the level of abstraction is changed. In order to create holistic design catalogs for cognitive functions different levels of complexity as well as different levels of granularity have to be covered. This helps to manage system and product complexity and to increase model granularity by breaking down functions into elementary functions that can then be linked to single-domain design catalogs.

Figure 1 (left) shows all possible design catalogs for cognitive products structured according to catalog types, complexity and granularity. Solution patterns with high complexity and low granularity, e.g. in solution catalogs, are linked to design catalogs with a lower complexity and low granularity. This is visualized in Fig. 1 (left) with the black arrow pointing from the left side of the building block in the back to the left side of the building block in the front. An example for a solution pattern with high complexity and low granularity is for example a generic system architecture for CTS as proposed in [14], see Fig. 1 (right).

Beyond the classification of meta-design catalogs for cognitive products their internal structure is of great importance because they need to cover solutions including elements of different domains. By comparing the internal structure of design catalogs from different domains, the following issues have to be considered to create holistic and unambiguous design catalogs for cognitive products that are valid independent of complexity, granularity and catalog type:

- a (formal) description of the problem/function and the solution is given
- solutions are accessible through a kind of index
- limitations of the solution space through parameters.

Next, the advantages of existing design catalogs and catalogs of design pattern are combined to create a suitable catalog structure for cognitive products. Thus, at first a universally valid index of design catalogs for cognitive products is required and proposed according the taxonomy of cognitive functions [11]. The taxonomy of cognitive functions was created by analyzing scientific publications from different domains with regard to cognitive capabilities and cognitive functions and structuring the found terms in an unambiguous way in a taxonomy. Using cognitive functions as an index for design catalogs seems appropriate because all kind of cognition can be traced back to them. Depending on the hierarchical level of the cognitive function that has to be realized technically, different links point to different solution patterns in the main part of the catalogs with different levels of abstraction. “to act”, a very abstract cognitive function, points to a very generic solution pattern generally describing fundamental requirements as well as to sub-patterns providing more

Index

Primary Pattern Name	Link	Secondary Partern Name	Link	…
to perceive	*link a*			
to learn	*link b*			
to understand	*link c*	to interpret (to construe, to see)	*link c.1*	…
		to solve (to work out, to figure out)	*link c.2*	
		to appreciate (to take account)	*link c.3*	
		…	*link c.n*	
to know	*link d*			
to think (to cogitate, to cerebrate)	*link e*	to reflect (to think over)	*link e.1*	…
		to reason	*link e.2*	
		to plan	*link e.3*	
		…	*link e.n*	
to decide	*link f*	to judge (to adjucate, to try)	*link f.1*	…
to act (to move)	*link g*	to react	*link g.1*	…
		to interact	*link g.2*	
		to move	*link g.3*	
		…	*link g.n*	
…	…	…	…	…

Generic Link
"link n"

Main Part

Pattern Name	"name"				
Problem Description	description of the problems that pattern "name" solves				
Solution Description	**Description**	**Sub-Pattern**	**Domain**	**Link to Domain-Specific Catalog**	**Description**
	general description of the solution for pattern "name"	link to sub-patterns (if no further sub-pattern is available continue with domain specific solutions/patterns)	**Mechanical Engineering**	link me	
			Electrical Engineering	link ee	
			Computer Science	link cs	
			……		
Consequence Description	description of consequences when applying pattern "name"				

Fig. 2 Internal structure of design catalogs for cognitive functions with index and main part

specific solutions for subfunctions of "to act", e.g. for "to interact" or "to move" (Fig. 2). The main part of the catalog contains the solution patterns for the cognitive functions. Every solution pattern is first characterized by a name according to the cognitive function and a description of the problem that can be solved with it to avoid wrong applications of the pattern. Then the solution provided in the pattern is described. In addition, links to sub-patterns are included, in case the user is looking for something more detailed. Finally, the solution is broken down into domain-specific components of the solution, either objects in object catalogs, processes in process catalogs or tailored solutions in solution catalogs. A description of consequences concludes the every pattern including e.g. limitations of the pattern or possible disturbances influencing the solution.

5 Application

This section shows how solution patterns of design catalogs for cognitive products are identified, using as an example cognitive product developed by an interdisciplinary student team, and how to allocate the solution patterns to the design catalogs. Afterwards, the identified solution pattern can be used to support the search for solutions in the conceptual design phase of future cognitive products.

The cognitive product from which solution patterns are identified is a toy called "Virtual Opponent Slot Car" and was developed in a class on the theme "Cognitive Toys" by a team of four students from ME and EE. The goal of the students was to develop a slot car toy that is fun, even if no human opponent is available. To achieve human like behavior and skills it was decided that the virtual opponent learns to drive around the track from the human player. For every segment the speed of the human-driven slot car is measured and the maximum speed is stored in order to recall it during a race. Since a game with optimal performance would become boring rather quickly, a tactic function was implemented that makes the virtual opponent act according to the human driver's performance. In case the human-driven slot car is behind the virtual opponent, it drives slower depending on the distance and in case the virtual opponent is behind the human-driven slot car it drives as fast as possible. This way, the two slot cars usually stay close together and a close finish situation is generated keeping the game exciting all the time.

A picture of the prototype is shown in Fig. 3 on the left and the high level cognitive function structure on the right. The virtual opponent perceives positions of the two slot cars and the average user speed for every section of the track and compares it with the known maximum speed for that section. In case the actual speed is higher than the maximum known speed it learns the new maximum speed from the user. The virtual opponent acts according to its knowledge about the maximum user speed.

A frequently reoccurring cognitive function while developing cognitive products is "to perceive". Therefore, a solution pattern for "to perceive" has been abstracted from the virtual opponent describing the general problem, the related solution and consequences exemplarily. All parts of the solution pattern are included in Fig. 4. The pattern name is *"to perceive"* according to the cognitive function and it is appropriate to solve problems related to "becoming aware of something through senses". The generic solution pattern describes how a technical system can perceive by identifying subfunctions that have been found in prototypes, e.g. the virtual opponent. The action to perceive requires the sensing of signals in the environment and internally and the processing of them according to the existing knowledge of the system and the context [15]. Sub-patterns are

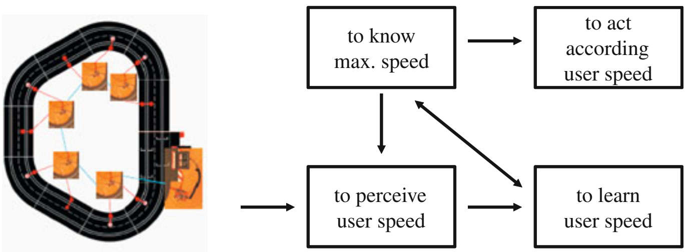


Fig. 3 "Virtual Opponent Slot Car" (*left*) and cognitive function structure of the product (*right*)

Pattern Name	"to perceive"				
Problem Description	Provide a solution about how a technical system becomes aware of something through senses. This pattern is relevant when a system is not only meant to do signal processing but has to consider context as well.				
Solution Description	**Description**	**Sub-Patterns**	**Domain**	**Link to Domain-Specific Catalog**	**Description**
	the action "to perceive" requires the sensing of signals in the environment and internally and process them according to the existing knowledge of the system and the context	*-to know* *-to sense* *-to process data*	**Mechanical Engineering**	-	-
			Electrical Engineering	*-sensor-catalogs* *-processor catalogs*	find appropriate sensor for the desired perception
			Computer Science	*- data processing algorithms*	find appropriate algorithm for the perception task
Consequence Description	- depending of what needs to be perceived different sensors are required - depending on what sensor is used different software is required - …				

Fig. 4 Solution pattern of "to perceive"

assumed for other functions, e.g. to sense or to process and other cognitive functions, e.g. to know. The consequences on this pattern are that, depending on what needs to be perceived, different sensors, processors and software, etc. are required. Linking this solution pattern with a domain specific pattern is partially possible, e.g. the link to object catalogs in electrical engineering containing sensors and processors is possible. The allocation of the solution pattern in the structure of meta-design catalogs for cognitive products has to consider the pattern type, complexity and granularity. The granularity in "to perceive" is low as well as the complexity. The solution pattern fits well into a solution catalog because it describes schematically how to make a technical system perceive something through senses. It neither describes an object nor a process. It is allocated to the light grey building block in the front of Fig. 1.

Because the textual description above and Fig. 4 are very abstract, an additional graphical representation of the pattern is considered helpful. This graphical representation has been developed in SysML (Fig. 5). The model includes operators and flows. The flows define the inputs and outputs of the operators and the operators conduct an activity on the flow. The combination of flow(s) and one operator is considered here as one function. In the example several functions together accumulate to the cognitive function "to perceive". Cognitive functions and flows in the activity diagram shown in Fig. 5 are further explained in [11].

In Fig. 6 components have been allocated to the subfunctions presented in Fig. 5. These components are capable of realizing the functions they are allocated to. In the case of the solution pattern "to perceive" the components belong to other domains, e.g. sensors are electronic objects and can be found in object catalogs of the electrical engineering domain.

By adding components to the solution pattern the granularity of the system model is increased but the model complexity increases likewise. For this reason it is good to start with an abstract pattern and model and successively detail it throughout the development process.

Coming back to the sample application of the virtual opponent perception is realized through the functions and components described below. The function "to sense" is realized through Hall Effect sensors that are placed around the racing

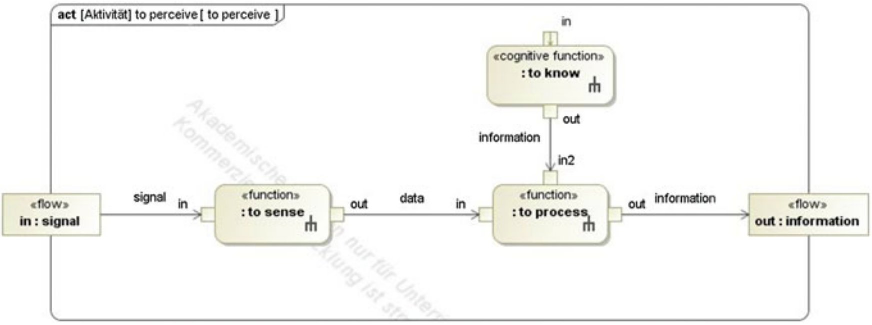


Fig. 5 Graphical representation of the solution pattern "to perceive" including functions

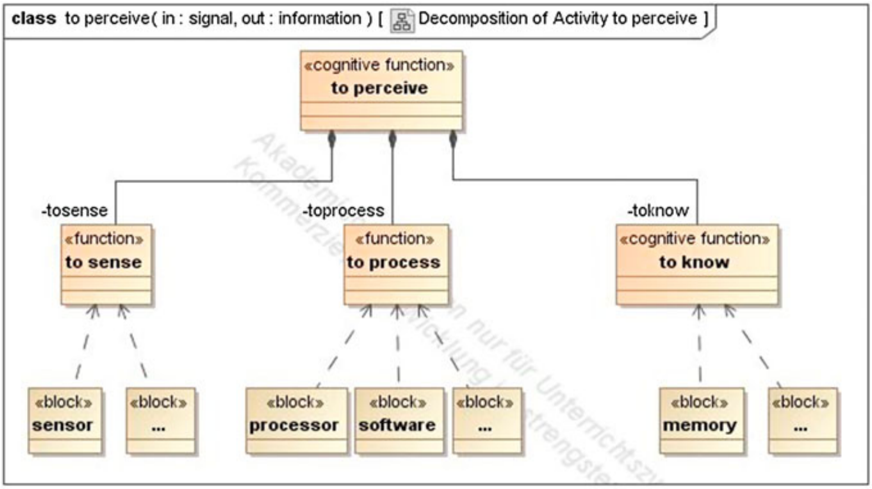


Fig. 6 Graphical representation of the solution pattern "to perceive" where components are attached to functions

track and detect magnetic fields ("signals"). They output data every time a magnetic field is within their range. A magnet is attached to the bottom to the slot car already to increase the traction. Therefore, no adaptation of the slot car was necessary. The processing of the sensor data is accomplished by a combination of the micro controller AT90USB162 mounted on an AVR-USB-162 development board from OLIMEX, a laptop and software. The software requires the sensor data and knowledge about the previous position as well as a definition about how the change in sensor data and position has to be interpreted. Therefore, knowledge about different sensor data has to be stored in the memory of the micro controller.

6 Discussion

Meta-design catalogs for cognitive products support their conceptual design phase by providing generic solution patterns that can be reused. They close the current gap of missing solution patterns tailored to cognitive functions that can not be broken down to elementary functions yet and therefore are realized using interdisciplinary solutions. By directly addressing cognitive functions a further decomposition into elementary functions is usually unnecessary.

Instead of creating meta-design catalogs for cognitive products that contain domain-specific solution patterns or even objects at component level they are interlinked with domain-specific catalogs avoiding ambiguity. That is possible because domain-specific design catalogs and catalogs of design patterns are structured similar and are partially identical to the proposed meta-design catalogs.

To date, the use of meta-design catalogs for cognitive products is limited by the number of solution patterns stored inside and the paper-based structure. The number of solution patterns must be increased significantly in order to benefit from the meta-design catalogs. This will be done in future research. As a starting point the authors are going to analyze the cognitive products they already developed, extract solution patterns and integrate them in the meta-design catalogs. It is expected that enough solution patterns will be found to do some basic evaluation of the design catalog by testing it during the development of a new cognitive product.

As proposed earlier in the paper a software implementation of the meta-design catalog structure is necessary, supporting: the systematic integration of new solution patterns, the search for solutions according to the problem description at the required level of complexity, granularity and type of catalog, and an effective representation of the solutions with links to other, domain-specific catalogs. Ideally, files containing a model of a solution pattern can be included in the meta-design catalogs, e.g. SysML models, and an interface to the modeling tool is available enabling an easy integration of the solution into the own model.

7 Conclusion

This paper presents a framework of meta-design catalogs for cognitive products supporting the conceptual development. They are structured according to catalog type, complexity and granularity from an external viewpoint and each catalog has the same internal structure consisting of an index and a main part. The main part itself consists of a pattern name, a problem description, the solution pattern and consequences arising through the application of the solution pattern. Solution patterns managed in meta-design catalogs for cognitive products are linked to other solution patterns containing cognitive functions as well as to domain specific design patterns.

Acknowledgments This research is part of the Cluster of Excellence, Cognition for Technical Systems—CoTeSys (www.cotesys.org), founded by the Deutsche Forschungsgemeinschaft (DFG).

References

1. Alexander C, Ishikawa S, Silverstein M, Jacobson M, Fiksdahl-King I, Angel S (1977) A pattern language. Oxford University Press, Oxford
2. Koller R, Kastrup N (1998) Prinziplösungen zur konstruktion technischer produkte. Springer, Berlin
3. Roth K (2001) Konstruieren mit konstruktionskatalogen—band II. Springer, Berlin
4. VDI 2222 Page 2 (1982) Design engineering methodics—setting up and use of design catalogs. Beuth
5. Mathias J, Eifler T, Engelhardt R, Kloberdanz H, Birkhofer H, Bohn A (2011) Selection of physical effects based on disturbances and robustness ratios in the early phases of robust design. Int Conf Eng Des (ICED11) 5:324–335
6. Whitney DE (1996) Why mechanical design cannot be like VLSI design. Res Eng Design 8:125–138
7. Gamma E, Helm R, Johnson R, Vlissides J (1995) Design patterns—elements of reusable object-oriented software. Addison-Wesley, Reading
8. Derhake T (1990) Methodik für das rechnerunterstützte erstellen und anwenden flexibler konstruktionskataloge. PhD Thesis, TU Braunschweig
9. Gausemeier J, Frank U, Donoth J, Kahl S (2009) Specification technique for the description of self-optimizing mechatronic systems. Res Eng Design 20:201–223
10. Metzler T, Shea K (2010) Cognitive products: definition and framework. International Design Conference—DESIGN 2010, pp. 865–874
11. Metzler T, Shea K (2011) Taxonomy of cognitive functions. Int Conf Eng Des (ICED11) 7:330–341
12. Pahl G, Beitz W, Feldhusen J, Grote K-H (2007) Engineering design: a systematic approach. Springer, Berlin
13. Rees G (2001) Seeing is not perceiving. Nat Neurosci 4–7:678–680
14. Beetz M, Buss M, Wollherr D (2007) Cognitive technical systems: what is the role of AI? Lect Notes Comput Sci 4667:19–42
15. Fellbaum C (1998) WordNet: an electronic lexical database. MIT Press, Cambridge

Extracting Product Characters Which Communicate Eco-Efficiency: Application of Product Semantics to Design Intrinsic Features of Eco-Efficient Home Appliances

Shujoy Chakraborty

Abstract So far the development of Eco-efficiency in home appliances has only concentrated on their technological attributes, overlooking the communication of Eco-efficient qualities through the aesthetical appearance of such appliances i.e. a meaning to be transmitted to the user. Technical attributes are communicated through extrinsic features i.e. labelling, branding, packing [1]. These are considered as semiotic content (not concerned with semantics) and give information regarding the product independent of meaning, and as such have no direct relation to the product appearance or character [2]. This paper will explain the application of product semantic theory to re-design the product characters of home appliances which communicate their Eco-efficient qualities through their intrinsic features within a non-instrumental product experience. The final output will be a set of design guidelines consisting of 6 product characters—*Futuristic, Feminine, Unconventional, Practical, Simple, Smart*—which appliance designers can apply. Product characters are adjectival constructs or visual metaphors [3, 4]. Design theorists have pointed out that companies which are able to communicate a specific meaning (such as Eco-efficiency) through their product appearance can achieve a competitive market advantage [5]. Athavankar [6] cited product semantics as having amongst others 2 core goals, (1) Improving user-product interaction. (2) Demystifying complex technologies. The intention of semantics as a design theory was to apply linguistic theories into a design process to develop 'readable' or 'self-evident' products through easy to apply methods [7].

Keywords Product characters · Eco-efficiency · Home appliances

S. Chakraborty (✉)
Politecnico Di Milano, 38/A Via Durando 20158 Milan, Italy
e-mail: shujoy.chakraborty@mail.polimi.it

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_26, © Springer India 2013

1 Introduction

Currently communication of Eco-efficiency is a mixed effort in the appliance industry, consisting of energy labelling, advertising and marketing strategies, thus giving it an ambiguous meaning confusing the user. It has been established that when the meaning of what a product has to communicate is not clear to the consumer, then, he or she will have difficulty in assessing the product and will therefore appreciate the product less [5]. Semiotic content like signage and labeling are not concerned with meaning communication [2].

The weak role of design in Eco-efficient appliance development is consequently due to the considerable ambiguity surrounding the exact meaning of Eco-efficiency in language. It is often referred to as: green design, eco design, environmental design, etc. Schmidheiny [8] says Eco-efficiency is *the production of goods and services which meet human needs while reducing environmental impacts*. This linguistic shortcoming i.e.: inaccurate usage is also reflected in the design approach towards Eco-efficiency especially within the appliance industry reflecting Krippendorff [4, 9, 10] who says meanings of artifacts are founded in language.

This research rests on 2 important design theories in order to encode the intended meaning of 'Eco-efficiency' into home appliances through their intrinsic features. First, the 'human centred' approach to Product Semantics as discussed by Krippendorff [4, 9], and second the 'product communication model' as discussed by Crilly et al. [11] both of which have overlapping concerns, and at the same time contain several unique insights into how to make products more expressive of their intended meaning.

Intrinsic product features are physical attributes—form, geometry, colour, proportion, and composition as opposed to extrinsic features which are strictly related to a manufacturer's marketing identity—packaging, branding [1]. A non-instrumental product interaction is based only on visual sensing of the artifact by the user with no mechanical or physical manipulation involved [12].

Why home appliances? Within the Europe home appliances account for the largest share of domestic energy consumption. With refrigerators and freezers accounting for 15 % of residential consumption followed by washing machines accounting for 4 %, and dishwashers, ovens, and clothes dryers accounting for around 2 % of total residential end use [13]. On its part the EU has set an efficiency guideline to increase appliance efficiency by 20 % at the end of 2020. Typically Eco-efficiency is largely looked upon as a debatable investment by important functionaries such as marketing and finance within appliance companies [14] and increasing the market performance of Eco-efficient appliances will help to address this situation.

Finally the research approach adopted in this paper is a 'Design-led' and 'Expert Mindset' approach highlighted by Liz Sanders [15] in her 'Map of Design Research'. This means that this research relies primarily on the input of design experts for attribution of product characters, and deriving visual manifestation of language based adjectives, while having an element of participatory mindset only in certain key stages of the entire process, such as capturing user feedback (i.e. adjectives) on design concepts.

1.1 Human Centred Approach to Product Semantics

Semantics as a discipline has traditionally been applied to study spoken languages and the study of meanings in languages, but its application into product design has been pioneered by Krippendorff and Butter in 1984 [16, 17]. The intention of semantics as a design theory was to apply linguistic theories into a design process to develop 'readable' or 'self-evident' products through easy to apply methods [7]. The early design theorists of semantics namely Butter [18] and Krippendorff [4, 9, 10] strove to develop it as a new approach to design [7, 19] through what they called the Human Centered view of design, a break from Luis Sullivan's "Form follows function" doctrine by instead proposing "Form follows Meaning". Unlike Crilly [11] and Krippendorff [10] warns not to confuse semantics with concerns of ergonomics which according to him is a machine centred view drawing upon objective evaluation of performance and mechanics removing human perception and faculties from consideration. The human centered approach to semantics is based on the attribution of 'characters' in products to express a meaning. The perception of visual appearances in products has a fairly rich historical precedence. Apart from semantics, other domains which overlap into this subject area are aesthetics, psychology, consumer research, sociology, marketing, semiotics, and ergonomics [16, 20].

Krippendorff defined Product Semantics as *a study of the symbolic qualities of man-made forms in the cognitive and social contexts of their use and the application of the knowledge gained to objects of industrial design*. Blaich [21] defined product semantics as *an area of inquiry or discipline concerned with the meaning of objects, their symbolic qualities, and the psychological, social, and cultural contexts of their use*. Athavankar [6] cited product semantics as having 2 core goals, (1) Improving user-product interaction, (2) Demystifying complex technologies.

The core concern of human centred design is acquiring 'second order understanding' according to Krippendorff [4]. Second order understanding entails understanding how users understand the artifacts designed by the professional. "Designers and their stakeholders merely understand differently" and since human centred design is designing for others, therefore it is the designer's job to acquire this understanding of another's understanding.

The human centred view pursued in this research is diverse from the view shared by design theorists and HCI community who propagate increasing the intuitiveness of products with the application of semantics and familiarise the user with the unfamiliar Crilly [11, 20, 22], Brown[7], [23], Evans and Thomas [24] and Norman [23]. Instead, the human centred view as Boess [19] says is an interpretation of Semantics directly derived from Semiotics, which is the study of signs, and looked at forms as proponents of language.

1.2 Meaning

A meaning is always someone's meaning [4]. Artifacts acquire meaning through use, and watching how users use an artifact can give insights into the attributed meaning. Thomas [26] points out that "meaning of form is a human production, as it is both malleable and undefined". Meaning is born in perception, thus it is essentially a human construct, and is only limited by people's capability to imagine [26]. It thus follows that any form by itself has no meaning, but is rather "a window to opportunity" according to Thomas [26]. Hekkert and Schifferstein [12] say that it is only through interaction with people that objects acquire a meaning. According to Krippendorff's human centred approach objects are open to interpretation, and language structures provide for how artifacts are perceived. Since forms trigger meanings, therefore forms can also subvert meanings [26]. The same form can trigger multiple meanings, based on the scenario in which it is present. A knife in a kitchen means entirely different than in the hands of a man in a dark alley. Thomas [26] points out that context influences the interpretation of a form, thus shaping the message it communicates.

Since meaning is born out of human perception it follows that meaning is influenced by personal past experiences of the user being a psychological construction. Past experiences and encounters influence meaning attribution. Krippendorff [4] points out that meaning is not constant and is invoked by 'sense' and so in this way related to 'perceived affordance' according to [27] theory of ecology.

Materials can have a bearing on the communication of meaning. Handcrafted wood denotes craftsmanship; metal surface is associated with precision, and plastic with cheap products [28].

1.3 Character, Characteristics, and Attributes

Both in product semantics and character theory it is a basic assumption that artefacts can be bearers of a message through the characters which they express. A character can be indicative of the external appearance, internal functioning, or behaviour of the artifact.

Demirbilek and Sener [16] say that all manufactured products make a statement through shape, form, texture, and colour. According to Janlert and Stolterman [29] a character can be ascribed with as much as a casual glance. Attributing characters makes it easier for users to anticipate the functioning of the object and also explain its behavioural patterns to the user. It thus follows that users tend to make a connection between certain appearances and the characters they attach to them i.e. transparent surfaces appear more futuristic, and organic forms appear more feminine. Based on these insights it can be said certain characters can potentially form stable relations with certain appearances and this interdependency can be an opportunity for designers.

Characters have to be "planted" into a product with great care. A complex product such as a car or an appliance is made up of several characters and even 1 character wrongly attributed can be misleading and detract from the carefully cultivated message which the product is trying to communicate. Product characters are adjectival constructs or visual metaphors and can be expressed through languages structures. [3, 4]. Thus designers have to be doubly careful with the details and features they utilise to attribute a certain character.

A character is a unity of characteristics i.e. not a simple collection, but with related characteristics integrated into a coherent whole [29]. This means all the characteristics united to send a common message to the user of the artefact.

A characteristic is interpreted as a qualifier of attributes. A characteristic is a kind of a higher order attribute, a meta attribute that applies to all attributes within a character or individual. Knowing a few of the characteristics constituting a character enables one to guess the remaining ones.

A sum of attributes which are qualified by a certain characteristic go into forming 1 characteristic, and a group of similarly constructed characteristics intending the same meaning combine to form 1 character. The hierarchy is thus pyramidal in structure.

1.4 Communication in Product Design

Based on Shannon's model of communication discussed in 'A mathematical theory of communication', Crilly et al. [11] explain how users experience the designer's intension through product forms. The designer is the source, the author of the design which seeks to communicate a meaning to the user. The product is the transmitter of this message through its intrinsic and extrinsic product features. The environment within which the product is sensed and the meaning attached is the channel, and the sensing user is the receiver of the original communication, where the sense of sight is of primary importance. The destination is the psychological response (emotional + cognitive) of the user who has sensed the product, and refers to the judgments which the user makes based on the information received by the senses. *These judgments refer to evaluation of the perceived qualities of the products being sensed* [11].

The design process discussed in the next section will aim to encode the meaning of Eco-Efficiency in washing machines based on the communication model derived below by the author (Fig. 1). This model emerges from combining the 'product communication' model as discussed by Crilly et al. [11] and the 'human centred' approach to Product Semantics as discussed by Krippendorff [4, 9]. The

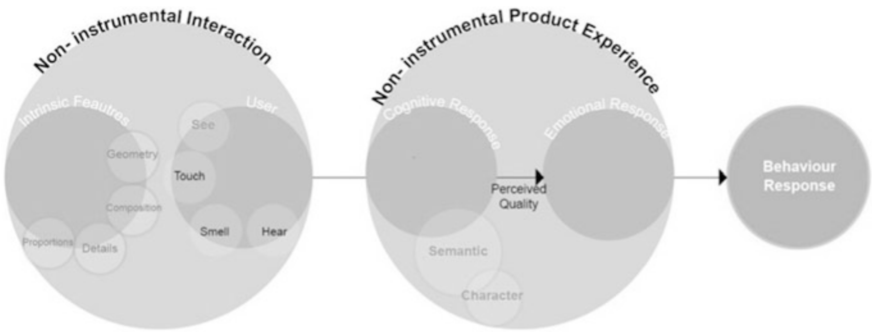


Fig. 1 Author's product communication model. *Source* Doctoral thesis

non-instrumental interaction consists of product intrinsic features (form, geometry, composition) and visual sensing of these features by the user. A non-instrumental interaction leads to a non-instrumental product experience which consists of a cognitive response being triggered (semantic interpretation) by the attributed product character (Eco-efficiency in washing machines). This cognitive response leads to an affective reaction leading to a positive behavioural outcome (approaching the product instead of ignoring the product) by the user.

2 Redesigning Product Characters Through a Design Process

The approach described here is aimed at re-designing the product characters expressing the Eco-efficiency of a washing machine, using a design process.

A washing machine was consciously selected as a test category for this study because it is an appliance category more-or-less typologically constant throughout all the major global markets. Other appliance categories, such as a cooktop or fridge for example, vary substantially in terms of typology (i.e. built-in versus free standing) across Europe, Asia, and North America which has a substantial impact on the appliance appearance. Since this design process relies heavily on capturing feedbacks from a culturally and geographically diverse set of users, therefore an appliance category had to be selected which was easily recognised. Below are the 7 steps of the design process:

1. See how product designers attribute Eco-efficiency in washing machines using a design workshop.
2. Conduct a visual questionnaire capturing adjectives through which non-expert users identify each concept.
3. Compile and classify adjectives captured through feedback from users.
4. Shortlist, rank, and group the classified adjectives into groups. Each group will represent a product character. 6 groups were constructed.

5. Build a mood board visually attributing the 6 product characters. These mood boards will act as guided stimulation for designers.
6. Conduct a second design workshop, asking designers to attribute a character set to a washing machine concept design with the help of a visual mood board representing each product character.
7. Perform a second questionnaire asking if the washing machines designed with the aid of product characters and mood boards appear Eco-efficient.

The steps 4–7 of the research process were adapted from the process suggested by Klaus Krippendorff in *The semantic turn*, 2006, itself an adaptation of the process suggested by Reinhardt Butter in *Putting Theory into Practice: An Application of Product Semantics to Transportation Design* [17] which in turn is similar to the 5-step *metaphoric links* process introduced by Athavankar [30]. Butter's *somewhat linear with clearly distinguishable phases* 8 step heuristic (experience based) process was designed specifically to apply the theory of product semantics to develop products.

2.1 The 7-Step Design Process

Step 1 *Design Workshop—IIT, Guwahati—M.Des:* The design workshop in IIT, Guwahati was planned over a period of 7 days with 8 students from the Master in Design-second year (M.Des-II) students. Since a clear trend of visually expressing Eco-efficiency has not yet emerged in the appliance industry, this workshop was designed to test how designers would approach the expression of Eco-efficiency through the intrinsic features of an appliance. The brief given to the students was: *Express the Eco-efficiency of a washing machine only through its intrinsic features affecting the appearance without disrupting too much the current technical architecture of it.*

The output of the workshop strictly maintained focus towards expressing Eco-efficiency through the form, geometry, proportions and composition of the appliances. Hekkert and Karana [28] define form as "the boundary of matter by which we distinguish (these) objects from each other and their environment" (Muller 2001). Shape is defined as that which *determines an object's boundary, abstracting it from other aspects, such as colour and material* (Chen 2005) [28].

Since at this stage of the design process, the workshop intentions were relatively general, i.e. the product character associated with Eco-efficiency were yet unknown, the concepts were delivered in a digital file format making it possible to remove a lot of background noise and colours (in the form of colour, materials, finish, and context) which might distract the user. This consideration was taken keeping in mind the insights of Hekkert and Karana [28] on how meaning attached to materials and colour can effect the user's perception of shape and form of the product. All students worked individually and delivered 8 concepts in total.

It was observed that the students were having significant difficulties in developing an aesthetic intervention for a washing machine which expressed its Eco-efficient qualities without impacting its typology. For designers, working on just the aesthetical level of a product without manipulating its internal workings on a typological level, seemed to be an inadequate level of intervention. The author realised a practical limitation of the concepts of the semantic theory proposing communication of a meaning through the product's appearance, as they were not easily accepted by the professional design community. Athavankar [6] too attests to this challenge by saying *It is a normal practice to mix issues like product function, aesthetics, technology and culture in discourses of form. Isolated discourses on form have always been seen as suspect.*

Step 2 *Visual questionnaire with non-expert users*: The objective of this step was to collect and capture a list of adjectives which potential non-expert might utilise to identify each concept. Krippendorff says *by definition, the character of an artifact consists of all adjectival constructions that a community of stakeholders in that artifact deems suitable to that artefact*. The questionnaire was displayed maintaining visual clarity and focus on only the form and geometry of the concepts, all colour, finish, material, and backgrounds were removed. All the concepts were visualised in black and white against neutral or white backgrounds.

Users were asked to attribute 3 adjectives spontaneously to each concept and rate the Eco-efficiency of each as "very Eco-efficient, some-what Eco-efficient, and not Eco-efficient". There were 30 respondents having a 50–50 male–female distribution and they were aged 23–53 with mixed nationalities. None of the respondents were from product design or allied fields.

Step 3 *Compilation and classification of captured adjectives*: Only 3 of the 8 concepts which were voted by at least 50 % of respondents as appearing Eco-efficient and were selected for evaluation of this step (Fig. 2). The objective adjectives i.e. adjectives which measure the physically measurable properties of an artifact were singled out and discarded. This was done following Butter [18, p. 55] who elaborated upon the qualitative communication which products must make. He says when generating a list of qualities which a product seeks to make to the user one must disregard the *factual attributes* which represent the objective, measurable qualities of "how something actually works" and keep only the

Fig. 2 Top 3 ranked washing machine concepts from IIT-Guwahati workshop:concept **1** (60 % voted very eco-efficient); concept **2** (50 % voted very eco-efficient); Concept **3** (50 % voted very Eco-efficient).

"expressive or semantic attributes" which represent the more communicative qualities of a product and the meaning which it communicates. All remaining adjectives coming from the 3 concepts were classified as *aesthetic adjectives, adjectives of social value, adjectives of emotions, and adjectives of interface qualities* (Krippendorff, The semantic turn, pp. 177).

Step 4 *Shortlist, rank, and group the classified adjectives* (*KJ Method*): The KJ Method is a technique which simplifies effective group decision making. It is based on the premise that when participants are informed of each other's perspectives on the same subject their decision making power can increase drastically [30]. The details of this process will not be described as they are readily available in current literature.

This process was performed as a focus group of 4 design experts within the author's research group. The objective of this activity was to rank the adjectives selected from previous step and arrange them into characteristic groups. Each group was then given a representative adjective voted from within each group which was demarcated as the product character representing that particular characteristic group (Fig. 3).

Based on the frequency of usage captured from the previous questionnaire each adjective was ranked. Thus the highest ranked adjectives became dominant characters and the lower ranked adjectives became recessive characters. The final group of 6 characters was—*futuristic, feminine, unconventional, practical, simple, smart*. The attributes within each character serve as a further indication to the designer about the qualities each character represents. From a point of view of language the attributes can also be regarded as synonyms of the character they represent. The opposite adjective (*antonym*) of each character was also indicated using a thesaurus though not visually represented. The characters will act as desirable qualities for the next stage design workshop, and their opposites will act as undesirable qualities which the designers have to definitively avoid.

Step 5 *Visual mood boards—attribution of product characters :* A visual mood board was constructed for each of the above 6 characters. If characters represent the sensory experience of the object, then mood boards are the manifestation of that experience in the form of product features depicted visually. Krippendorff [4] suggests including images of competing products, factory samples, magazine cutouts, sketches, and drawings.

Character	Futuristic (12)	Feminine (12)	Unconventional (9)	Practical (7)	Simple (5)	Smart (5)
Attributes	Modern	Light, Slender, Delicate	Unique, Different, Original, Surprising, Novel, Amazing	Convenient, Utilitarian	Easy	Brilliant, Genius, Sharp, Clever
Antonym	Traditional	Agressive	Conventional	Unpractical	Complex	Naive
	Dominant Characters			Recessive Characters		

Fig. 3 Adjectives arranged as characteristics and characters from KJ method

The mood boards were built with the participation of 4 design experts (i.e. design researchers) within a group discussion focused on which images (from mixed product categories) best manifest each product character. Although the users were the primary contributors in the previous steps of capturing adjectives and classifying the adjectives, this step was entrusted to design experts which is a reflection of the "Design-led" and "Expert mindset" proposed by Sanders [15]. There is consensus in literature [5, 18, 31] which warns that designers possess superior visualisation and attribution capabilities able to connect verbal and visual language.

Step 6 *2nd Design workshop—Poli.Design—Master in Design Engineering:* Instead of asking designers to focus on communicating Eco-efficiency, this workshop aimed to achieve the attribution of the given product characters. Each student was asked to re-design the appearance of a front loading washing machine by attributing the given character set. The 6 characters arranged in 7 combinations of 3 characters each. This was done to achieve the best fit between the number of students (14) and the number of characters (6). Each character combination setting consisted of 2 dominant characters and 1 recessive character. The design students were asked to prioritise the expression of the dominant characters with the expression of recessive character acting as a support for the overall character attribution of the washing machine. Each character set consisting of 3 characters was appointed to 2 designers (total of 14 designers were present) in order to not make the final outcome too characteristic of the capabilities of a single designer.

The character sets were as follows (the first 2 characters in each set are dominant):

(1) futuristic, feminine, smart; (2) futuristic, feminine, practical; (3) futuristic, unconventional, simple; (4) futuristic, unconventional, smart; (5) feminine, unconventional, practical; (6) feminine, unconventional, simple; (7) feminine, futuristic, simple;

Step 7 *2nd questionnaire—Capture feedback using a Semantic Differential scale :* 2 of the 14 students couldn't complete the desired objectives of the workshop therefore 12 concepts were used for the final questionnaire analysis. The students were asked to deliver their concepts against a white background, to reduce the impact of noise. It was decided to retain the presence of colour in the images, even though most of the concepts only used hues of light grey, white, and transparency to illustrate their concept. This was done to judge the impact specifically on 2 concepts which used pastel tones such as red and green and 1 concept which utilised a woodgrain finish which can be an early pointer to the appearance specifications of Eco-efficiency which designers possess and users might validate. This questionnaire was performed online utilising a semantic differential scale to evaluate each concept and consisted of 20 respondents (11 females and 8 males) of age group 19–54 with mixed nationalities. Of the 12 washing machine concepts, all but 1 (utilising a woodgrain finish) succeeded in communicating the attributed meaning of Eco-efficiency to the end users, thus potentially pointing towards woodgrain finish as a 'dead metaphor' [4] or a cliché. The criterion for success was defined as any concept which scores higher than 50 % in the user feedback study.

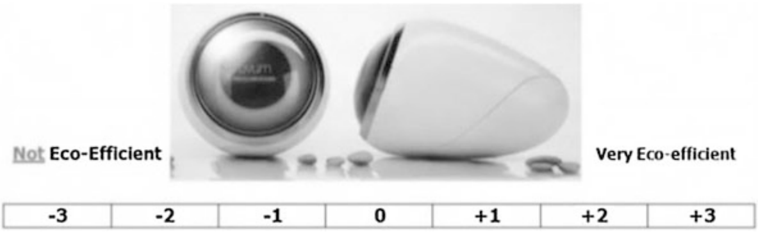


Fig. 4 Online questionnaire with semantic differential (*SD*) scale. (Figure shows concept 1: *futuristic, unconventional, simple*—score 71/120 = 59 % vote)

Fig. 5 Concept no. 4, concept no. 6, and concept no. 10

According to the SD scale (Fig. 4) the range of votes varied between −3 (not at all Eco-efficient) to +3 (Very Eco-efficient) for each concept, thus 'zero' being the over-all neutral median and −60 to +60 being the extremes thus achieving a range of 120 points (sum result of 20 user feedbacks).

The top 3 concepts (Fig. 5) achieved a score of 83/120, 84/120, and 86/120 on the SD scale therefore achieving a success rate of 69 % (concept 10—*futuristic, feminine, smart*), 70 % (concept 4—*futuristic, unconventional, simple*), and 72 % (concept 6—*futuristic, feminine, simple*).

3 Conclusions

It has been said more than once in existing literature that theoretical concepts relating to product semantics have been notoriously difficult by the professional design community to accept [7, 24]. Boess [19] further points out that most designers find it confusing to work with attributing meanings in product design. Keeping these observations in mind, the design students were not given an academic grounding regarding the background and theoretical constructs of Product Semantics and meaning communication, being asked only to focus on character attribution, reflecting similar observations made by Evans and Thomas [24] in their workshop exploring application of product semantics with design students.

The success of all the concepts could also be put down to the selection of the product characters (or appearance attributes) assigned to the designers, seeing as ordinary users have limited skills in reading products and even differentiating amongst them [5]. Blijlevenset al. [5] cite Simplicity, Modernity, and Playful as appearance attributes universally best recognised by non-professionals. According to them appointing these appearance attributes within design guidelines increases the likelihood of a successful communication of intended meaning to non-experts. By no means are these attributes meant to replace the expert based attributes described in literature. Among the 6 characters which the design students were asked to attribute in the final workshop at least 2 of them, i.e. Futuristic (modern) and Simple, corresponded to the universal appearance attributes cited above. This is not surprising as the product characters were user generated in the first place. Blijlevens et al. have also demonstrated these appearance attributes are universal in nature thus lending credibility to these product characters as having relevance in consumer product categories beyond home appliances.

These product characters need to be seen as a light thrown in this subject area, and would need to be tested in several appliance categories to be regarded as robust design guidelines. The results portrayed here are not immune to the influence of trends in perception of Eco-efficiency, based as they are on human centeredness and not Aesthetic Theory which prescribes normative specifications on appearances of products [4].

References

1. Lee M, Lou YC (1996) Consumer reliance on intrinsic and extrinsic cues in product evaluations: a conjoint approach. J Appl Bus Res 12(1):21–29
2. Krippendorff K, Butter R (2008) Semantics: meanings and contexts of artifacts. In: Schifferstein H, Hekkert P (eds) Product experience. doi: www.elsevier.com
3. Gorno R, Colombo S (2011). Attributing intended character to products through their formal features. Paper presented at: DPPI'11 Dppi: international conference on designing pleasurable products and interfaces, Milan, June
4. Krippendorff K (2006) The semantic turn, a new foundation for design. Taylor, Boca Raton, FL
5. Blijlevens J, Creusen MEH, Schoormans JPL (2009) How consumers perceive product appearance: the identification of three product appearance attributes. Int J Des 3(3): 27–35. Retrieved from www.ijdesign.org
6. Athavankar U (2009) From product semantics to generative methods. Paper presented at international association of societies design research Iasdr 2009: rigor and relevance in design, Seoul, Oct 2009
7. Brown C (2006) Product semantics: sophistry or success? In: Feijs L, Kyffin S, Young B (eds) In: Design and semantics of form and movement DeSForM 2006, Koninklijke: Philips Electronics N.V, pp 98–103
8. Cooper T (1999) Creating an economic infrastructure for sustainable product design. J Sustai Prod Des (8): –17. Retrieved from http://www.cfsd.org.uk

9. Krippendorff K (2008) The diversity of meanings of everyday artifacts and human-centered design. In: Feijs L, Hessler M, Kyffin S, Young B (eds) Design and semantics of form and movement DeSForM 2006 Koninklijke: Philips Electronics N.V, pp 12–19
10. Krippendorff K (1989) On the essential contexts of artifacts or on the proposition that “design is making sense (of things)”. Design Issues 5(2):9–39. Retrieved from http://www.jstor.org/stable/1511512
11. Crilly N, Moultrie J, Clarkson JP (2004) Seeing things: consumer response to the visual domain in product design. Design Studies 25:547–577. Retrieved from www.elsevier.com/locate/destud
12. Hekkert P, Schifferstein HNJ (2008) Introducing product experience. In: Hekkert P, Schifferstein HN (eds) Product experience, 1st edn. Charon Tec ltd, USA, pp 1–8
13. Mills B, Schleich J (2010) What’s driving energy efficient appliance label awareness and purchase propensity? Energy Policy 38(2):814–825
14. Cramer J (1997) Towards innovative, more eco-efficient product design strategies. J Sustain Prod Des (1):7–11. Retrieved from http://www.cfsd.org.uk
15. Sanders L (2008) An evolving map of design practice and design research. Interactions 15(6):13–17 doi: 10.1145/1409040.1409043
16. Demirbilek O, Sener B (2003) Product design, semantics and emotional response. Ergonomics 46(13/14):1346–1360
17. Vihma S (2007) Design semiotics- institutional experiences and an initiative for a semiotic theory of form. In: Michel R (ed) Design Research Now- Essays and selected projects. Birkhäuser, Basel, pp 219–232
18. Butter R (1989) Putting theory in practice: an application of product semantics to transportation design. Design Issues 5(2):51–67. Retrieved from http://www.jstor.org/stable/1511514
19. Boess S (2008) Meaning in product use: which terms do designers use in their work? In: Feijs L, Hessler M, Kyffin S, Young B (eds) Design and semantics of form and movement DeSForM 2006, Koninklijke: Philips Electronics N.V, pp 20–27
20. Crilly N, Moultrie J, Clarkson JP (2008) Shaping things: intended consumer response and the other determinants of product form. Des Stud 30:224–254
21. Blaich RI (1989) Philips corporate industrial design: a personal account. Des Stud 5(2):1–8. Retrieved from http://www.jstor.org/stable/1511511
22. Crilly N (2011) Do users know what designers are up to? Product experience and the inference of persuasive intentions. Int J Des 5(3): 1–15. Retrieved from http://www.ijdesign.org/ojs/index.php/IJDesign/index
23. Wikström L (1996) Methods for Evaluation of Products’ Semantics, PhD Thesis, Chalmers University of Technology, Sweden
24. Evans M, Thomas P (2011) Products that tell stories: the use of semantics in the development and understanding of future products. Paper presented at City University International conference on engineering and product design education, London, September
25. Norman DA (1988) The design of everything things. Currency Doubleday, USA
26. Thomas R (2006) A new dialog. In: Feijs L, Kyffin S, Young B (eds) Design and semantics of form and movement DeSForM 2006, Koninklijke: Philips Electronics N.V, pp 10–18
27. Gibson JJ (1979) The Ecological Approach to Visual Perception, Houghton Mifflin, Boston MA
28. Karana E, Hekkert P (2010). User-material-product interrelationships in attributing meanings. Int J Des 4(3):43–53. Retrieved from www.ijdesign.org
29. Janlert LE, Stolterman E (1997) The character of things. Des Stud 18(3):297–314
31. Spool JM, (2004) The KJ technique: a group process for establishing priorities, http://www.uie.com
31. Lawson R, Storer I (2008) ‘styling-in’ semantics. In: Feijs L, Hessler M, Kyffin S, Young B (eds) Design and semantics of form and movement DeSForM 2006, Koninklijke: Philips Electronics N.V, pp 41–49

Indian Aesthetics in Automotive Form

Chirayu S. Shinde

Abstract Indian sense of the beautiful concerned with pure emotion applied to evolve an external appearance of a clearly defined area of automobile. Having gotten an idea of Indian aesthetics, the points and keywords that were closest to the insights gained were penned down. The process of defining Indian Aesthetics started with sketching forms that inculcated physical and emotional inspirations gained through research. Eleven primary forms were created in styrene foam, giving a tangible form to my verbal definition of ideas and emotions. A palette of contemporary Indian volumes, surfaces and lines, was hence created. It is this pallet that has been used later in coming up with an Automotive form that suggests a new style of cars for the world, the Indian Style.

Keywords India · Aesthetics · Automotive Form

1 Introduction

India has a rich culture and heritage, a result of absorption and assimilation of multitude of ideas and practises over the last 5,000 years. The advent of colonial rule and later, the focus on economic sustenance, affected the process, as the world embraced abstraction in art and automobiles. The unstructured variety of exposure post independence explains the confusion in the aesthetic preferences of people of the nation today. India's design practise tries to assimilate and adapt to two centuries of evolution that defines today's global philosophies of modernism, lightness and well-being as per Indian aesthetics and tastes [1].

C. S. Shinde (✉)
Mobility and Vehicle Design, IDC, IIT Bombay, Mumbai, India
e-mail: chirayu.shinde@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_27, © Springer India 2013

India is one of the biggest consumers of automobiles today, yet a very few true indigenous offerings have been introduced to the world. This paper suggests an approach to evolve an external appearance of a clearly defined area of an automobile with an Indian sense of beautiful concerned with pure emotion. The work hopes to come up with an automotive form that suggests a new style of cars for the world, the Indian style.

1.1 The Approach

Book reading, extensive visual examination and cursory survey was performed to garner an understanding of evolution of modern abstraction through study of art movements and their effects on automotive styling. For gaining insights into Indian Aesthetics, a study of present was done, which later went on to the study of the evolution of architecture and sculpture. The insights and interpretation were penned down and given a tangible form in the form of Styrofoam models forming the basis for further exploration and suggestion.

2 Context—Art Movements and Effects on Vehicle Design

It was important to understand how the concept of abstraction came into today's world and how it affected society. The fashion and art has changed with time, so has automotive styling. Here we will see in brief how these changes occurred from the advent of automobiles and how context was found to be relevant to design evolution.

2.1 Art Nouveau and Secessionism, Expressionism, Fauvism

Art Nouveau was started by energetic artists to create an international modern style in response to the industrial revolution. Sinuous lines were introduced. It simplified the ornate Victorian styles.

Inner moods and feelings as opposed to external appearance were incorporated through expressionist ideas using powerful colours and dynamic compositions. Similar ideals of emotions and expressions were strengthened by fauvists during the age [2].

These ideas can be seen in the vehicles, like Benz Victoria, 1893, Oldsmobile Curved Dash, world's first mass produced car, 1901 and Sunbeam Tourer, 1910 to name a few.

The whole shape of the cars of this time could be said to have lacked the appeal to the senses that the modern sculptural forms do [3].

2.2 Avant-Garde Strengthens: Cubism, Futurism, Constructivism, Art Deco, Bauhaus

Development in technology, medicine, communication, and transportation changed the social structures of the world. This was also a major shift from survival to self-actualization with theories of Sigmund Freud and Carl Jung. A struggle to break away from past art was initiated with Cubism. Dynamism, vitality and power of the Machine Age was expressed. Rhythm and Sequence was brought in to glorify the beauty of Speed. Constructivism took these ideas further with identifying and giving importance to the negative space.

Art deco's linear symmetry was a distinct departure from art nouveau representing elegance, glamour, functionality and modernity. Bauhaus tried to bring together fine arts and applied arts. The usefulness of machines was acknowledged in creating simply designed objects without excess decoration [2].

As cars shape evolved, wheels tended to become smaller. Passengers moved forwards and downwards. Cab forward design came up i.e. the windows moved forwards [3].

Voisin C11 Lumineuse, 1926, was the first effort to carry all passengers within the wheel base providing added comfort. It also provided increased side window area. It could be called as the first example of a car that emphasised on sightseeing. The design of Chrysler Airflow was imitated throughout 1930s. Examples like Fiat Balilla, 1934 and Cord 812, 1937, reflected the influences of lifestyle and the cities on vehicle styling quiet accurately.

2.3 Avant Garde Prevails: Minimalism, Conceptualism, Hyperrealism, Now

Minimalism stripped art to essentials. Focus was on Ideas behind art. Simple geometrical shapes were used reducing colours and textures. The actual final product is not as important as the process was asserted by ideals of Conceptualism [2].

Approximately by this time car bodies evolved from being desperate discrete elements into a unified form. As a result 1960s gave birth to stunning pieces of art, like the Citroen DS, Jaguar E-Type, Lamborghini Miura and Countach, Ferrari 250 GT [3].

Today limitations to one's imagination are drastically reduced due to technological advancements. Even conceptual and abstract art is brought to a stage where it is very difficult to deny the possibility of it not being real or abstract [2].

2.3.1 Observations

The world tried to detach itself from the classical theories of art and come up with art movements like art nouveau, futurism, constructivism, so that the arts and sensitivities became more abstract and emotive, rather than external/direct impressions. Advent of colonial rule in India, to be talked about later, overlapped with the birth of the discussed modern abstraction and invention of automobiles. This raises question about abstraction in India, if it has evolved as it has in the rest of the world, for over past 200 years.

2.3.2 Indian Styling for Vehicles a Need

These movements were not merely ideas towards art but also influenced other spheres like architecture, lifestyle and design. The International style in architecture created a monotony in buildings and cities all over the world. It ultimately led to growing resentment against dehumanization of modern cities and buildings all over the world. At around 1970s a critical evaluation of the modernist principles began and hence Post-Modern movement emerged in the west. This encouraged other countries to look at their heritage to create a modern architecture which respected the context and avoided the homogeneity and monotony of the International Style [1].

Cars have today evolved from being a mode of transport and a display of stature to a deeper reflection of emotions, feelings, expressions and an identity [4].

In case of vehicle styling, and the sensitivities and emotions attached with a vehicle seem to be in a state of infancy as we have been formally exposed to the industry only in 1991, i.e. after the Indian automotive industry was liberalised. India is world's sixth [5] largest producer of automobiles today. Yet a very few true indigenous offerings have been introduced to the world.

3 Indian Aesthetics

Indian Cities have been constantly "Inventing, Re-Inventing and Adjusting" themselves to their ever evolving demographics. As a result of this "Kinetic" quality, cities in contemporary India lack the legibility that they possessed at the turn of the century. A greater part of India's population has shifted to urban areas. This has produced chaotic growth and general apathy in their administration [1].

A lack of guiding principle is seen either at the Micro or Macro level. Large-scale architecture in cities is usually site specific, bound by client intentions and restricted to, in most of the cases, superficial styling [1]. Could this chaos be contagious and affect other spheres, vehicle styling being one of them?

When it comes to Indian Aesthetics, Elephants or peacocks, arches and domes, Temples and Fortresses and their sculptures, peace and spiritualism, may come into one's mind. What further raises curiosity is the thought of how much of these ideas are a result of today's work. A majority of what we see today may seem to lack meaning or purpose and merely be a replica of these [1]. We explore this looking at the major eras seen by Indian Subcontinent in this section starting from the Indus valley [1].

3.1 Indus Valley: 3300–500 BCE

The Indus civilisation produced statuettes resembling the hieratic style of contemporary Mesopotamia, while others are done in the smooth, sinuous style that is the prototype of later Indian sculpture, in which the plastic modelling reveals the animating breath of life (prana). Bronze weapons, tools, and sculptures indicate sophistication in craftsmanship rather than a major aesthetic development [6].

3.2 Mauryan Empire: 327–200 BCE

Buddhism was of great importance during this period and believed that the heart of beings is like an unopened lotus: when the virtues of the Buddha develop therein the lotus blossoms. This is why the Buddha sits on a lotus in bloom [6, 7]. Hence one can see how the elements of lotus have been used extensively in their architecture and sculpture.

The soft volume and the sinuous lines of the petals of lotus incorporated, make the sculptures and structures of this period humble and peaceful. The receptacle and the small hemispherical bumps could be an inspiration for the Stupas with a Chhatri atop. The Chaitya entrances with their repetitive arches can be thought of being derived from the structure of lotus flower [6], (Fig. 1a).

3.3 Gupta Empire and Fragmentation: 280–750 CE

The Period witnessed prolific and rigorous developments in temple architecture with extensive use of stone.

Buddhist art flourished during this period, which has often been described as a golden age. As in all periods, there is little difference in the images of the major Indian religions, Buddhist, Hindu, and Jain. Large stone figures, stone and terracotta reliefs, and large and small bronzes are made in the refined Gupta style, with extensive attention to ornamental details [6], (Fig. 1b).

3.4 Architecture and Sculpture of the Hindu Dynasties: 600–1100 CE

The Hindu Dynasties revived throughout India and a characteristic temple plan was developed. Innumerable temples were built and were so richly embellished with sculptural details that their style is called “Sculptural Architecture”. The Khajuraho temples in central India (c.1,000) represent one of the high points of the Nagara buildings, and the Sun Temple at Konark (c.1,250) reveals, in its famous erotic sculptures, carvings that combine balanced mass with delicate execution. The Jain temples at Mt. Abu, constructed entirely of imported white marble and dating from the 10th and 13th century have plain exteriors but are ornately carved inside [6], (Fig. 1c).

3.5 Islamic Rule and Mughal Empire: 1206–1769 CE

A confluence of its Arabic traditions, calligraphy, inlay work and decorative traditions of India can be seen during this period. Islamic art expresses the beauty as an aspect of God through structures, designs and decoration (Fig. 1d).

Mughal art and architecture, an Indo-Islamic-Persian style combined elements of Islamic art and architecture and this resulted in Sufism (Fig. 1e). Originally, Islamic believers needed a tomb for nothing more than placing the body, but due to common people who believed in holy persons, or rulers who held attachment to the present world, erecting splendid mausoleums came about [1]. Where Islam prohibits building of mausoleums, the Taj Mahal stands today as a testimony to fusion and evolution that took place here.

3.6 The Advent of Colonial Powers: 1799–1947

A very different climate, crafts, skills, materials and technologies played a major role in the evolution of an architecture that remained British to the core but was Indian in execution. Key features would be, a dominant roof, deep verandahs all around and elaborate ventilation architecture in India. The concept of bungalows has its roots in Bengal [1], (Fig. 1f).

The concept of trade later turned to a rule and these foreign powers maintaining stronghold of their parent nations throughout their time, was found unique to this era. Little of the glorious tradition of Indian artistic achievement survived British rule [6] which has led to a constant effort to revive what is lost.

3.7 Today

There has been a prolonged distance from arts and crafts, as even after independence the artists and craftsmen were promoted to run a small scale industry which involved mere replication rather than involvement of the artist in exploring and interpreting what his clients expected [1]. Though there has been a great evolution and reinterpretation of Indian culture, it still lags behind in free thinking and expression [1].

The images of pillars of the respective eras (Fig. 1a–f) depict an aspect of absorption and assimilation discussed in this section.

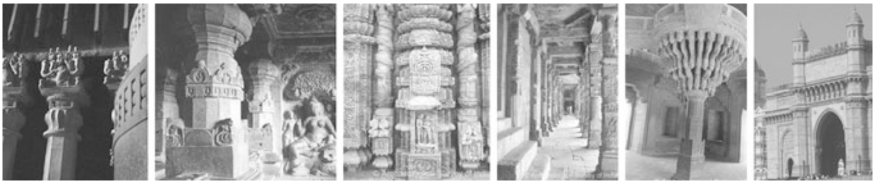


Fig. 1 **a** Karla caves. **b** Ellora caves. *Source* http://asi.nic.in/images/wh_ellora/pages/024.html, 7.2.2012. **c** Sun temple. *Source* http://asi.nic.in/images/wh_konark/pages/019.html, 10.2. 2012. **d** Quwwat-ul-Islam Mosque: http://asi.nic.in/images/wh_qutb/pages/012.html, 10.2.2012. **e** Diwan-e-Khas: http://asi.nic.in/images/wh_fatehpursikri/pages/025.html, 10.2.2012. **f** Gateway of India

4 The Interpretation of Indian Aesthetics

India's design practise faces the need to assimilate and adapt to the two centuries of evolution that defines today's global philosophies of modernism, lightness and well-being as per Indian aesthetics and tastes [1]. What follows in this section are (suggestions on/interpretations of) Indian Aesthetics which are based on the study done, observations made and insights gained.

4.1 Interpretation

The forms are never skinny but voluminous. They are never stripped down to their functional elements, and if so, their functional elements are also beautified. Volumes are created with liberal, but not wasteful use of resources.

The use of Datura and Lotus flowers has played an important role in the evolution of Indian Aesthetics, as they were used by the earliest of known civilisation, the Indus Valley and the Mauryans and then later the Vedic and others that followed.

Multiple Limbs have been shown so as to hail the multiple capabilities of the divine beings. Respect to the five elements, air, water, earth, fire and space has always been given. This can be seen even today as the temples are built such that the first rays of sun fall on the idols of Gods.

Sinuous lines are a prominent feature of sculptures and motifs across all ages. A play of surface around a basic form is seen. Harmony of elements that are complete in itself, are placed around a central element gently evolving the form and giving it a meaning. A sense of celebration, happiness and joy suggests playfulness of the forms. Tranquillity and control on self should also be reflected. The form should reflect its inner beauty and external sensuousness, in subtle but direct way, like the art of dance, nothing is left to chance, as each gesture seeks to communicate ideas and each facial expression the emotions.

5 Expressions

Creation of primary forms out of styrene foam was to come up with a palette of volumes, surface and lines that defined the points of views and the key words set. It was necessary to come up with these as it was felt there exists a lack of forms that are contemporary abstractions of Indian Aesthetics. These forms are to define, and to show, a fresh take on contemporary abstractions of Indian Aesthetics that would form the basis for further explorations.

5.1 Primary Form Explorations

5.1.1 Dynamism

A voluminous form that suggests swift movement led to fusing a slender and dynamic side profile with relatively huge top profile (Fig. 2).

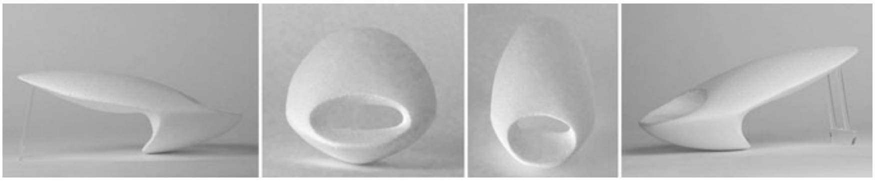


Fig. 2 Dynamism

5.1.2 Datura

Datura Flower has always been associated with Lord Shiva. This possibly explains the ribs running vertically along pillars during the Gupta period, like those on the flower (Fig. 3).

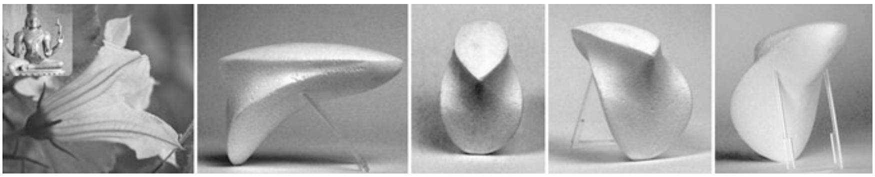


Fig. 3 Datura

The form reflects the silhouette of Datura and essence of Shiva, the destroyer and creator. The relatively flat top gives seriousness to the form. The top drooping down and the surface beneath with a broad mouth in the front narrowing down, at the rear end, gives the form a sense of power and control. The elements of the form appear emerging from behind the surfaces giving a mysterious peek into its underlying capabilities.

5.1.3 Arghya

The exact moment of water falling off one's palms as an offering to god has been captured. The Spherical bulge on the front with an element below has been thought of reflecting the generosity and faith with which offering is made (Fig. 4).

Fig. 4 Arghya. *Source* (l*eft first*): http://www.thesipoflife.com/wp-content/uploads/2010/04/Kumbh-Haridwar-2010-3.jpg

5.1.4 Lotus

Abode of the Buddha, Lotus is a representation of chakra or ones aura (Fig. 5).

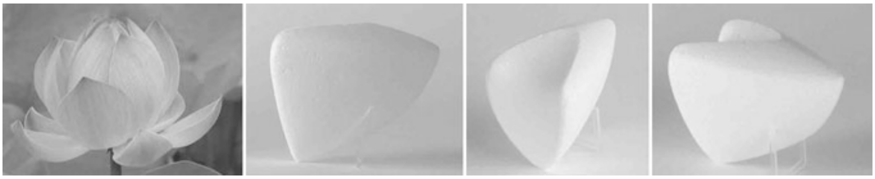


Fig. 5 Lotus

A simple, soft triangular form depicts the bud of lotus from the sides. The movements of surfaces and intersections give a mix of soft and sharp shadows. The surface on the side gently holds the core of the form. Two petals, on the top, created out negative and positive volumes depicting replication. The form raises emotions of peace and simplicity.

5.1.5 Buddha

Visualizing one meditating, sitting cross-legged, in a Chaitya that has pillars with lotus like bulges and ribs all around with a huge Stupa in the front has led to the form (Fig. 6).

Fig. 6 Buddha

The form has two elements, one in the centre and the second around it. From the side, it comes up like enlightened being making it firm and aware, while the top surface droops down making it humble. It also mimics the stance of Buddha meditating.

5.1.6 Banyan Tree and Yogi

A perfect symbolization of eternal life due to seemingly unending expansion is the Banyan tree (Fig. 7). Often Yogis are shown meditating under it (Fig. 8).

The form consists of vast surfaces creating an immense volume that resemble the characters of a banyan tree. The bottom has been defined separately and the huge volume that grows up from it represents the shoots of the tree. The volume overhanging on the top signifies shade/closure to whatever is beneath it.

Fig. 7 Banyan tree

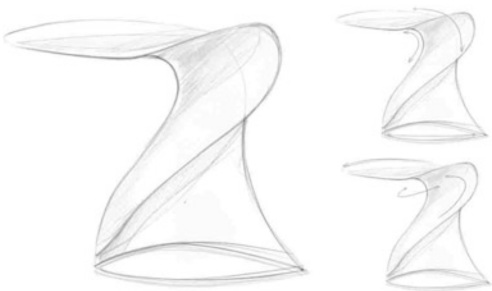
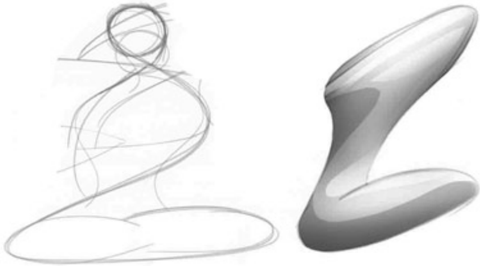


Fig. 8 Yogi



Yogi (Fig. 8) with its subtle form of a human sitting cross-legged in a meditative state shows the boldness of the enlightened saints of India.

5.1.7 Sensuous

Innumerous sensuous sculptures of Yakshis form the Mauryan period and the expressive erotic female sculptures from the temples of Khajuraho and the Sun temple of Orissa made this expression undeniable.

Fig. 9 Sensuous. *Source* (*left first*): http://asi.nic.in/images/wh_khajuraho/pages/009.html

This form (Fig. 9) is an abstraction of a curvy Indian Lady wearing a sari preparing for her ablutions sitting by a water tank. The transition from the top volume to the bottom represents the slenderness of the waist of a lady as she sits down with her legs held close with the knees bent. Enough volume has been given to the thighs and the breasts as in the sculptures to accentuate the sensuality in a very subtle yet direct way.

5.1.8 Elephant and Playful Sensuous

The beloved Lord Ganesha, the care taker and his playful image, and the ride of the Kings, the grandeur of it, the infinite replications on the Indian sculptures, lead to this form of elephant.

The form (Fig. 10) is very voluminous and round giving it a presence and the playfulness. The movement to the legs and the shape given makes the huge form very nimble. The head, ears and one of the forelegs is embedded in a single volume.

Fig. 10 Elephant

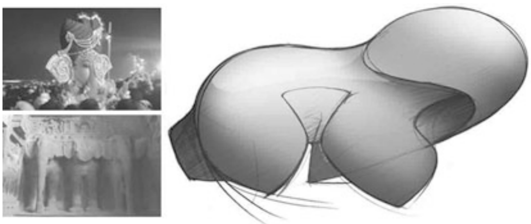


Fig. 11 Playful sensuous

Experimentation with sensuous and playfulness lead to this voluminous form with curvy and sinuous lines (Fig. 11). Opposite characters of innocence and maturity of an Indian lady can be seen in the form. The form consists of two volumes, representing the breasts and the hip of a lady, thrown along the form giving a hint of carelessness and innocence.

5.1.9 Flame

Fire has always been associated with Indian practises. The feeling of warmth and celebration attached with fire has been emulated through the soft form with crisp edges by the merging of concave and convex surfaces that give a nice play of light and shadow (Fig. 12).

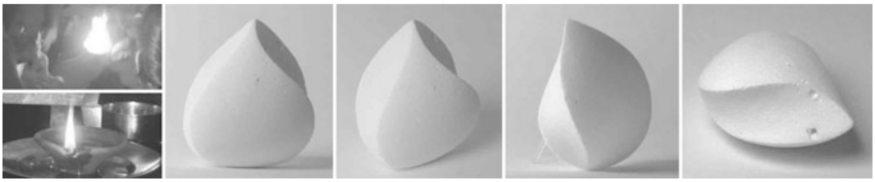


Fig. 12 Flame

Curvy edges give fluidity to the form very subtly. The volume ends in a defined way in all directions reassuring that it is a calm flame and not an erratic fire. This form shows discipline through its controlled movements.

5.1.10 Peepal (Sacred Fig)

Lord Datta, an embodiment of Brahma Vishnu and Mahesh (Shiva) hence the Lord of creation, sustenance, prosperity, well-being and destruction is believed to reside in every living being. Peepal is considered to be his dwelling (Fig. 13).

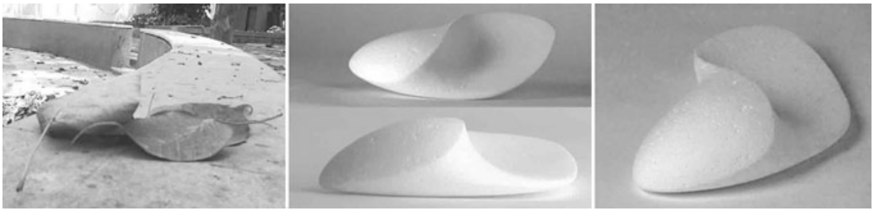


Fig. 13 Peepal

Derived from three dry peepal leaves kept together, the form is one continuous surface that folds the way a dry peepal leaf does. This surface meets at the centre giving a soothing curvy edge that emerges from the front volume. As it moves along the form, it disappears on to the surface merging with the volume. The way positive and negative space has been incorporated in the overall volume of the form makes it full and voluminous, while it appears to be so thin, raises curiosity.

5.2 Secondary Form Explorations

Having created a pallet of volumes and surfaces that defined my perception and understanding of Indian aesthetics, their usage in deriving automotive forms had to be focused on (Fig. 14).

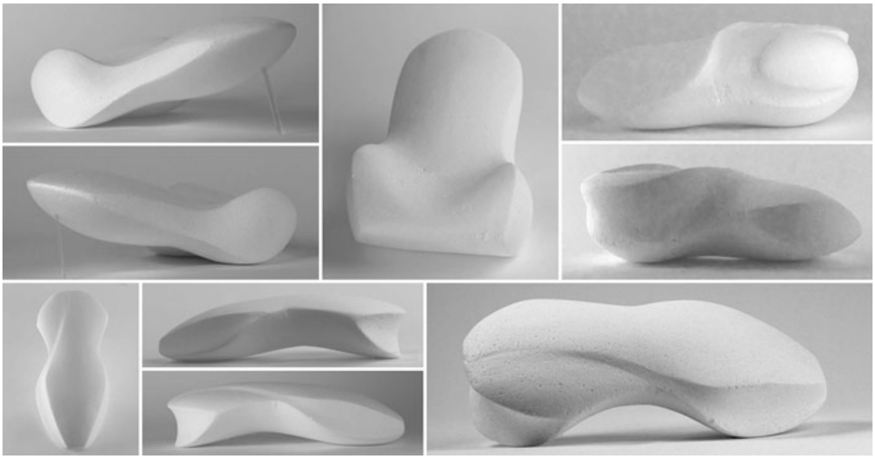


Fig. 14 The process fusion and experimentation

Hence the process of fusion of these elements was commenced through sketches at first and then a few physical models. These explorations are an experiment towards application of this pallet in creating more complex forms maintaining the feel of the primary forms. These forms are not intended to be defined as the primary forms, but an experiment of fusion of the same.

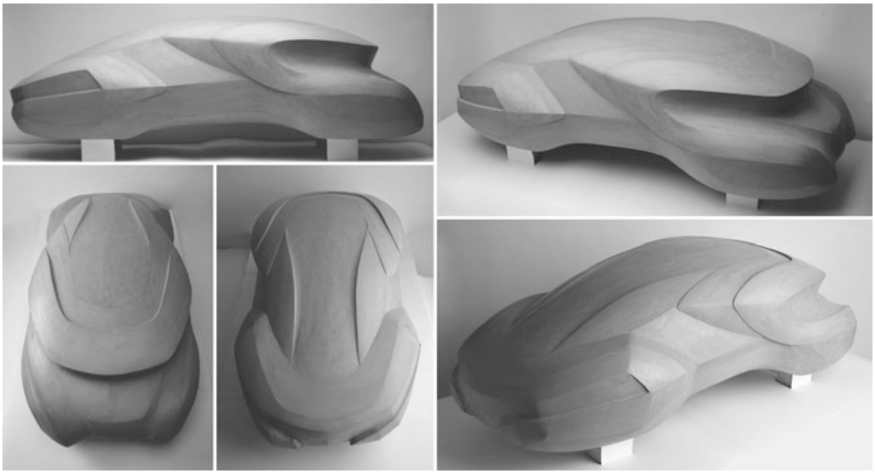


Fig. 15 Sutra

5.3 Deriving the Final Form: Sutra

The form was to appear very soft and simple from a distance, and closing and completing the form from all the sides was a move in the direction. The surfaces and elements were to adhere to the form and not appear to detached especially at the ends and hence create a soft volume. The form was to be open to deriving different configurations of vehicles out of it and an amalgamation of the definition of Indian Aesthetics perceived.

Composure and a controlled flow were to reflect from the form to resemble the Indian ideals of awareness, mental, physical and spiritual, and tranquillity. The use of long, continuous and soft lines, hence surfaces and volumes, in arriving at the form was an attempt towards the thought (Fig. 15).

The form was to involve onlookers in the play of concave and convex surfaces, the reflections and shadows created by them and the flow suggested, making it presence felt directly yet subtly raising ones curiosity to know more about it. Going closer it would reveal a play of sinuous lines flowing over the form very gently, defining each element of it one after another. The lotus petal like element that emerges out from over the rear and progresses from the side up to the centre of the form is an example in the direction. A continuous band can be seen to take the onlooker on a trip all over the form, gently arching its way along the centre and again twisting its way back to the top at the front.

Each element was handled to portray its completeness, being a part of and coherent to the form, so that even if they were to be considered individual, would still be complete. These elements then would contribute equally to the overall form of the concept. The elements were to maintain continuity, physically and visually, throughout the form.

With its contours repeating like the petals of lotus, as viewed from the top, Sutra is a work towards the use of replication of elements in automotive forms. The top surface was handled with crisp creases having a very gentle flow/waviness as they traverse the form, to render sensuousness to the form.

The form uses the pallet of volumes, surfaces and lines, created through primary and secondary forms hence suggesting the possible application of the pallet in automotive styling. Sutra is a collection of aphorisms relating to some aspect of the conduct of life [8]. The name was found closest to the purpose of the form and hence given to it.

Acknowledgments My work on "Indian Aesthetics and Automotive Forms" owes gratitude to my professors K. Munshi, K. Ramachandran and Nishant Sharma, at IDC, IIT Bombay and friends/batch-mates Keith D'souza and Mohit Gupta for their valuable inputs that helped me immensely in the ideation of the concept. I am equally thankful to anonymous reviewers who from time to time throughout the making of the model helped me with their feedback. A special mention remains to be made of the invaluable support of Anisha Malhotra, Pratik Shinde and Ellina Rath in the completion of the paper.

References

1. Pal P (2000) Reflections on the arts in India. Marg Publications, Mumbai, pp 63, 85, 87, 101, 109
2. Hodge S (2011) 50 Art ideas you really need to know. Quercus pp 92–135, 176-183, 196–203
3. Zumbrunn M, Cumberford R (2004) Auto legends classics of style and design. Merrel Publication, US
4. Andrew Noakes (text), Paul Turner and Sue Pressley (design), Philip de Ste. Croix (editor) (2011) Great Cars: a sensational collection from classics to the modern greats. Parragon, UK
5. http://oica.net/wp-content/uploads/total-2011.pdf, 8 Mar 2012
6. http://www.infoplease.com/ce6/.html. The Columbia electronic encyclopedia© 1994, 2000–2006, on Infoplease. © 2000–2007 Pearson Education, publishing as Infoplease, 28 Feb 2012. <http://www.infoplease.com/ce6/ent/A0825105.html>
7. Spirituality in art, Museum pre-visit packet, Utah museum of fine arts, pp 13 2008
8. Sutra. Online Etymology Dictionary. Douglas harper, historian. 14 Oct 2012. < Dictionary. com http://dictionary.reference.com/browse/sutra>

Bibliography

9. Taschen A, Photos, Von Schaewen D (eds) (2008) Indian style. Taschen GmbH
10. BharathRamamrutham, Ghurde M, Shah S, Von Tschurtschenthaler D (eds) (2004) Indian design. Daab GmbH
11. Kimes BR, Goodfellow WS, Furman M (2005) Speed, style and beauty: cars from the Ralph Lauren collection. MFA Publications

Understanding Emotions and Related Appraisal Pattern

Soumava Mandal and Amitoj Singh

Abstract Understanding of emotions and the appraisal patterns associated with emotions is vital in the fields such as user experience design, product design, advertising and fashion. People respond with different emotions to the same situation depending on how they interpret, or appraise the situation. It is important for a designer to understand the differentiation in emotions in order to design emotion-laden products. But assessment and mapping of emotions is always a tough task, because the topic itself is subjective and abstract. It is in this context that this paper presents an approach to differentiate emotions and to map emotions on the basis of the related appraisal patterns.

Keywords Emotion · Experience design · Abstract · Human cognition · Appraisal

1 Introduction

The world of design has been solely dominated by either usability i.e. ease of use and esthetics or combination of both. But the definition of meaningful design is slowly shifting from usability and efficiency to holistic aspects of emotional

S. Mandal (✉)
User Experience Designer, Bangalore, India
e-mail: soumava.mdes08@gmail.com

S. Mandal
IIT Delhi, New Delhi, India

A. Singh
Emotion Centered Design and Innovation Expert, New Delhi, India
e-mail: amitoj_design@yahoo.com

A. Singh
Industrial Design, IIT Delhi, New Delhi, India

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_28, © Springer India 2013

experiences and affect. Only in recent years, psychologists, designers, marketing gurus (Norman 2004; Demet 2002; Bagozzi et al. 1999; Jordan 2000) are trying to articulate cognitive decision making pattern of customers through emotional experience. To understand emotional aspects, design authors have been back to cognitive aspects of eliciting emotion i.e. appraisals.

1.1 Definition

According to appraisal theorists (Lazarus 1991; Oatley and Johnson-Laird 1989), emotion is a mental state of alacrity which is elicited from a diagnostic cognitive framework. This framework helps intelligent organisms to make the decision of subsequent activity. It depends on various parameters like relevance with goals and coping power of the organism according to the nature of stimuli. The coping power dictates the bipolar dimension of an emotion: positive or negative valence. Positive emotions are joy, happiness. Fun etc. and negative emotions are anger; disgust etc. emotions are varied from simple, primary which is triggered by behavior with high survival value to complex emotion which is triggered by complex multi-layered cognitive processing. Plutchik (1997), in his famous circumplex model, showed how these emotions are inter related with different intensity and combinations, and how mixing of these primary emotion can generate complex emotions with different valence like color wheel [1] (Fig. 1).

The study of positive emotions is important and interesting because designers are often prescribed to create a product experience with intension to evoke certain kind of positive emotion while interacting with users. Engagement, enticement is result of human appraisal to positive emotions. With clear goals, high level of equilibrium between individual skills and task challenges and clear immediate results user will fully engrossed in any task having high level of satisfaction-mostly leads to positive emotion [2]. If skill level or individual level of coping power is retarded with respect to challenge, it leads to anxiety.

2 Different Framework of Emotions and Their Relation Among Them

Jordan (2000), Norman (2004) and Desmet (2002) are trying to define the framework of eliciting emotion. These frameworks are outcomes of various research results done by various psychologists (Lazarus 1991; Frija 1994; Scherer 2001; Ortony 2005). Though the interpretation of these frameworks are different, but their philosophical aspects are interrelated.

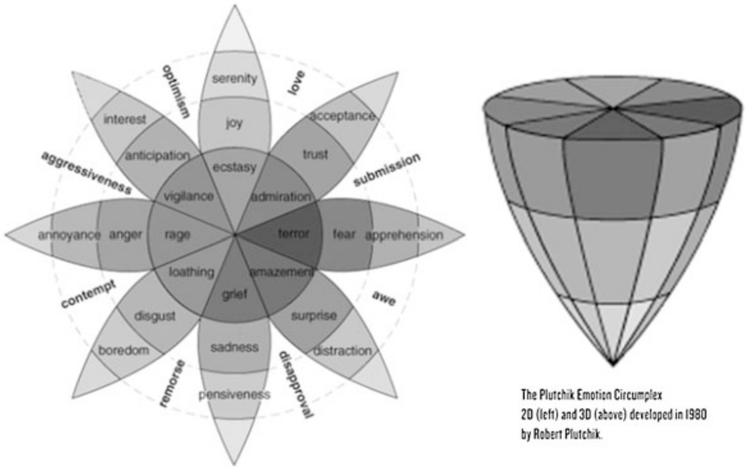


Fig. 1 Circumplex model of Plutchik. *Source* emotions and life: perspectives from psychology, biology, and evolution: Robert Plutchik

2.1 Jordan's Pleasure Theory

Foundation of famous four pleasure theory proposed by Canadian anthropologist Lionel Tiger, later popularized by Pat Jordan, lies on 'human pleasurability'. This theory is very straight forward and only implies for simple emotions, but it doesn't explain complex multi-layered emotions like thrill [3]. The 4 parameters are:

- Physio—related to the body and the senses.
- Psycho—related to the mind and the emotions.
- Socio—related to social acceptance, relationships and status.
- Ideo—related to values and beliefs.

2.2 Norman's Theory of Emotion

Neuro-biological process theory discusses how information is processed in different levels: visceral, behavioral and reflective. The automatic, prewired primary level, the visceral level: this layer deals with sensory aspects of an experience. The second level: this subconscious thinking is the Behavioral level of processing in everyday life. And the third level is the most complex advanced level: reflective layer which deals with conscious consideration and reflection learned during past experiences [4].

2.3 Desmet's Appraisal Theory

As a designer it is very important to have an in-depth knowledge on appraisal patterns of emotion so that one can use this concept while designing a product. And designer can generate a product to evoke certain emotions. People respond with different emotions to the same situation depending on how they interpret, or appraise. Appraisal theories state experiencing an unpleasant emotion requires appraising a situation as harmful to personal well-being, whereas a pleasant emotion involves appraising a situation as beneficial. In this context appraisal theorist proposed several cognitive appraisal components. These are: motive consistency component, expectation confirmation component, agency component, standards conformance component, coping potential component, certainty component, valence, goal congruency, goal conduciveness, normative significance [5].

By observing these theories, a common pattern and inter-relation can be found. For example Jordan's Physio-pleasure theory and Norman's visceral level processing manifest same interpretation in different way. Jordan's Psycho, Socio and Ideo-pleasure, Norman's behavioral and reflective level of processing and Desmet's appraisal theory demonstrate same core philosophy.

3 Research

3.1 Prolog

We have taken five positive emotions: Happiness, joy, excitement, thrill and fun. The preliminary aim of the research is to make dimensions on how each of these emotions these pleasing emotions can be differentiate.

Question we are trying to address are:

- These emotions have very similar meaning and they are abstract too. So are there any dimensions on which we can differentiate them?
- Is there any pattern?
- Which emotions are too similar for people?

3.2 Sample and Data Collection

Forty two university students (age between 24 and 30) were recruited for a volunteer research study. 15 out of 42 students were females. Half of the students have design background. An interview was designed to identify the participant's appraisal pattern. They have been asked to recollect any situation or product that they have faced or experienced last time along with a set of questionnaire and interview. Video/audio recording has been taken.

3.3 Analysis

The video/audio recordings have been transcribed. These corpuses are used as the unit of analysis. The verbatim comments are printed and cut into several corpuses, and rearrange into group with the similar corpuses. These chunks have been coded into several categories. Table 1 provides exemplary statements for all emotions. Latent content is also included into the analysis to notice silence, sighs, stammering, and postures to infer whether participants are finding difficulties to distinguish among emotions or trying hard to recollect a certain emotion. The number of times that a category repeats has been recorded in the study and analyzed. And finally mapping has been done with the co-relation among these categories and the emotions.

4 Findings

4.1 Prolog

We already conceive literary meanings of these emotions. But can the dictionary definition of these emotions exactly be mapped with actual perception of these emotions! Based on the interviews and questionnaires, 4 major types of dimensions are being address. These are Amplitude, Time, frequency of occurrence and association with social interactions. On these parameters we can map these abstract emotions.

4.2 Happiness

The dictionary meaning of emotion 'Happy' says:

- Feeling, showing or causing pleasure or satisfaction……Cambridge [6]
- Delighted, pleased, or glad, as over a particular thing……dictionary.com [7]
- Experiencing pleasure or joy; Satisfied; enjoying well-being and contentment……Webster [8]

The associate keywords/emotions are related to higher level of wish fulfillment, contentment and satisfaction after achieving desired goals-an activity based emotion. Most of the users say when they achieve his desired goal. The value/amplitude antecedent of this emotion is very high. But another important factor is responsible to determine the mapping of this emotion: expectancy or subjective control over achievements. For happy it is partial control over achievement i.e. the uncertainty factor is pretty high at the same time the user has high motive relevance and congruence. Users perceive that the action-control expectancy and action outcome-control and situation. For e.g. one has done a good amount preparation and he

Table 1 Example of statements referring to different parameters

Category	Sub category	Example	Participant ID	Emotion
Social interaction	With closed ones	…When I proposed her and she accepted…	Participant 1	Happy
	With others	…with my old Panjab wale friends when I booze…	Participant 6	Fun
Frequency of occurrence	Seldom	…After the interview result of Supergas where I got selected through campus placement…	Participant 1	Thrill
	Often	…when play cricket with my cousins during my vacation…	Participant 3	Thrill
	Very often	…When 1 am with my roommates and friends doing mischiefs…	Participant 1	Fun
Duration of experience	Long (lasted for days)	…Last time I was with my family members, whole week I was happy…	Participant 2	Happy
	Moderate (lasted for an hours or several hours)	…When she accepted, the whole night I felt very happy, and recollecting…	Participant 1	Happy
	Very less (lasted for a min or little more)	…when result out…	Participant 4	Excitement
Intensity of arousal	Very intense	…After the interview result of Supergas…, it was very intense…	Participant 1	Thrill
	Moderate	…hanging with my friend, it was fun but moderately intense…	Participant 2	Fun
	Less intense	…When went for marketing with my best friend, it was less intense…	Participant 3	Joy

expects that he will get through the entrance exam, but at the same time he has a fear to failure as so many students are aspiring i.e. negative valence. This mixed valence creates internal predicament after the activity for the goal. Because of this uncertainty, the emotion steps up from joy level to happy level. Happy is more cherishable, flat and creates a long lasting impression (Fig. 2).

4.3 *Joy*

The dictionary meaning of emotion 'Joy' says:

- The emotion of great happiness; Make glad or happy……Webster [8]
- The emotion of great delight or happiness caused by something exceptionally good or satisfying; keen pleasure; elation……dictionary.com [7]
- Great happiness……Cambridge [6]

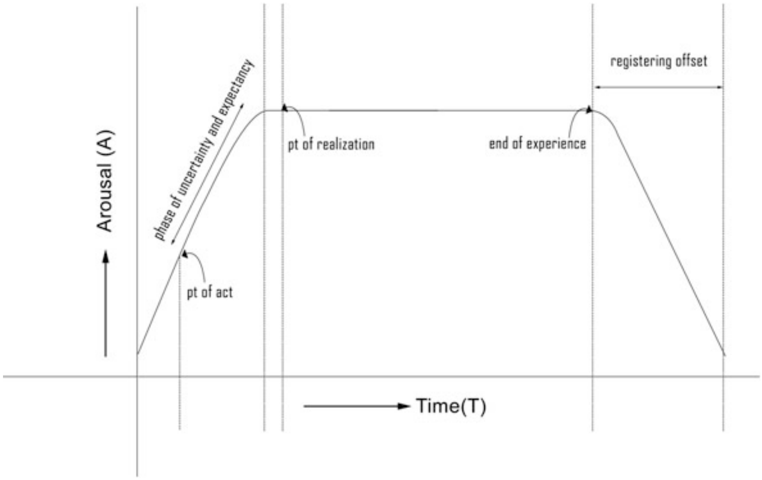


Fig. 2 Proposed journey of experience model: Happy. *Source* self-study

Joy and happy are almost synonymous. People find difficulty to distinguish between them because of the thin layer. Because like happy, joy is also a flat emotion, but the time-extent of this emotion is little less and sometimes momentary. User has less motive relevance and congruence. Being with friends, meeting with my boyfriend, riding bikes, getting stipends has low motive relevance, it's a pleasant emotion, if one is getting stipend, one will be able to spend her assistantship that money on buying things whatever he/she wants. One does not have any repulsion to feed someone else with that money. He/she is not involved with her evaluation of his/her resources and options for coping. The process of going to the level of joy is as fast as the dropping the experience line (Fig. 3).

4.4 Excitement

The dictionary meaning of emotion 'Excitement' says:

- The state of being emotionally aroused and worked up……dictionary.com [7]
- To make someone have strong feelings of happiness and enthusiasm……Cambridge [6]
- Feeling of lively and cheerful joy……Webster [8]

In excitement the amplitude of arousal is very high, but the same time the frequency of occurrence is quite low. There is low expectancy or no expectancy of outcome but which is highly consistent with the motive relevance. For e.g. first time movie watching, first time meeting with girlfriend, to see own name in the campus interview—a student who has mediocre preparation, have very low expectation of getting job, and then he suddenly sees his name in the list of successful candidate, he experiences excitement (Fig. 4).

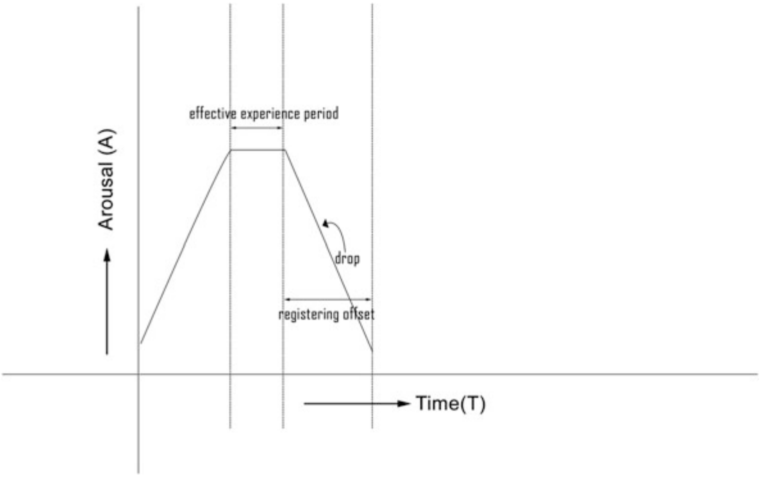


Fig. 3 Proposed journey of experience model: Joy. *Source* self-study

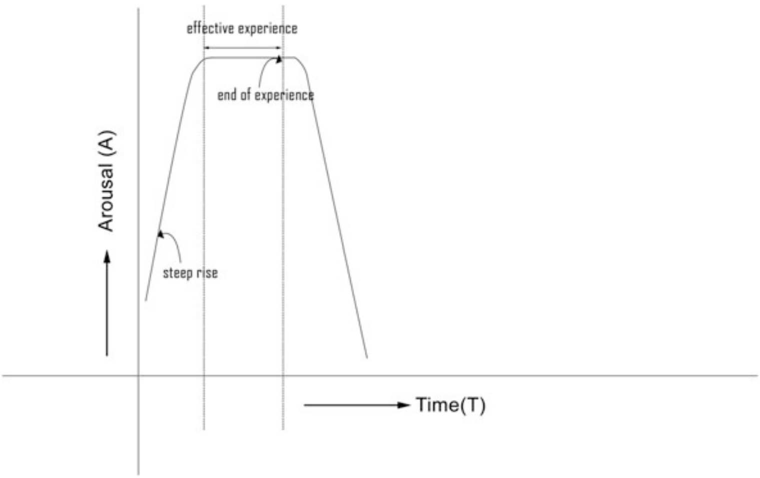


Fig. 4 Proposed journey of experience model: Excitement. *Source* self-study

4.5 Thrill

The dictionary meaning of emotion 'Thrill' says:

- The swift release of a store of affective force……Webster [8]
- A feeling of extreme excitement, usually caused by something pleasant……Cambridge [6]

Amplitude of arousal is the highest among these emotions and frequency of the occurrence is zero, most of the time it is the first time and last time for a particular event. For e.g. first time riding on rollercoaster elicits the experience of thrill, but second time experience with rollercoaster evokes excitement rather than thrill and the association with social interaction is least with this emotion. The environment is apparently adverse and it gives a perception of negative valence, but the cognition force organism to readdress as a positive valence. The arousal level is very high with physiological signs like sweating. But the cognition suggests and the event/product lies in positive valence. This emotion is ambivalence in nature (Fig. 5).

4.6 Fun

The dictionary meaning of emotion 'Fun' says:

- Providing enjoyment; pleasantly entertaining……Webster [8]
- A source of enjoyment, amusement, or pleasure……dictionary.com [7]
- Pleasure, enjoyment, amusement……Cambridge [6]

The distinct feature of this emotion is high level of social interaction but positive valence amplitude of arousal is low. For e.g. roaming with friends and the day outing with family requires high level of social interaction, and the frequency of occurrence is also very high, but the amplitude of arousal is very low. But on the other hand, the experience time-span is very high.

In the Figs. 6, 7, 8, 9, these positive emotions have been mapped with respect to different parameters. In all the graphs, parameters i.e. Social interaction, frequency of occurrence and the time-span have been plotted with respect to arousal. A particular emotion which has shown highest value on these dimension, has been taken as highest unit, and other emotions have been mapped relatively based on the content analysis.

5 Implication on Design Decision

Now the question is how these parameters can further extrapolate design decisions while designing an experience.

5.1 Synthesize Physio-Pleasure

If we analyze the experience journey of these positive emotions (refer Figs. 2, 3, 4, 5, 6), a common pattern of all these positive emotions is increase of amplitude of arousal within positive quadrant or from negative to positive valence with respect

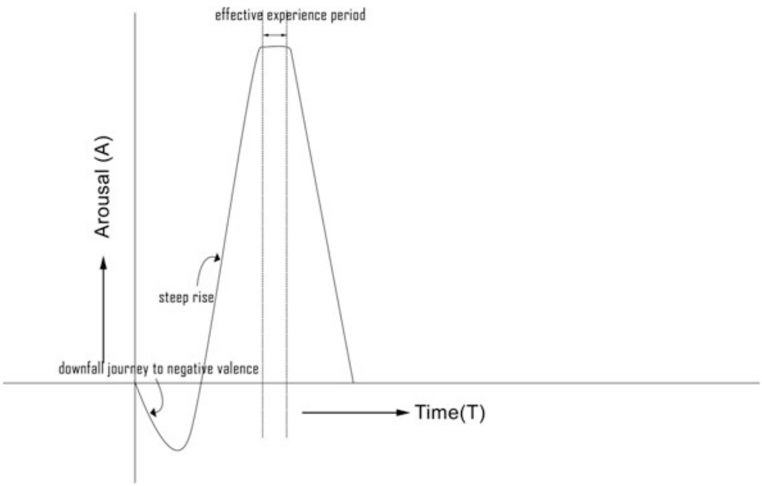


Fig. 5 Proposed journey of experience model: Thrill. *Source* self-study

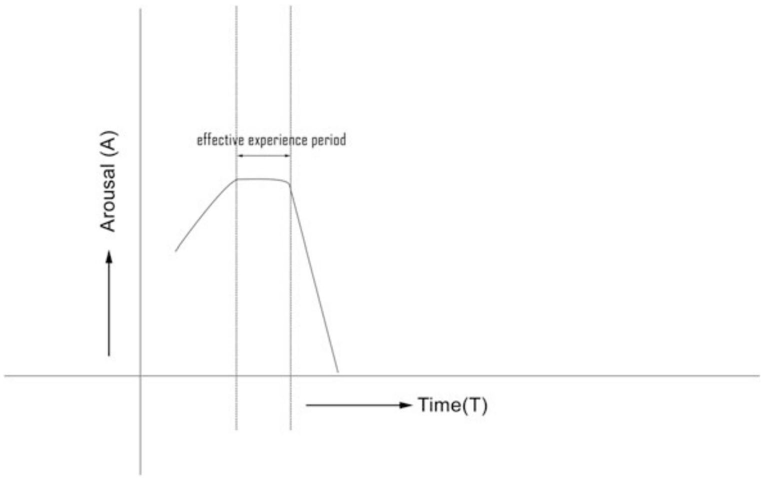


Fig. 6 Proposed journey of experience model: Fun. *Source* self-study

to time. Now question is how a designer can increase an arousal. In the research, participants often refer an experience that is associated to synthesizing physio-pleasures i.e. any five senses or combination of multiple senses. They refer to an experience of visiting Taj Mahal in the moonlight i.e. visual pleasure, listening to Bach or Mozart i.e. auditory pleasure, having dinner in a restaurant with family i.e. pleasure of taste.

The classic example of visual stimulation is experience design in stalls in Delhi auto-expo 2010: If we compare the stalls of Hero-Honda and Yamaha [9, 10]. Hero-Honda as a brand emphasizes on the fact that it is a common man's commuter where

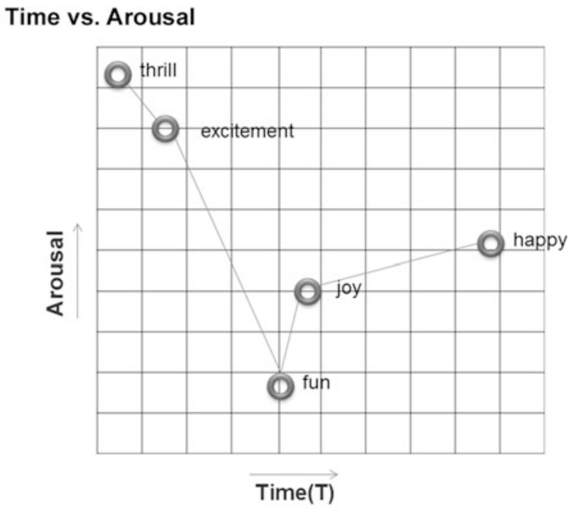


Fig. 7 Time versus amplitude of arousal. *Source* self-study

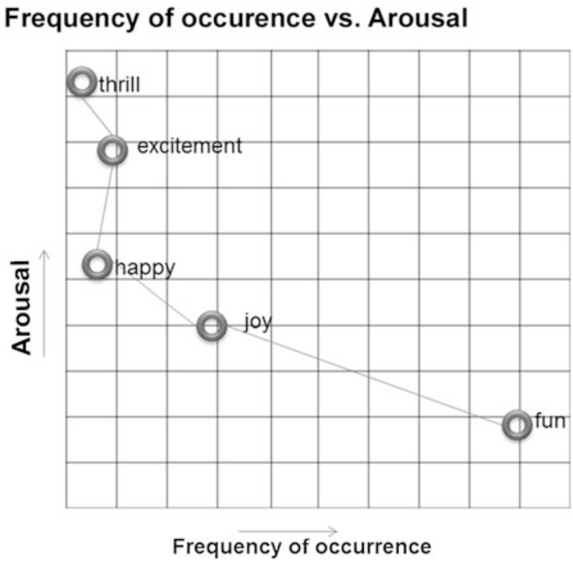


Fig. 8 Amplitude of arousal versus frequency of occurrence. *Source* self-study

joy of riding is their central philosophy, so the use of bright ambience, sounds of refreshing water-curtain creates a visual and aural pleasure which accentuates the brand identity. On the other hand, Yamaha's ambience was little dark, posing models in sensual way on top of the bikes creates a visual message of masculinity, adventurous and raunchy nature of the brand (Figs. 10, 11).

Another classic example is goosebumpspickles.com's enticing photography of pickles [11] or Tata-Nano's home page justifying their tagline "khusiyon ka chaabi-key to happiness" [12] (Figs. 12, 13).

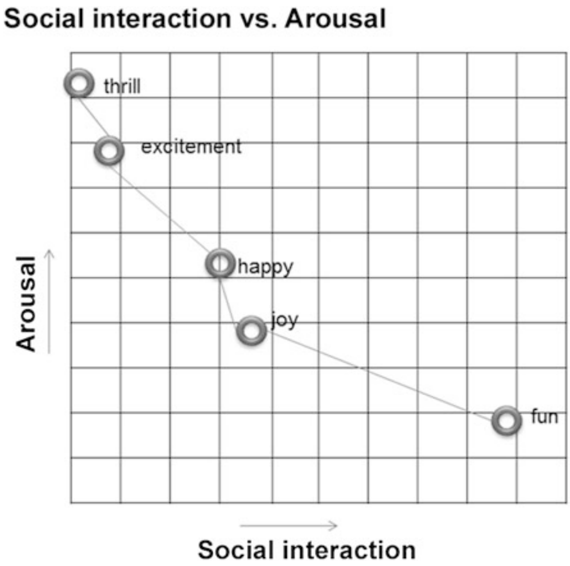


Fig. 9 Amplitude of arousal versus social interaction. *Source* self-study

Fig. 10 Hero-Honda stall auto-expo-2010. *Source* http://www.superbikesindelhi.com

5.2 Changing Persuasion with Positive Way

One of the important patterns from research is expectancy (refer to Sect. 4.2) and frequency of occurrence of events (refer to Fig. 8). Revealing unexpected positive elements in a subtle and intelligent way creates a surprise in positive way, changes the user anticipation and image towards the product experience. For example, Flipkart always promises to their customer that purchased product will be reached within 3–4 working days, but generally product comes within 1–2 days. Here users' expectation and persuasion changes because of promptness of the logistic

Fig. 11 Yamaha stall auto-expo-2010. *Source* http://www.2wheelsindia.com

Fig. 12 Homepage of Goosebumpspickle. *Source* http://www.goosebumpspickles.com/

Fig. 13 Homepage of Tata-Nano. *Source* http://tatanano.inservices.tatamotors.com/tatamotors/home.htm

and supply chain management system of the Flipkart. This transforms Flipkart to India's largest online retailer with 2.6 million users and daily revenues of Rs 2.5 crore [11] (Fig. 14).

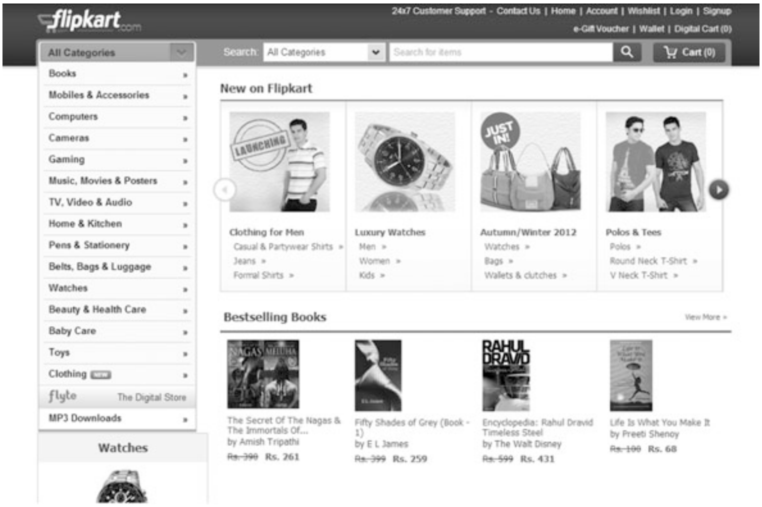


Fig. 14 Homepage of Flipkart. *Source* http://www.flipkart.com/

5.3 Stimulate Socio-Psychological Interaction

Most of the positive emotions has one common factor is high social interaction (Happy, Joy and Fun). Human beings are born with a natural instinct to find their natural place in society. For example, Facebook, top social networking website, is not a primary channel of communication or necessity like phone, but still according to Bureau of Labor Statistics report, the average Facebook user spends more than 11 h per month on Facebook [14].

5.4 Experience the Dynamics in most Usable Way

Usability is an integral part of emotional design. Though Norman says that even a product is esthetically appealing but little difficult to use, user will try to get the right path. But with excellent usability, the whole experience of easy completion of task elicits emotions and attachment with the product. Comments like "When I saw my 60 years old mother was easily able to use my gift-an iPhone, I felt so happy about it. It just took 2 days", make researcher to think about the beauty of usability.

Classic example is cleartrip.com. At the very first instance visually it's just clean website, nothing more than that, but experience during ticket booking elicits positive emotions, attachment with the website, because of efficiency and the performance of the website. The main reason behind this kind behavioral pattern is because appraisal theory says that relevance of the goal and attainment of goal in easiest possible way, elicit positive emotion (Fig. 15).

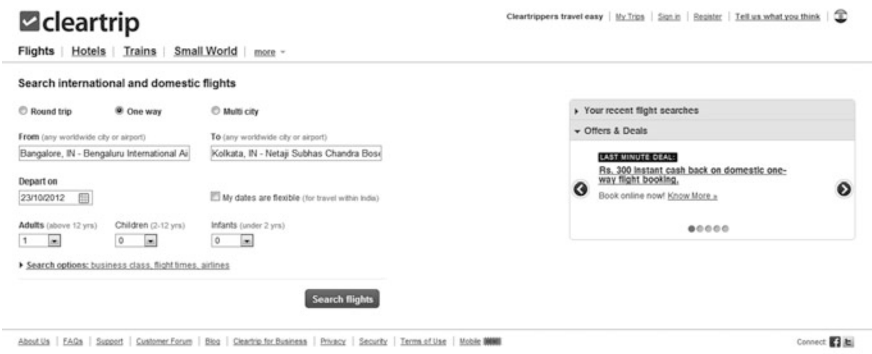


Fig. 15 Homepage of Cleartrip. *Source* http://www.cleartrip.com/

6 Conclusion

In general what we perceive or are taught about literary meanings of some of the important positive emotions are not same, as people appraise this emotion differently. There is a huge deflection in terms of articulating and understanding the dictionary meaning of these emotions. We have seen that though these emotions like happy-joy-fun or thrill-excitement are quite synonymous by nature but they have a very thin boundaries and their journey of experience are completely different with each other. But at the same time, these emotions can be mapped with certain set of parameters: Amplitude of arousal, time and social interaction and frequency of occurrence. These parameters further address the hidden cognitive meaning of these emotions and its implication on design decision. Though the appraisal of emotion is very abstract and subjective with individuals because of complex, multi-layer construct of human cognition, this paper is trying to address a framework on which these emotions can be re-articulated.

References

1. Plutchik R (2003) Emotions and life: perspectives from psychology, biology, and evolution. American Psychological Association, Washington
2. Kivikangas JM (2006) Psychophysiology of flow experience: an explorative study. Department of Psychology, University of Helsinki
3. Jordan PW (1999) Pleasure with products: human factors for body, mind and soul. In: Green WS, Jordan PW (eds) Human factors in product design: current practice and future trends. Taylor & Francis, London, pp 206–217
4. Norman D (2005) Emotional design: why we love (or hate) everyday things. Basic Books, New York
5. Demir E, Pieter MA, Desmet PMA, Hekkert P (2009) Appraisal patterns of emotions in human-product interaction. Int J Des 3(2):41–51

6. http://dictionary.cambridge.org/
7. http://dictionary.reference.com/
8. http://www.merriam-webster.com/
9. http://www.superbikesindelhi.com
10. http://www.2wheelsindia.com
11. http://www.goosebumpspickles.com/
12. http://www.cleartrip.com/
13. http://businesstoday.intoday.in/story/flipkart-online-shopping-e-commerce-order-books-online/1/20797.html
14. Bureau of Labor Statistics, June 2010 and Facebook Press Room, 2011
15. http://tatanano.inservices.tatamotors.com/tatamotors/home.htm
16. Kolb D (1984) Human factors in product design: current practice and future trends. Talyor & Francis, London, pp 206–217
17. Norman D The design of everyday things
18. Ellsworth PC, Schereï KR Appraisal processes in emotion
19. Desmet P, Hekkert P (2007) Framework of product experience. Int J Des 1(1):57–66
20. Bagozzi PR, Gopinath M, Nyer PU (1999) The role of emotions in marketing. J Acad Mark Sci 27(2):184–206

Part IV
Human Factors in Design

Force JND for Right Index Finger Using Contra Lateral Force Matching Paradigm

M. S. Raghu Prasad, Sunny Purswani and M. Manivannan

Abstract The paper aims at deriving the Just Noticeable Difference (JND) for force magnitude recognition between left and right index finger of human hand. The experiment involves establishment of an internal reference stimulus, using the left index fingers of the hand, by the subject, which is perceived and matched under contra-lateral force matching paradigm. A combination of virtual environment and a force sensor was used to derive the just noticeable difference for index-finger force application. Six voluntary healthy young adult subjects in the age group of 22–30 years were instructed to produce reference forces by left index finger and to reproduce the same amount of force by the right index finger, when the subjects were confident enough of matching same amount of force, the force values of the both the left and right index finger were recorded simultaneously for 5 s at 10 Hz. Five different trials were conducted for different force levels ranging from 2 to 5 N. The percentage real JND and absolute JND were derived for all the subjects. It was found that the Force-JND obtained was approximately 10 % across all subjects. Results also show that subjects tend to underestimate force at high force levels and overestimate at low force levels. The results obtained can be used as basic building block for the calibration of virtual reality based minimally invasive surgery related tasks and force based virtual user interfaces ranging from touch pad to assistive tools.

M. S. Raghu Prasad · S. Purswani · M. Manivannan (✉)
Haptics Lab, Biomedical Engineering Group, Department of Applied Mechanics,
IIT Madras, Chennai 600036 Tamil Nadu, India
e-mail: mani@iitm.ac.in

M. S. Raghu Prasad
e-mail: raghuprasad.m.s@gmail.com

S. Purswani
e-mail: sunny.purswani89@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_29, © Springer India 2013

Keywords Just noticeable difference · Contra lateral matching · Force matching · Finger force perception · Visual cognition

1 Introduction

The Just Noticeable Difference (JND) is a measure of minimum difference between two stimuli necessary in order for human to differentiate between the two with certainty. Many researchers have focused on JND for force in human subjects but none of them have explored force JND for a single finger. Specifically the index finger force JND corresponds to the amount of differential sensation that an individual can negate while estimating the magnitude of a given stimulus.

In past, experimental results produced by various researchers have indicated the observable range of force JND to be between 5 and 10 %. Weber measured JNDs roughly 10 % in experiments involving active lifting of 907 g weights by the hand and arm [1]. Human force control and force resolution for the effective design of haptic interfaces was reported in [2] the study also emphasized the fact that humans are less sensitive to pressure changes (i.e. force changes, when contact area is fixed) when contact area is decreased. The JND was around 10 % for pinching tasks involving finger and thumb at a constant holding force [3]. A force matching experiment about the elbow, found a JND ranging between 5 and 9 % by Jones et al. [4]. Brodie and Ross [5] had obtained JNDs lying in the same range for tasks involving the active lifting of 2 oz. weight. These research works are focused either on whole limb/arm based weight estimation or finger-thumb based combinations. On the contrary, our study is primarily based on the single finger static force application of right index finger, without any involvement of any other muscle groups. Also, our study concerns the active force JND, rather than passive JND.

Various paradigms have been adopted in prior research works to obtain the force JNDs for various muscle groups. For example, Pang et al. [3] adopted one interval, two alternative forced-choice paradigms. On the other hand Jones et al. [4] utilized the method of contra-lateral force matching with generating force ranging between 15 and 85 % of the maximum voluntary contraction (MVC range: 169–482 N). An up-down transformed response rule (UDTR) paradigm, a modified form of staircase method, for both active and passive weight lifting procedures was put forth by Brodie and Ross [5]. But, most of these paradigms involve perception of force as well as movement, based on the apparatus being used for the respective experiments. Our experiment doesn't involve application of any of the conventional TSD (theory of signal detection)-based techniques due to absence of artificial external stimuli to match. The experiment involves establishment of an internal reference stimulus by the subject, which is perceived and matched by the homologous set of muscles of opposite limb, under the purview of magnitude estimation psycho-physics technique. This mechanism involves a controlled force variation and not the rate of change of the depth of skin-indentation in index-finger application [6, 7]. Moreover, the technique used here is responsive to the fact that people do not produce constant forces spontaneously unless they are artificially controlled [7, 8]. In our experiment, subjects gradually increased self-produced force to a peak value that is visually displayed and then contra laterally matched. The primary purpose of the study is to investigate the force perception of human right index finger using contra lateral matching tasks and to evaluate the % force JND for a range of forces.

1.1 Contra Lateral Force Matching Paradigm

A contra-lateral force matching paradigm is a typical method used by various researchers to study the force perception [9–13] it is a mechanism of matching forces generated by muscle group of the any of the limbs on one side of human body by using the same set of muscle group of the other side of the body. This matching action has been observed to involve CNS (Central Nervous System) and involves a small amount of lag in information exchange between the two sides when compared to the ipsilateral force matching paradigm, which involves matching action of muscle groups on the same side of human body. Contra-lateral force matching is a popular methodology for comparing force perception and control. A comparison of matching performance between ipsilateral and contra lateral finger force matching tasks and to examine the effect of handedness on finger force perception was conducted [14], the results from the experiment indicate that the absolute, rather than relative finger force is perceived and reproduced during ipsilateral and contra lateral finger force matching tasks [14].

2 Methods

2.1 Subjects

Subjects described here are 6 healthy members of the Indian Institute of Technology Madras community, age 26 ± 4.1 years, weight 69.5 ± 8.36 kg, height 172 ± 5.22 cm, hand length from the index fingertip to the distal crease of the wrist with hand extended 16.9 ± 1 cm, hand width at the metacarpophalangeal joints (MCP) level with hand extended 8.1 ± 0.6 cm. All subjects were prescreened verbally for self-reported handedness, and history of visual, neurological, and/or motor dysfunction. All subjects gave informed consent. No subject was known to have any neurological and visual perception disorders. Five Subjects were right handed and one subject was left handed.

2.1.1 Apparatus

Each subject was comfortably seated on a chair facing a computer monitor and asked to place both of his/her upper limbs on a wooden table positioned at the same height as of the side support of the chair, thereby maintaining a correct symmetry with respect to the medial axis of the body. The angle made by the index finger with the shoulder joint was approximately 90°. Each subject was instructed to maintain a constant index-finger pressing posture during the course of the experiment. The monitor on which a visual feedback was given was placed 15° below eye level at a distance of 0.6 m away from the participant. Two Force Sensitivity Resistors (FSR) of Interlink ™ make were used as force sensors.

The two FSR's one each for left and right hands were mounted on a wooden board such that symmetry was maintained with respect to the hand positions. In order to avoid fatigue precautionary care was taken in positioning the FSR's in accordance with the participant's index fingers. The two square FSRs were connected to the Analog to Digital Converter embedded in a controller over a parallel voltage divider circuit with 1 KΩ loads each, under 5 V input supply as shown in Fig. 1.

3 Contra Lateral Force Matching Procedure with Visual Feedback

During each experimental trial, subjects were asked to reach a target force bar of constant thickness (0.15 N) by pressing left-index finger over a 2″ Square FSR (Resolution—0.01 N), which were calibrated for given range of application of force [15]. The touch surfaces of both FSRs possessed same texture and were devoid from presenting any tactile cues or spatial attenuation which could result in biased force sensation. Once the subject reached the target force level the background color of display changed as shown in Fig. 2, indicating the attainment of the target force. When the subject was able to maintain the target force level over a period of 4–5 s, he/she was instructed to press the similar FSR on the right side of the arrangement using his/her right-index finger and try matching the force, without any visual feedback. No information was given to the subjects about the matched force value attained by the right index finger. Once, subject assured that he/she had attained the same force on right-index finger, data was recorded for 5 s at a sampling rate of 10 Hz and the trial was completed. Each subject was presented with 4 different force levels of 2, 3, 4 and 5 N and each level was delivered 5 times, with equal a priori probability during the course of experiment, thereby making each experiment comprise of 50 trials. A constant target force range was set across all force levels which allowed subjects to deviate from the target by a constant force of 0.15 N (i.e. 7.5 % at 2 N; 5 % at 3 N; 3.75 % at 4 N and 3 % at 5 N) this window of 0.15 N has been chosen carefully, by keeping in mind the

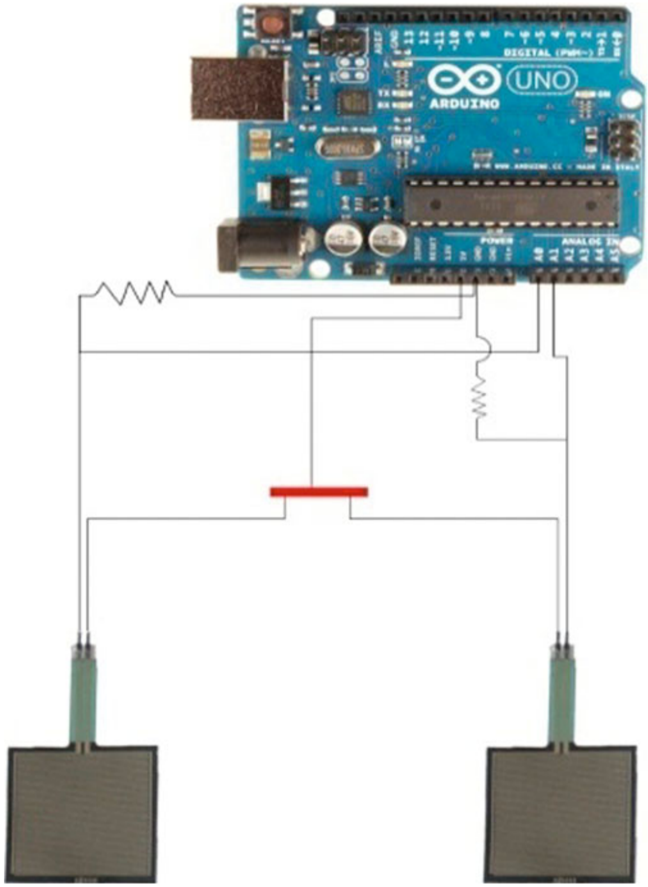


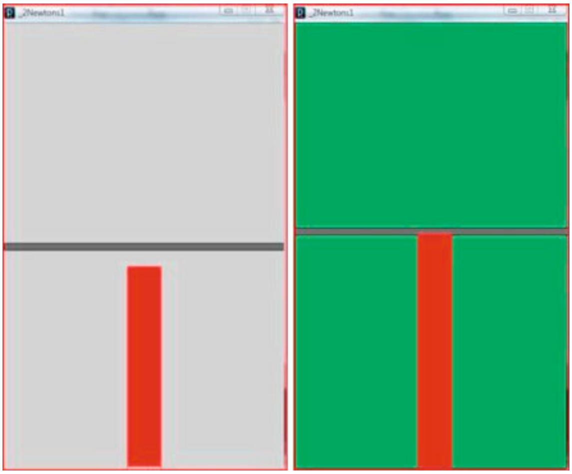
Fig. 1 Square FSRs are connected to the controller ADC

constant force error recognition results under visual feedback, as described in [8]. Subject was able to vary the force magnitude over the FSR, based on the calibration performed for electrical signal to force value conversion.

4 Data Analysis

Difference in force applied between the reference and matched value was calculated for the force-matched data across 6 subjects. The difference in real and absolute % force JND for each subject was computed separately. For a given reference force R_i and a matched force M_i the % real force JND for a single sample is obtained from Eq. (2) and the % absolute force JND is obtained from Eq. (3).

Fig. 2 Visual feedback



[Before Target] [On Target]

$$\% \, Force \, \mathrm{Real} \, JND = (M_i - R_i) \times 100/R_i \tag{2}$$

$$\% \, Force \, Absolute \, JND = Abs|(M_i - R_i) \times 100/R_i| \tag{3}$$

where i is the no:of of samples.

Similarly for 50 samples, average absolute % force JND and real % force JND per trial is computed using Eqs. (4) and (5).

$$\% \, Force \;\; Absolute \, JND = \frac{\sum_{i=1}^{50} |M_i - R_i| \times 100/R_i}{50} \tag{4}$$

$$\% \, Force \;\; \mathrm{Real} \, JND = \frac{\sum_{i=1}^{50} (M_i - R_i) \times 100/R_i}{50} \tag{5}$$

Parameters such as mean, standard deviation, standard error and variance were analyzed in detail to investigate the effect of change in % force JND across different subjects at different force levels ranging from 2 to 5 N. Table 1 summarizes the statistical analysis performed on the data set.

5 Results and Discussion

The absolute and real % force JND were obtained from each subject using contra lateral force matching paradigm. The distribution of % force JND values across subjects over various force levels in the graph, indicate that diversion of matched

Table 1 Mean, standard deviation (SD), standard error (SE) and variance (VAR) of the real and absolute % force JND across 6 subjects

Force level (Newton)	Mean % real force JND	Mean % abs force JND	SD % real force JND	SD % abs force JND	SE % real force JND	SE % abs force JND	VAR % real force JND	VAR% abs force JND
2	14.233	13.610	4.830	4.099	1.972	1.673	23.331	16.799
3	3.078	9.696	2.974	2.122	1.214	0.866	8.845	4.502
4	−4.996	7.856	2.418	2.825	0.987	1.153	5.846	7.980
5	−6.780	8.292	2.143	2.185	0.875	0.892	4.594	4.776

force values tend to contract as the force level increases. This indicates that subjects tend to produce similar static forces in a close range when the reference forces are high. Moreover, mean real % force JND values change sign between 3 and 4 N as illustrated in Fig. 3, which suggests that there exist certain set of force levels between this ranges, where subjects tend to match the reference forces most accurately, as per the contra-lateral force matching paradigm.

The pattern obtained from the average absolute % JNDs of each subject as shown in Fig. 4 indicate that at low force levels subjects tend to overestimate the reference forces and underestimate the reference force at higher force levels. Our

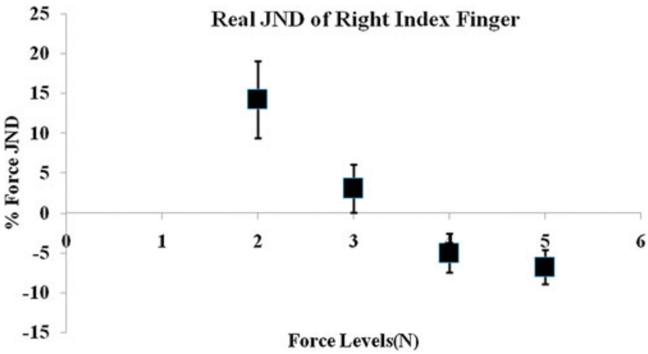


Fig. 3 Averaged real % force JND with mean and standard deviation

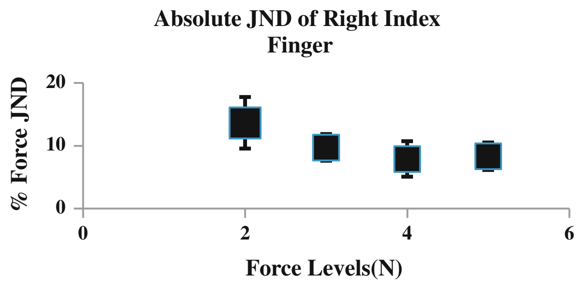


Fig. 4 Averaged absolute % force JND with mean and standard deviation

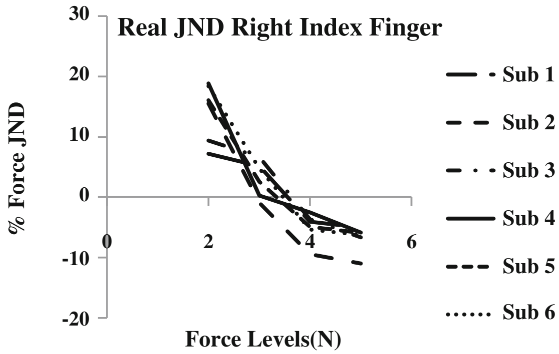


Fig. 5 Real value of % force JND of six subjects

main findings were: (1) The % force JND is larger for very small force intensity levels such as 2 N and decreases as the force stimuli increases to higher force levels such as 5 N, (2) The averaged absolute % force JND graph as illustrated in Fig. 4 follows Weber's law, (3) The decision making process of subjects took more time at lower force levels and response time was less for higher force levels.

The standard errors and standard deviations of the lower force JNDs were found to be greater than the JNDs (as shown in Fig. 4) of the higher force levels. This indicates that the subjects were more confident matching the reference force stimuli in their response to higher % force JNDs when compared to the lower force JNDs. The % force JND resolution was high at higher force levels compared to the % force JND resolution at lower force levels this indicates that the subjects were able to closely match the self generated reference stimuli by the left index finger with their right index finger at higher force levels.

Figure 5 Illustrates the real value of % force JNDs of all the subjects plotted across force levels ranging from 2 to 5 N. The graph shows that out of 6 subjects 2 subjects managed to attain lower % force JND at lower force levels. The absolute % force JND of all the subjects is shown in Fig. 6.

From our experiment we observed that absolute % force JND was roughly around 10 %, as shown in Fig. 7, when compared to JND obtained from active weight lifting

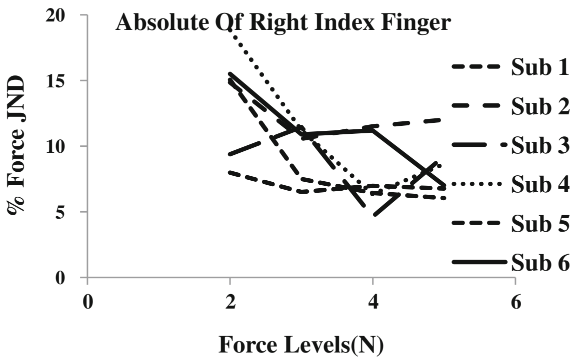


Fig. 6 Absolute value of % force JND of six subjects

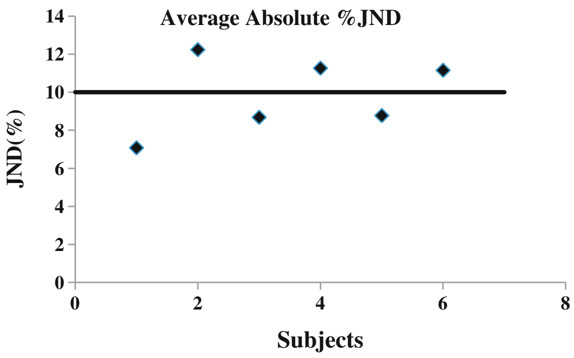


Fig. 7 Averaged % force JND of six subjects

Table 2 Absolute % force JND across all subjects

Subject	2 N (%)	3 N (%)	4 N (%)	5 N (%)	Mean (%)
One	8	6.52	6.98	6.78	7.07
Two	14.85	10.567	11.51	12.02	12.24
Three	9.38	11.45	4.63	9.237	8.68
Four	18.84	11.22	6.36	8.64	11.26
Five	15.06	7.5	6.45	6.05	8.77
Six	15.5	10.9	11.2	7.02	11.15
Mean (%)	13.6	9.7	7.85	8.3	9.86 (net)

and force matching about the elbow. A number of significant elements, however, distinguish our paradigm from previous tasks reported in literature. Table 2 presents the complete set of absolute % force JND values obtained across all 6 subjects, during course of their individual experimental runs.

6 Conclusion

% Force JND experiment produced JND values for the static force increment task averaging out 10% approximately. These JND results have closely followed the Weber's law and have fallen in the allowable range of values obtained in past research works. These experimental results prove to be pivotal in establishing a force-based virtual environment which would be operated by force based tactile interface on real-time synchronization with the system. The present paper attempts to obtain the % force JND values for static force application, specifically using index finger. A contra-lateral force matching paradigm is adopted to obtain the matching forces and corresponding force JND's. Our experiment does not consider the displacement at the point of application of force and handedness during contra lateral force matching tasks.

The experiment involves use of a force sensitive resistor (FSR), as a force transducer for obtaining the force values and related parameters. Each subject performs 20 force-matching trials for four different force levels. Each trial involved matching left-index reference force window with the right-index finger by application of force over the FSR. The forces generated by the right and left index finger and the resulting % force JND supports the notion that cutaneous feedback from the contact surface of the FSR influences the perception of force within subjects [16]. Each subject performed experiment under identical conditions without bias. It was observed that the % force JND resolution at higher force levels were better when compared to the force resolution at lower force levels, indicating that the subjects responded positively to higher force stimulus.

Also, the nature of force matching for low and high force levels was observed to be on the lines of similar past research work involving contra-lateral force matching technique. The results obtained from the experiment using the described set of attributes, opens up scope for future work involving experimental validation of the same range of force JNDs in virtual laparoscopic surgery training environment. The experiment results and data provide a frame work to build an understanding of sensory and motor deficit to the physically challenged community. Moreover, the procedures we devise here can help us explore JNDs as they change during the course of recovery. Once this has been done, the development of adaptive rehabilitative environments tailored to patients' particular sensitivities can begin. Future work could be extended to providing calibrated framework for various force-based virtual user-interfaces (UI), ranging from touchpad to assistive surgical training tools and simulators.

References

1. Weber EH (1978) The sense of touch. Academic Press for Experimental Psychology Society, London
2. Tan HZ, Mandayam BE, Srinivasan A, Cheng B (1994) Human factors for the design of force-reflecting haptic interfaces. Dyn Syst Control DSC–vol 55–1
3. Pang X, Tan HZ, Durlach NI (1991) Manual discrimination of force using active finger motion. Percept Psychophys 49(6):531–540
4. Jones LA (1989) Matching forces: constant errors and differential thresholds Perception 18(5):681–687
5. Brodie E, Ross H (1984) Sensorimotor mechanisms in weight discrimination. Attention Percept Psychophys 36(5):477–481
6. Greenspan JD (1984) A comparison of force and depth of skin indentation upon psychophysical functions of tactile intensity. Somatosens Res 2(1):3348
7. Goodwin AW, Wheat HE (1992) Magnitude estimation of contact force when objects with different shapes are applied passively to the finger pad. Somatosens Mot Res 9(4):339–344
8. Srinivasan MA, Chen JS (1993) Human performance in controlling normal forces of contact with rigid objects. Adv Robot Mechatron Haptic Interfaces DSC-vol 49, ASME
9. Gandevia SC, McCloskey DI (1977) Effects of related sensory inputs on motor performances in man studied through changes in perceived heaviness. J Physiol 272(3):653–672

10. Gandevia SC, McCloskey DI (1977) Changes in motor commands, as shown by changes in perceived heaviness, during partial curarization and peripheral anaesthesia in man. J Physiol 272:673–689
11. Cafarelli E, Bigland-Ritchie B (1979) Sensation of static force in muscles of different length. Exp Neurol 65(3):511–25
12. Kilbreath SL, Refshauge K, Gandevia SC, (1997) Differential control of the digits of the human hand: evidence from digital anaesthesia and weight matching. Exp Brain Res 117(3):507–511
13. Jones LA (2003) Perceptual constancy and the perceived magnitude of muscle forces. Exp Brain Res 151(2):197–203
14. Park W-H, Leonard CT, Li S (2008) Finger force perception during ipsilateral and contralateral force matching tasks. Exp Brain Res 189:301–310
15. Flórez1 JA, Velásque A (2010) Calibration of force sensing resistors (FSR) for static and dynamic applications. ANDESCON, IEEE, 15–17 Sept 2010
16. Jones LA, Piateski E (2006) Contribution of tactile feedback from the hand to the perception of force. Exp Brain Res 168(1–2):298–302

Modeling of Human Hand Force Based Tasks Using Fitts's Law

M. S. Raghu Prasad, Sunny Purswani and M. Manivannan

Abstract Conventional Fitts's model for human movement task finds a common application in modern day interactive computer systems and ergonomics design. According to Fitts's law the time required to rapidly move to a target area is a function of the distance to the target and the size of the target. This paper describes experimental process for prediction of minimum movement time, in a force-variation based human performance task involving right index finger. In this study we have made an attempt to extend the applicability of the conventional Fitts's model for a force based virtual movement task, without taking position into account and evaluate human performance metrics for such tasks. An experiment was conducted in which 6 healthy young adult subject's in the age group of 22–30 years performed force based movement tasks. During each trial, subjects were asked to reach an initial force bar of given thickness W Newtons, corresponding to allowable tolerance. Once the subject's had reached initial level, they were instructed to reach out the target force bar of same thickness W as quickly as possible and bring it back to the initial force level bar, thereby completing 1 iteration. Time required for 10 such iteration was noted for each subject. The results from the experiment show that the relationship between movement time and index of difficulty for force tasks are well described by Fitts's law in visual guided, force-based virtual movement task.

M. S. Raghu Prasad · S. Purswani · M. Manivannan (✉)
Haptics Lab, Biomedical Engineering Group, Department of Applied Mechanics,
Indian Institute of Technology, Madras, Chennai 600036 Tamil Nadu, India
e-mail: mani@iitm.ac.in

M. S. Raghu Prasad
e-mail: raghuprasad.m.s@gmail.com

S. Purswani
e-mail: sunny.purswani89@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_30,

Keywords Fitts's law · Virtual reality · Human computer interaction · Human performance modeling · Ergonomics

1 Introduction

Display ergonomics is primarily governed by the Fitts's model [1] involving estimation of movement time involving limb movements over UIs like mouse, joystick, remote controller etc. Generic definition of the Fitts's model is based on the information capacity of the CNS to execute a physical movement task, assisted by the reflection of the same in the virtual environment over a visual display. But, there exist wide variety of modalities involving tasks which present movement in virtual environment but are restricted from significant amount of movements from the user side, and mostly involve accomplishment of the job based on application of a force—torque combination. For example, pressing and pinching task in laparoscopic grasper, z-movement using force-based touch screen etc. Hence, there was a need of establishing a relation for the estimation of movement time for such category of tasks and validate the results over one of the force-based modality.In conventional way, Fitts's law has proved itself effective in predicting movements times involving replication of human limb movements over virtual environments. In this paper we attempt to validate applicability of Fitts's law in force application-based virtual movement task, involving no human movement. In this experiment, the movement amplitude A, for a particular trial task has been replaced by difference in initial and target force, and target width W has been replaced by allowable force tolerance at both initial and target force levels. The procedure is aimed at predicting the minimum movement time, with no allowable delay, which would be set as a base equation for calibrating all sorts of possible force application based movement tasks with variable attributes.

1.1 Fitts's Law

Ergonomics of Human Computer Interface designs have been predominately driven by the Fitts's model of movement time. This model has proven its effectiveness in improving usability of UIs and optimal designing of the size and location of user interface elements. It can also be used to predict the performance of operators using a complex system, assist in allocating tasks to operators, and predict movement times for assembly line work. However it does have some disadvantages, which include un-directional movement prediction and absence of consistent technique of error detection. Various research and comparison studies have evolved around Fitts's model, some of which extend its scope beyond

1-Dimension usability others explore the possible applicability of this movement task based model in different modalities and signal forms. Fitts [1] conducted the reciprocal tapping experiment across various subjects to validate his theory stating—ability to perform a particular movement is directly characterized by the information capacity of brain and is affected by the alternate possibilities of movements. As part of his experiment, subjects were asked to tap two rectangular plates alternately with a stylus. Movement tolerance and amplitude were controlled by fixing the width of the plates and the distance between them. Subjects were instructed to take care of the accuracy by which they perform the movement task rather than speed of reaching the target points. As part of the Fitts's law expression, Index of Difficulty (ID) is specified as the amount of information required to select specific amplitude from the total range of possible movements, and is thus dependant on the amplitude of the movement (A), and the available target size/allowable tolerance to which it must be made (target width W).

$$ID = \log_2\left(\frac{A}{W} + 1\right) \tag{1}$$

Fitts's expression is closely related to the fundamental theorem of communication systems, derived by Shannon [2]. Thus, by varying ID (A and W), IP can be determined by recording MT over the various conditions. Fitts's concluded the invariability of IP over a certain range of values of ID. Using regression analysis, a linear relationship between ID and MT can be established [1, 2].

$$MT = a + b * ID \tag{2}$$

Here **a** and **b** are the information transmission coefficients. In this form, the reciprocal of coefficient b (1/b) is called the index of performance (IP), and its unit is in "bits/sec". The index of performance (IP) indicates how quickly the pointing can be done. The index of difficulty (ID) depends on the width (W) of the target and the distance (A) between the two targets. The difficulty of the task increases when the distance (A) increases or the width (W) decreases. Fitts's law has also been extended to two and three dimension tasks [3–5]. In the field of HCI, Card et al. was the first to apply Fitts' law in computer interfaces [6]. He compared the performances between a joystick and mouse. The results shown by the mouse movement task were comparable values of IP of order of 10 bits/s, to that of the tapping task perform by Fitts'. On the other hand, joystick produced an index of performance value of around 5 bits/s. The usage of Fitts's law reported in the literature [7–10] was based on position alone. After position alone and before our study the following is added. Human performance for pointing and crossing tasks depended on index of difficulty [11] and fitt's law has also been used to effectively predict movement times when steering through constrained paths and spring stiffness control [12, 13]. Our study aims at extending Fitts's law for force based tasks.

Fig. 1 Sitting posture of subject. Platform height was maintained at elbow level, providing least strained shoulder-elbow-wrist position

2 Methods

2.1 Subjects

Six healthy subjects of the IIT Madras community in the age group of 26 ± 4.1 years, weight 69.5 ± 8.36 kg, height 172 ± 5.22 cm, hand length from the index fingertip to the distal crease of the wrist with hand extended 16.9 ± 1 cm; hand width at the MCP level with hand extended 8.1 ± 0.6 cm. All subjects were pre-screened verbally for self-reported handedness, and history of visual, neurological, and/or motor dysfunction. All subjects gave informed consent. No subject was known to have any difficulty in processing proprioceptive estimation. Five Subjects were right handed and one subject was left handed.

2.2 Apparatus

Each subject was comfortably seated on a chair facing a computer monitor and asked to place both of his/her upper limbs on a wooden table positioned at the same height as of the side support of the chair as shown in Fig. 1, thereby maintaining a correct symmetry with respect to the medial axis of the body. The angle made by the index finger with the shoulder joint was approximately 90°. Each subject was instructed to maintain a constant index-finger pressing posture during the course of the experiment. The monitor on which a visual feedback was given was placed 15° below eye level at a distance of 0.6 m away from the participant. A Force Sensitivity Resistors (FSR) of Interlink™ make was used as force sensor.

An FSR for the right hand was mounted on a wooden board such that symmetry was maintained with respect to the hand position. In order to avoid fatigue precautionary care was taken in positioning the FSR in accordance with the participant's right index finger. The display was rendered using Processing 1.5, open source platform, on 160 GB–1.5 GHz, Core 2 Duo PC, running Windows Vista,

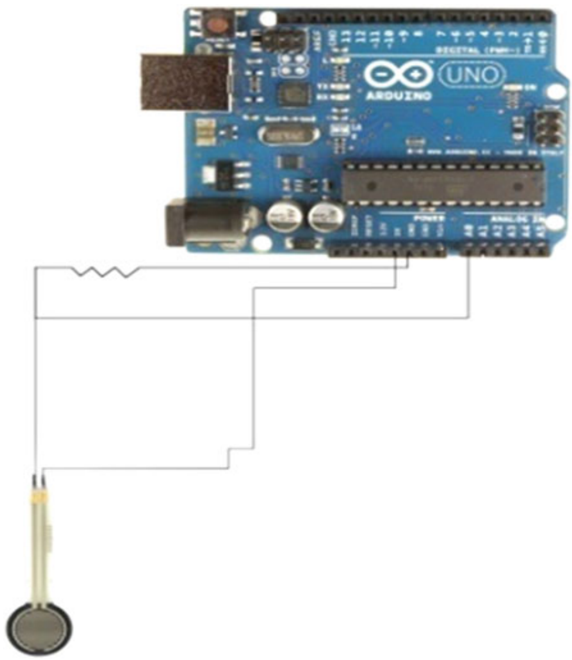


Fig. 2 Circular FSR are connected over a voltage divider circuit with 1,000 Ω loads, under 5 V supply. The input sensor values are triggered into serial port at 100 ms per iteration, with maximum information transmission capacity of 9,600 baud-rate

with 2 GB RAM. The experimental set-up as shown in Fig. 2 comprises of single FSR connected over a parallel voltage divider circuit with 1,000 Ω load under 5 V input supply. The input sensor values were triggered into serial port with a delay of 100 ms per iteration.

2.3 FSR Calibration

The FSR's were calibrated using known weights in the range of 100–1,000 g to obtain the exact values of force applied over the exposed surface of the FSR. A final relation was established between the resistance values of FSR and the applied force, Fig. 3 depicts the calibration graph of the FSR (Table 1).

3 Force Based Fitts's Protocol with Visual Feedback

During each run, subjects were asked to reach an initial force bar of given thickness W, corresponding to allowable tolerance. Once the subject had reached initial level, he was instructed to reach out the target force bar of same thickness W as quickly as possible and bring it back to the initial force level bar, thereby completing one iteration. Each subject was supposed to perform 10 such iterations per trial, where in each trial

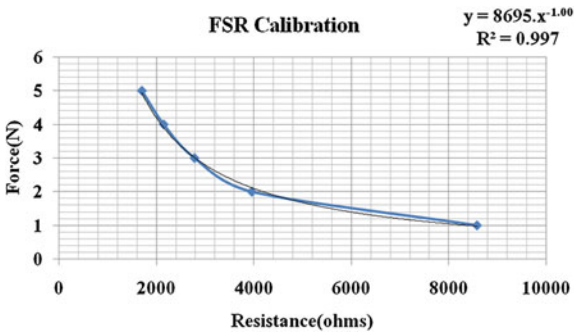


Fig. 3 FSR calibration curve with exponential fit

Table 1 FSR calibration data

Force (N)	Resistance (Ohms)
1	8,578
2	3,957
3	2,781
4	2,147
5	1,700

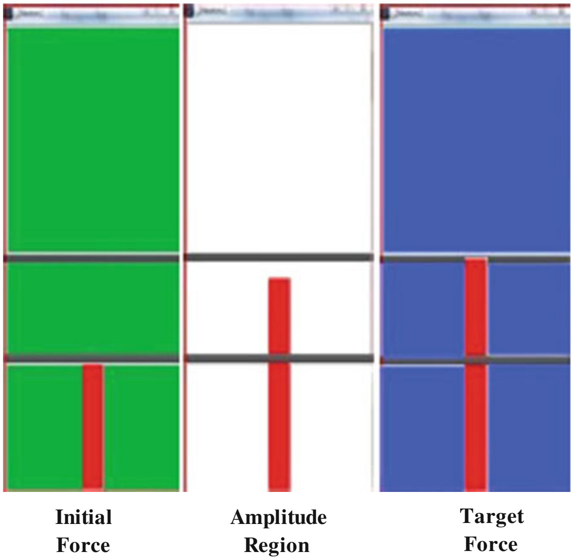


Fig. 4 Visual display

comprised of a unique set of initial force-level, target force level and thickness W. Subject was able to vary the force application by adjusting the pressure exerted by right-index finger over a 0.5″ Circular Force-Sensitive Resistor (Resolution—0.01 N).

Once the subject reached the initial force level, background color of display changed to green as shown in Fig. 4, indicating the attainment of the initial force level. Once the subject pressed over FSR and was able to move to the target force level for given thickness W, background color changed to blue, indicating attainment of target force level and instruction to come back to initial force level. Each subject underwent 50 trials as part of the experiment, force level being pair of combinations out of the (1 , 2 , 3 , 4 , 5 N) set and thickness W being values out of the set of (0.1 , 0.2 , 0.3 , 0.4 , 0.5 N). Each set of values were presented with equal a priori probability, without any bias.

4 Data Analysis

Each trial in subject-wise experiment comprised of 10 iterations, wherein sensor data values were stored at the rate of 10 samples per second. At the end of each trial, average value of all the iterations was calculated, in the following form as shown in Eq. (3).

$$MT_j = \frac{\sum_{i=1}^{10} T_i}{10} \tag{3}$$

MT_j is the average movement time for jth trial and T_i is the time taken by ith iteration. Similarly, average movement times were computed for all the 50 unique trials. Out of 50 MT values, certain set of combinations of A (Difference in force levels) and W (Allowable force tolerance) produced same A/W ration, thereby denoting same Index of Difficulty (ID). Hence, movement time for such sets of values for a given A/W was normalized to their mean.

5 Results and Discussion

Linear regression plot was performed over the final set of Index of Difficulty [ID = Log_2 (A/W + 1)] values against the respective minimum movement times (MTs). R-squared values were evaluated using least-square method for establishing the degree of correlation of the actual values with the corresponding regression plot. Process was repeated across all 6 subjects, individually. A direct

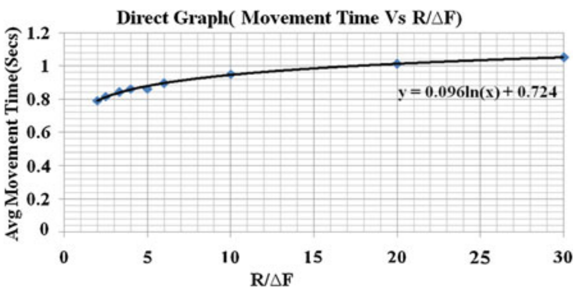


Fig. 5 A logarithmic fit to the data set of movement time and index of performance

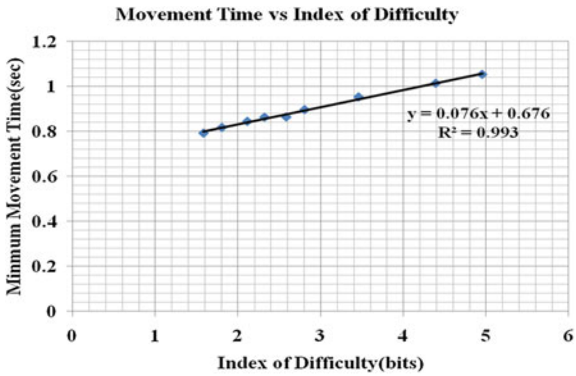


Fig. 6 A linear fit to the data of movement time versus index of difficulty

Table 2 Standard deviation and confidence values of all subjects

R/deltaF	ID	Sub1	Sub2	Sub3	Sub4	Sub5	Sub6	Avg (MT)	Std Dev	Confidence
2.00	1.58	0.71	0.73	0.89	0.69	0.83	0.90	0.79	0.09	0.08
2.50	1.81	0.75	0.73	0.98	0.72	0.88	0.85	0.82	0.10	0.08
3.33	2.11	0.74	0.73	1.08	0.80	0.87	0.84	0.84	0.13	0.10
4.00	2.32	0.83	0.79	0.73	1.10	0.86	0.86	0.86	0.13	0.10
5.00	2.58	0.93	0.80	0.79	0.89	0.86	0.91	0.86	0.06	0.05
6.00	2.81	1.10	0.69	1.05	0.75	0.79	1.00	0.90	0.17	0.14
10.00	3.46	0.87	0.76	1.18	0.90	1.06	0.94	0.95	0.15	0.12
20.00	4.39	0.96	0.78	1.23	0.91	1.15	1.05	1.01	0.16	0.13
30.00	4.95	1.03	0.79	1.28	0.93	1.20	1.08	1.05	0.18	0.14

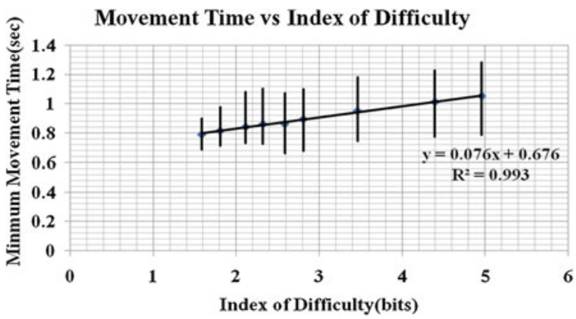


Fig. 7 Plot of movement time and index of difficulty

graph of Movement Time and index of performance is shown in Fig. 5 with a logarithmic fit where R = difference in Force levels and ΔF = allowable tolerance. The slope of the graph represents the performance of the control as for the data with visual feedback. Each subject produced R-squared values of more than 85 % accuracy corresponding to their projected linear regression plots of minimum MT versus ID, thereby validating 1D Fitts's law in force domain. Figure 6 shows the final plot of Movement time (MT) versus Index of Difficulty (ID) averaged across all 6 subjects. Plot presents an R-squared value of 0.993, denoting a very accurate representation of the Fitts's law in static force application based movement tasks over the pre-defined force range. Here final values of constants **a** and **b** are 0.676 and 0.076 respectively.

Table 2 depicts the standard deviation and confidence values across all subjects with the index of performance and index of difficulty. Figure 7 shows the graph of the ratio of difference in force levels to the allowable tolerance plotted over the data set of index of difficulty and movement time. The results indicate that Fitts's law applies to the activities in muscle space, as well as the movement and force in task space. The results from this study infer that Fitts's law applies to the activities in muscle space, as well as the movement and force in task space. This may imply that Fitts's law is determined in the level of the nervous system and is not affected by the dynamics of the limbs. The results strengthen the argument that the trade-off between speed and accuracy of the pointing movement is determined by the capacity of information transfer of the central nervous system (CNS), rather than the physical limitations of the arm, such as inertia and mechanical compliance [8]. Moreover during the course of the experiment, control rate and homing time turned out to be crucial factors in accomplishing the task under variable set of parameters [7, 14–16].

6 Conclusion

In this study we have explored the possibility of using the well established Fitts's model to force based human hand movement tasks. The final derivation of the Fitts' law expression after regression analysis over the generalized data collected across 6 subjects. R-squared value of more than 95 %, justifies the validity of Fitts's law in force-based movements in virtual environments irrespective of involvement of limb movements. The results from the experiment show that the relationship between movement time and index of difficulty are well described by Fitts's law in visual guided, force-based virtual movement task. These results, open up scope for extending this research to establishment of Fitts's law to 3-Dimensional virtual environments (e.g. laparoscopy surgical training platform) involving movements and orientations synchronized by application of multi-directional force and torque. Further the study can be used as a basic foundation in modeling and design of force based minimally invasive surgical training modules in order to assist resident doctors to hone their surgical skills.

References

1. Fitts PM (1954) The information capacity of the human motor system in controlling the amplitude of movement. J Exp Psychol
2. Shannon CE (1998) Communication in the presence of noise, In: Proceedings of the IEEE, vol 86(2). February

3. Murata A, Iwase H (2001) Extending Fitts's law to a three dimensional pointing task. Hum Mov Sci 20(6):791–805
4. Scott Mackenzie I, Buxton WAS (1992) Extending Fitts' law to two-dimensional tasks. In: Proceedings of ACM CHI conference on Human factors in computing systems
5. So RH, Chung GK, Goonetilleke RS (1999) Target-directed head movements in a head-coupled virtual environment: predicting the effects of lags using Fitts' law. Hum Factors 41(3):474–486
6. Card SK, English WK, Burr BJ (1978) Evaluation of mouse, rate-controlled isometric joystick, step keys, and text keys for text selection on a CRT. Ergonomics 21:601–613
7. Wall SA, Harwin WS (2000) Quantification of the effects of Haptic feedback during a motor skills task in a simulated environment, In: Proceedings of 2nd phantom users research symposium, Zurich, Switzerland, pp 61–69
8. Park J, Kim H, Chung W, Park S (2011) Comparison of myocontrol and force control based on Fitts' law model. Int J Precis Eng Manuf 12(2):211–217
9. Scott J, Brown LM, Molloy M (2009) Mobile device interaction with force sensing. In: Pervasive 2009, LNCS vol 5538, pp 133–150
10. Accot J, Zhai S (2003) Refining Fitts' law models for bivariate pointing. In: Proceedings of ACM CHI conference on human factors in computing systems
11. Casiez G, Vogel D, Balakrishnan R, Cockburn A (2008) The impact of control-display gain on user performance in pointing tasks. Human Comput Interac 23(3):215–250
12. Casiez G, Vogel D, Pan Q, Chaillou C (2007) Rubber edge reducing clutching by combining position and rate control with elastic feedback. In Proceedings of ACM CHI, pp 129-138
13. Dominjon L, Lécuyer A., Burkhardt J.M, Andrade- Barroso G, Richir S (2005) The bubble technique: Interacting with large virtual environments using haptic devices with limited workspace. In Proceedings of IEEE World Haptics, pp 639–640.
14. Accot J, Zhai S (2002) More than dotting the i's—foundations for crossing-based interfaces. In: Proceedings of ACM CHI 2002 conference on human factors in computing systems
15. Kattinakere RS, Grossman T, Subramanian S (2007) Modeling steering within above-the-surface interaction layers. In Proceedings of ACM CHI 2007 conference on human factors in computing systems
16. Casiez G, Vogel D (2008) The effect of spring stiffness and control gain with an elastic rate-control pointing device. In Proceedings of ACM CHI, pp 1709–1718

Self-Serving Well-Being: Designing Interactions for Desirable Social Outcomes

Soumitra Bhat

Abstract Well-being—individual and social—achieved through sustainable development is undoubtedly the overarching agenda for global public policy today. What could be the role of design in this new frame? The core question motivating this review is: How can design help us achieve well-being as individuals and society at the same time? The first part of this paper reviews the literature to frame the dilemma of social well-being. The second part reviews existing approaches to resolve social dilemmas. The third part reviews the current approaches to design for well-being. This is followed by a discussion about implications for design for achieving social well-being objectives, and an agenda, opportunities and key questions for research are outlined.

Keywords Social well-being · Interaction design · Inclusive development · Behavior change · Social dilemma

In the face of global inequality, rising consumerism, depleting natural resources and rising environmental threats, values of justice, conservation, sustainability and responsibility have become central issues in every discipline—economics, politics, social sciences, engineering, and design. This is matched by a rising awareness of the criticality of these issues and their causal links to the structural foundations of modern society in the minds of global citizens. Consequently, people are losing trust in the intention and capability of the institutions of old to look after people's best interests; they are losing faith in the free market due to corporations disproportionately valuing private profit over social equality and justice. Moreover, there is a sense that social problems represent collateral damage incurred in our apparently self-interested pursuit of personal good at the cost of the greater good—indicating a crisis

S. Bhat (✉)
UserINNOV Design Company, Mumbai, India
e-mail: soumitra@userinnov.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_31,

in personal values. Out of all this there is a rising sense of a collective responsibility to fix the state that we are in, leading us to reflect the things we've done and the ways we've gone about it. Well-being—individual and social—achieved through sustainable development is undoubtedly the overarching agenda for global public policy today [1]. What could be the role of design in this new frame?

The core question motivating this review is: How can design help us achieve well-being as individuals and society at the same time? The first part of this paper reviews the literature to frame the dilemma of social well-being. The second part reviews existing approaches to resolve social dilemmas. The third part reviews the current approaches to design for well-being. This is followed by a discussion about implications for design for achieving social well-being objectives, and an agenda, opportunities and key questions for research are outlined.

1 Individual Well-Being and Social Well-Being

Well-being has been the object of study in several disciplines including sociology, economics, psychology, biology, philosophy, etc. Well-being has been equated with welfare, capabilities, health related quality-of-life, hedonism, and the terms 'happiness', 'quality of life', 'well-being', 'life-satisfaction' have been used interchangeably, often confusingly so, in literature from these distinct disciplines. What has definitely emerged is that well-being is an umbrella concept under which several distinct types of well-being can be identified.

Veenhoven [2] presents a consolidation (Fig. 1) of the various types of well-being into a matrix schema as combinations of 'chances', 'outcomes', 'internal qualities' and 'external qualities', including a further distinction between the hedonistic and eudaemonist aspects of satisfaction with life [3]. If maximizing individual well-being is the ultimate goal, then it follows that an individual will choose to act in ways that will: (1) Improve the liveability of their environment; (2) Improve their individual ability to cope with life's problems; (3) Increase the utility of their life and make life meaningful; and (4a) get more pleasure out of life activities, (4b) Increase their level of satisfaction with individual dimensions of their life, (4c) Increase the frequency and duration of feelings of euphoria, (4d) Increase their satisfaction with their life as a whole. While some of these aims are achievable through individual action alone—mainly the individual, internal, passing well-being, most of the other aims require cooperative action amongst social members for successful achievement. Since these fruits of cooperative action are available to the entire society, a choice of action that maximizes individual well-being can therefore be seen to contribute towards social well-being as well. However, making this optimal choice is not easy. At a given instant, an individual has several known and unknown possibilities for action to increase their individual well-being. Not all actions will provide well-being to an equal extent. Some actions will increase well-being more than others while some actions will reduce well-being. Some actions will increase particular aspects of well-being

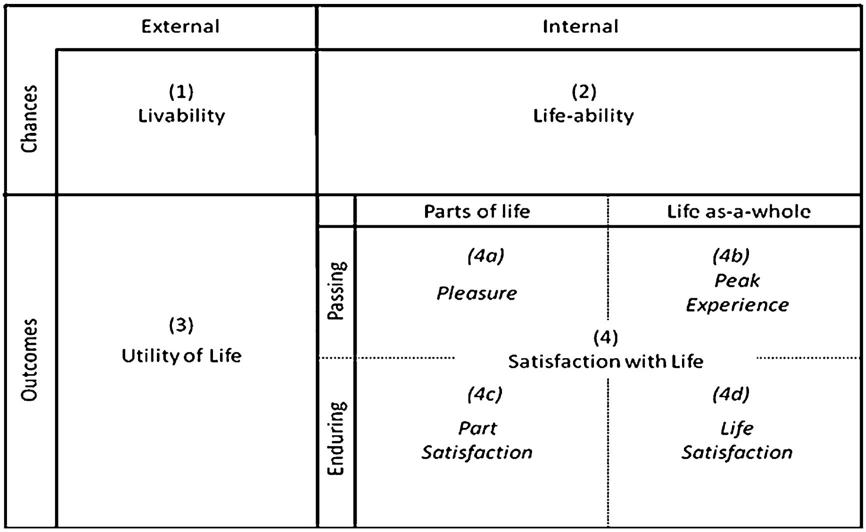


Fig. 1 Consolidated schema of well-being. *Source* Adapted from [2]

while leaving other aspects unchanged, or even reduced. Choosing between actions leading to well-being requires judgment involving probability and value.

Studies have shown that due to limits on working memory, individuals, when faced with choices involving uncertainty and judgements of probability and value, tend to rely on highly economical heuristics, to make these judgments. These heuristics, although largely efficient and effective, lead to cognitive biases that can sometimes give rise to severe, systematic, predictable errors in decision making [4]. As the choices we face become more complicated, we are unable to always choose consistently what would be in our best interests. According to Prospect Theory [5], we often fall prey to biases where we are more averse to losing something than gaining something (loss aversion), or where we prefer gaining a certain amount now rather than gaining the same amount in the future (diminished sensitivity). Applied to choices for maximizing well-being, prospect theory would predict that people tend to favor pleasure over displeasure and, immediate satisfaction over delayed satisfaction, even in cases where this may not be the optimum choice. This bias in judgment could make an individual erroneously give more preference to short-term hedonistic outcomes over long-term social outcomes.

Given such a bias, the compatible goals of individual and social well-being come to be perceived, at times, as seemingly opposing objectives. In such cases, the problem of social well-being appears to take the form of a social dilemma—a situation where private interests are at odds with collective interests. Such social dilemmas are defined by two properties [6]: (1) Each individual receives a higher personal outcome for a non-cooperative decision no matter what the other people in the community do; (2) The entire community is better off if all or most individuals cooperate rather than act selfishly. For the collective good, cooperation needs to be sustained and defectors need to be turned into co-operators. In the context of well-being, this implies that for achieving social well-being, individuals need to overcome their short-term, hedonistic bias and consistently choose the most effective course of action that leads to individual and social well-being.

2 Theoretical Perspectives on Resolving Social Dilemmas

Social dilemmas have been the definitive characteristic of the social condition since, perhaps, the dawn of civilization. Contemporary theories and approaches to resolve social dilemmas can be categorized under three perspectives—institutional, transformational, and individual.

2.1 Institutional Perspective

From the institutional perspective, the dilemma of social well-being resembles a 'public good' or 'collective action' problem. These problems result from a lack of coordination and cooperation between individuals within society. This individual failure to coordinate and cooperate has led to the emergence of institutions to guide individual behavior and safeguard our collective interests [7]. The institutional perspective tries to resolve the coordination and cooperation problems through the design and enforcement of rule-systems that regulate individual interactions. Three types of institutional approaches can be identified: (1) centralization, (2) individualization, and (3) collectivization [8].

Centralization involves the restriction of individual access to choices that the authority believes to be antithetical to achieving collective good. There are several disadvantages to centralization as an approach: (1) individuals generally do not like impositions on the liberty and freedom to decide what is good for them, (2) the costs imposed on the non-error making individuals is high, (3) when group members have the choice of creating rules amongst themselves, they do not prefer to be ruled by a central authority, and (4) individuals prefer to be led by an elected, democratic authority that allows group members to exercise some control over the decision-making process.

Individualization involves providing individuals with a market-oriented access to all possible choices.

Individuals prefer individualized systems when compared to central authorities because the market mechanisms are considered neutral, anonymous and impersonal. Individualization works best when the outcomes of available individual choices do not affect others. However, outcomes of individual choices almost always affect others and thus individualized systems, like markets, invariably give rise to negative externalities. Another problem with the introduction of individualization is that rather than perceiving resource use as a collective problem, individual users may start to perceive it as an individual problem [9].

Collectivization involves limiting market-oriented access or limiting the choices available to members of a community through regulation by a self-organized governance regime within that community. In contrast to centralization and individualization, collectivization lays emphasis on monitoring, transparency and democratic participation in the regulation of individual choice, which leads individuals to experience the rule systems and governance regime as trustworthy, efficient and fair [10]. It gives stress on trust, reciprocity and the evolution of social norms as essential mechanisms for the emergence of cooperation in collective action. Collectivization is favorable when both, market-oriented access is desirable and negative externalities need to be managed. Collectivization is also desirable when issues faced by the community are not centrally legitimized as problems due to lack of advocacy, or lack of motivation of central policymakers to address the issues, the result of which is a lack of resources employed towards resolution of community dilemmas.

2.2 *Transformational Perspective*

The transformational perspective sees the social dilemma as a problem of individual choice and tries to transform an individual's perception of a specific dilemma situation by changing the decision frame and pay-off structures [11]. According to decision theory it is costly for people to make effective judgments and process full information when faced with complicated decisions especially involving uncertainty and delayed consequences [4]. Faced with a difficult choice an individual will tend to rely on heuristics rather than effortful evaluation. Transformational interventions use this inertia of individuals towards cognitive effort to nudge them towards pro-social choices by reframing decisions using strategies like setting effective defaults, expecting errors, giving feedback, structuring choices, and giving incentives [12]. These strategies are useful because of their low implementation costs, low costs on non-error making individuals, large benefits for individuals who sometimes make errors and no restriction of choices available to users. Transformational strategies have recently gained popularity as a policy tool in the form of 'Nudges'. However, there is always a possibility for abuse of paternalism by governments, firms and choice architects in positions of power. Therefore there is a need for monitoring efficacy of outcomes and transparency of implementation for asymmetric paternalism to be effective [13].

2.3 *Individual Perspective*

The individual perspective looks at social dilemmas as problems of individual commitment and capability. The focus of this perspective is on promoting the individual factors that motivate, facilitate and empower individuals to act pro-socially. Several theories, predominantly from social psychology, have explored person-level factors that contribute towards pro-social behavior. Whether an individual will exhibit pro-social behaviour in dilemma situations has been linked to the individual's social value orientation—or the orientation of an individual to maximize both: joint outcomes and equality in outcomes [14]. Pro-social behaviour by an individual is mediated by (1) a high level of commitment to act towards socially desirable outcomes and (2) pre-existing cooperative value orientation (rather than a competitive or an individual one) [15]. Motivation to cooperate is also mediated by needs for belongingness and identity. It is believed that human beings have a basic desire to develop and foster meaningful social relationships and, via this, build up a shared social identity. When these needs are unfulfilled, for example when people are forced to leave a social group, their mental and physical well-being suffers. This might explain why people are motivated to cooperate in groups that they feel they belong to. Interventions that develop and maintaining strong community ties, or build social capital, promote feelings of belongingness and identity [16]. Studies have also shown that individual subjective well-being and ecologically responsible behaviour were positively correlated to an intrinsic value orientation, dispositional mindfulness, and a lifestyle of voluntary simplicity [17]. However, commitment and pro-social value orientations are not enough. Commitment for doing something needs to be backed by the availability of appropriate substantive freedom and capability without which a person cannot be responsible for doing that thing [18]. This view is integrated in the theory of planned behavior which views human action to be influenced by three factors: a favorable or unfavorable evaluation of the behavior (attitude); perceived social pressure to perform or not perform the behavior (social norm); and perceived capability to perform the behavior (self-efficacy). In general the more favorable the attitude and behavioral norm, and the greater the individual's perceived control, the stronger should be the individual's intention to perform the behavior [19].

3 Design Approaches Towards Social Well-Being

It was perhaps during the 1960s that a serious discourse emerged regarding the need for the implicit power of designers, to shape society through the intended and unintended consequences of their designs, to be backed by a responsibility to use this power for the social good [20]. Since then, the idea of social good as an objective of design has gathered momentum and several recent design efforts can be noted with objectives like (design for:) happiness, socially responsible behavior, sustainable consumption, human development, and social impact. There are also several recent studies that have explicitly targeted well-being or happiness as their objective, however, these either relate to health related well-being [21], psychological well-being [22] or individual happiness [23]—and do not look at well-being as a complex whole. Both, these efforts and studies, are complemented by theoretical and methodical developments within several contemporary design approaches. Although no studies as yet describe the direct application of these approaches to social well-being problems, they are categorized here according to their focus—institutional, transformational, or individual—and potential significance to resolving social dilemmas. The institutional perspective includes approaches such as computer-supported-cooperative-work (CSCW) design [24], socio-technical-systems design [25], and participatory design [26]—aimed at increasing coordination and cooperation. The transformational perspective includes emotional design [27], experience design [28], persuasive design [29] and design with intent [30]—approaches that use the affective and meditational qualities of artifacts to reframe choices and change pay-off structures. The individual perspective includes instructional design [31] and interventions from the theory of planned behavior [32]—approaches drawing on social psychology to enhance individual commitment and capabilities. A recent review posits that the choice between these perspectives to formulate an effective strategy should be dependent upon contextual factors and the specific nature of the social dilemma [33].

Several points can be observed from a review of the current landscape of design for social good: (1) the perspectives on social good target behavior change as a strategy to resolve social problems—a shift from designing artifacts to designing interactions; (2) although social well-being is linked to social consumption and sustainable development, it is not identical. An exclusive perspective on design for social well-being is therefore lacking; (3) cases explicitly targeting well-being as an objective are few, and target a particular aspect of well-being and not well-being as a whole or social well-being; (4) the explicit perspectives on design for social good are fairly recent, with few case studies available and, therefore, the development of a specific supporting body of knowledge is still in the early stages; and (5) there are several approaches that can potentially support a design for social well-being perspective, however, specific explorations in this area are lacking.

4 Towards Designing Interactions for Self-Serving Social Well-Being

A social design approach puts interactions, rather than artifacts, at the center as the ‘things to be designed’. In most social design approaches the starting point for framing the problem situation involves the notion that individual interests are *absolutely antithetical* to collective interests. This may be the case in tragedy-of-the-commons type of situations where desirable social outcomes are primarily equated with an equitable distribution of finite resources—for example, in sustainable consumption. In such cases, individuals would certainly be *materially* better off when they defect than when they cooperate. However, an exploration of the complex nature of individual well-being presents the idea that individual well-being and social well-being as intrinsically linked and positively correlated goals. Therefore, if social well-being is the desirable social outcome, then individual and collective interests are only *apparently antithetical* due to limitations of individual bounded rationality. The distinction is crucial in informing the designer's perception of social members as either helpless agents hopelessly trapped in a dilemma until saved through coercion, or as empowered agents who have the possibility—perhaps with a little education, persuasion and facilitation—to transcend their limitations and achieve individual and social well-being at the same time [34].

Although presented in this review as three separate perspectives for resolving social dilemmas—institutional, transformational and individual—the question is not one of choosing between coercion and persuasion. Any successful intervention strategy would intersect across these three perspectives. For a dilemma, apparent or absolute, to be resolved, there must be some co-operators in a group to begin with, there must be institutions that facilitate cooperation and coordination, there must be transformational solutions that reduce the temptation to defect, and finally, the numbers of co-operators must be increased by turning defectors into co-operators. In the case of social well-being, the ideal situation would occur when all the members of a collective act towards achieving individual well-being, as it is rightly understood, and thus, serve themselves with individual and social well-being. The key question then for design is: How can design support people in serving themselves with individual and social well-being?

Current case studies, under a broader topic of social design, have identified several open challenges such as: (1) defining the appropriate role, qualities and expertise of designers in promoting socially responsible behavior [33]; (2) identifying the appropriate problem frame for the successful resolution of social well-being problems [35]; (3) using dialog between designers for the effective management and resolution of dilemmas [36]; (4) facilitating coordination by building a shared understanding and shared commitment between diverse stakeholders towards resolving dilemmas [37]; and (5) taking a whole-system, long-term view and changing culturally dominant worldviews and value systems [38]. At the same time, there are potentially complimentary developments in collective intelligence and coordination theory [39] with ongoing experiments in using information technology to coordinate thousands of diverse stakeholders and lead to high quality collective decisions [40]. Fields like graph theory, evolutionary game theory [41] and behavioral game theory [42] are providing new insights into how and under what conditions bounded rational agents interact and form social networks and communities that display emergence of trust, fairness and reciprocity. Game theoretic approaches are not only interesting because of the insights they provide, but also because of the tools and methods they use for modeling complex systems, simulation and experimental design. Adopting a complex systems perspective to design for achieving well-being objectives seems to present several advantages due to its integrative nature, consideration for the autonomy of individual agents, and the inherent property of complex adaptive systems to self-organize and adapt that is desirable from a long-term, sustainability perspective [43]. Under the topic of sustainable business models, there is increasing interest in cooperative business models for their demonstrated resilience in times of crisis [44].

These issues and developments bring up concerns and possibilities that are directly relevant for design with a social well-being objective, although, systematic investigations under an explicit 'design for social well-being' perspective are lacking. Several key questions for further research can be identified: (1) How can designers build coordination and facilitate cooperation between thousands of stakeholder participants with diverse interests in an environment of fairness, transparency and trust?; (2) what are the qualities and expertise needed for a designer to be successful in designing for social well-being; and how can these be developed?; (3) what are the tools and methods that a designer can use to model dilemma situations for rapid simulation and selection between alternative intervention strategies?; (4) how can designers evaluate the short-term and long-term impact of outcomes from interventions across interdependent groups?; and (5) what are the organizational conditions, including business models, which can support design for social well-being? How can the activity of design for social well-being be organized and managed from a practical perspective?

5 Conclusion

Individual well-being is a socially interdependent construct within which individual and social goals are intrinsically linked and positively correlated. However, bounded rationality challenges individuals, while making the optimal choice between actions to maximize individual well-being, by giving the decision an appearance of a social dilemma. Derived from social psychological theories, prospect theory, and institutional theories, the individual, transformational and institutional perspectives to resolving social dilemmas outline a potential framework to support the design and analysis of interventions for achieving social well-being objectives. Although several current approaches under a generic 'design for social good' agenda can be identified, an explicit 'design for social well-being' approach is nascent and far from consolidated. There is a need for research across all formats: theoretical, case study, research through design, systematic experimentation. What has emerged so far is that an explicit focus on social well-being as an objective of design has the potential to broaden the field of design to incorporate a palette of multi-disciplinary perspectives and develop a shared vocabulary to engage in a global dialog on development. Designing for social well-being has important implications for all aspects of design: theory, expertise, methods, roles, embodiments, management and assessment. To design for social well-being, designers need to embrace complexity, share a long-term commitment towards positive change, and be aware of and manage their own bounded rational frames by actively seeking dialog and participation. In the new frame of global public policy that puts social well-being at the center of human development, design can support global efforts by supporting individuals to serve themselves with social well-being.

References

1. Stiglitz J, Sen A, Fitoussi JP (2009) The measurement of economic performance and social progress revisited. Observatoire Français des Conjonctures Economiques (OFCE). The ESPON, 2013
2. Veenhoven R (2010) Capability and happiness: conceptual difference and reality links. J Socio-Econ 39(3):344–350
3. Deci EL, Ryan RM (2008) Hedonia, eudaimonia, and well-being: an introduction. J Happiness Stud 9(1):1–11
4. Tversky A, Kahneman D (1974) Judgment under uncertainty: heuristics and biases. Science 185(4157):1124–1131
5. Tversky A, Kahneman D (1992) Advances in prospect theory: cumulative representation of uncertainty. J Risk Uncertainty 5(4):297–323
6. Dawes RM (1980) Social dilemmas. Annu Rev Psychol 31(1):169–193
7. Calvert R (1995) The rational choice theory of social institutions: cooperation, coordination, and communication. Mod Polit Econ: Old Top New Dir Polit Econ Inst Decis, Cambridge University Press 216–268
8. Van Vugt M (2002) Central, individual, or collective control? Am Behav Sci 45(5):783–800
9. Tenbrunsel AE, Messick DM (1999) Sanctioning systems, decision frames, and cooperation. Adm Sci Q 44(4):684–707
10. Ostrom E (2010) Beyond markets and states: polycentric governance of complex economic systems. Am Econ Rev 100(3):641–672
11. Tenbrunsel AE, Northcraft GB (2009) In the eye of the beholder: Payoff structures and decision frames in social dilemmas. Soc Decis Mak: Soc Dilemmas, Soc Val, Ethical Judg, Ser Organ Manag, Psychology Press 95–115
12. Camerer C, Issacharoff S, Loewenstein G, O'Donoghue T, Rabin M (2003) Regulation for conservatives: behavioral economics and the case for 'Asymmetric Paternalism'. Univ PA Law Rev 151(3):1211–1254
13. Thaler RH, Sunstein CR (2008) Nudge: improving decisions about health, wealth, and happiness. Yale University Press, USA
14. Van Lange PAM (1999) The pursuit of joint outcomes and equality in outcomes: an integrative model of social value orientation. J Pers Soc Psychol 77(2):337
15. Van Lange PAM, Agnew CR, Harinck F, Steemers GEM (1997) From game theory to real life: how social value orientation affects willingness to sacrifice in ongoing close relationships. J Pers Soc Psychol 73(6):1330
16. Forrest R, Kearns A (2001) Social cohesion, social capital and the neighbourhood. Urban Stud 38(12):2125–2143. doi:10.1080/00420980120087081
17. Brown KW, Kasser T (2005) Are psychological and ecological well-being compatible? The role of values, mindfulness, and lifestyle. Soc Indic Res 74(2):349–368
18. Sen AK (1990) Individual freedom as social commitment. India Int Centre Q 17(1):101–115
19. Ajzen I (2005) Attitudes, personality, and behavior. McGraw-Hill International, New York
20. Papanek V, Fuller RB (1972) Design for the real world. Thames and Hudson, London
21. Larsson A, Larsson T, Leifer L, Van der Loos M, Feland J (2005) Design for Wellbeing: Innovations for People. ICED 05. In: 15th International conference on engineering design: engineering design and the global economy. Engineers Australia, p 2509
22. Coyle D, Linehan C, Tang K, Lindley S (2012) Interaction design and emotional wellbeing. In: Proceedings of the 2012 ACM annual conference extended abstracts on human factors in computing systems extended abstracts, ACM, pp 2775–2778
23. Desmet PMA (2011) Design for happiness; four ingredients for designing meaningful activities. In: Proceedings of the IASDR2011, the 4th world conference on design research, vol 31

24. Bødker S, Bouvin NO, Wulf V, Ciolfi L, Lutters W (2011) ECSCW 2011. In: Proceedings of the 12th European conference on computer supported cooperative work, Springer, Aarhus Denmark, 24–28 Sept 2011
25. Whitworth B, moor AD (2003) Legitimate by design: towards trusted socio-technical systems. Behav Inf Technol 22(1):31–51
26. Bodker S, Pekkola S (2010) A short review to the past and present of participatory design. Scand J Inf Syst 22(1):45–48
27. Desmet PMA, Porcelijn R, Van Dijk MB (2007) Emotional design; application of a research-based design approach. Knowl Technol Policy 20(3):141–155
28. Hassenzahl M (2010) Experience Design: technology for all the right reasons. Synth Lect Human-Centered Inf 3(1):1–95
29. Redström J (2006) Persuasive design: fringes and foundations. In: Proceedings of the First international conference on Persuasive technology for human well-being, Springer-Verlag 112–122
30. Lockton D, Harrison D, Stanton N (2008) Design with Intent: Persuasive Technology in a Wider Context. In: Proceedings of the 3rd international conference on Persuasive Technology, Springer-Verlag pp. 274–278
31. Schunk DH, Zimmerman BJ (2012) Motivation and self-regulated learning: theory, research, and applications. Routledge, London
32. Ajzen I (2011) Design and evaluation guided by the theory of planned behavior. Soc psychol Eval, Guilford Publications, pp. 74–100
33. Tromp N, Hekkert P, Verbeek PP (2011) Design for socially responsible behavior: a classification of influence based on intended user experience. Des Issues 27(3):3–19
34. Ostrom E (1990) Governing the commons: the evolution of institutions for collective action. Cambridge University Press, Cambridge
35. Dorst K, Tietz C (2011) Design thinking and analysis a case study in design for social wellbeing. Res Des-Support Sustain Prod Dev (ICoRD'11) 104–111
36. Oak A (2012) 'You can argue it two ways': the collaborative management of a design dilemma. Design Stud 33(6):630–648. doi: 10.1016/j.destud.2012.06.006
37. Conklin J (2005) Dialogue mapping: building shared understanding of wicked problems. Wiley, New York
38. Wahl DC, Baxter S (2008) The designer's role in facilitating sustainable solutions. Des Issues 24(2):72–83
39. Malone T, Laubacher R, Dellarocas C (2009) Harnessing crowds: mapping the genome of collective intelligence. SSRN eLibrary
40. Introne J, Laubacher R, Olson G, Malone T (2011) The Climate CoLab: large scale model-based collaborative planning. IEEE 2011 international conference on collaboration technologies and systems (CTS), pp 40–47
41. Szabó G, Fáth G (2007) Evolutionary games on graphs. Phys Rep 446(4):97–216
42. Camerer CF (2011) Behavioral game theory: experiments in strategic interaction. Princeton University Press, Princeton
43. Folke C, Carpenter S, Elmqvist T, Gunderson L, Holling CS, Walker B (2002) Resilience and sustainable development: building adaptive capacity in a world of transformations. AMBIO: J Human Environ 31(5):437–440
44. Birchall J, Ketilson LH (2009) Resilience of the cooperative business model in times of crisis

Do We Really Need Traditional Usability Lab for UX Practice?

Anshuman Sharma

Abstract Many IT companies in India and across the globe have "User experience" (UX) associates to support UI and Usability. Many of these companies have a well organized UX practice with their own targets, profit and loss statements. Some of the companies boast of a having support of extensive Usability Labs and user testing infrastructure. The billing of usability testing services is much higher than the UI design and usability review services. The IT services companies have a model of offshore development for cost reduction and many usability labs are underutilized. The investment to set-up and run a usability lab is made with the objective of winning additional business and show more value to clients. There are a very few projects which really need detailed UX participation, user research and user testing through usability labs. Usability labs are expensive to establish and maintain. This brings us to the questions of ROI and whether the high cost of usability lab infrastructure is justified. This paper looks at the various aspects and business models which can help an IT company decide whether to set-up a usability lab or not and what can be an ideal model to sustain it.

Keywords HCI · User experience design · Usability practice · Usability testing · User testing · User research · Usability lab · Client lab · Usability process

A. Sharma (✉)
User Experience Design, L&T Infotech, Whitefield, Bangalore 560066, India
e-mail: anshuman.sharma@lntinfotech.com; anshusa@yahoo.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_32, © Springer India 2013

1 Introduction

User Experience Design as a practice has evolved over the last couple of decades. Businesses and clients have started realizing the value of "User Experience" (UX) practice and the contribution that a usability lab can make.

IT business management is usually reluctant to bear the cost of setting-up UX practice and majority of the expense is spent on setting up the usability lab infrastructure. The main reason could be attributed to the business model followed by IT companies of product or services businesses, where usability is still in its nascent stages [1].

The "Return On Investment" (ROI) of usability labs and what value it brings to the business and clients is still not fully visible. The penetration of usability for leading application development companies is ever increasing. One reason is the importance given to usability practice by clients. Another reason to build usability lab infrastructure by the software development companies is to show their intention to make usable products [2].

Many companies believe that usability labs are expensive and that they are a place to garner only scientifically valid data [2]. This is not entirely true as the labs evolve qualitative data as well. Usability tests conducted through Usability Lab helps the usability professionals and Product development teams to gather data about the interaction of the user with the designed application/software. This data is evolved by observing the user/participant interact with the design [3].

1.1 What is UX?

User experience in ISO FDIS 9241-210 is defined as: "A person's perceptions and responses that result from the use and/or anticipated use of a product, system or service".

Usability or user experience can be measured during or after the use of a product, system or service. The ISO definition suggests measures of user experience are similar to measures of satisfaction in usability [4]. This definition was subsequently refined to evolve the definition of Usability.

User experience or UX in short is an umbrella term coined to collectively represent visual designers, interaction designer, usability analysts and front-end engineers. The UX stream looks the software application design and its usage. The responsibility of UX team is to look at the aesthetics of the application, ease of use and its intuitiveness.

The UX team needs to work closely with the business analysts to review whether the business needs and the user needs are being met. The UX team also needs to work closely with the technology teams to get the designs and recommendations implemented. The job of a UX designer is challenging as he needs to meet business requirements, look at technological constraints and propose designs that meet the end user requirements.

1.2 How to Set-Up Usability Lab?

A Usability Lab usually consists of two rooms, the participant's test area also known as 'Participant's room' and the participant viewing area also known as 'Observation room'. Conventionally, these areas are separated by a one-way mirror (Fig. 1). Usability analysts sit in the 'Observation room' and the participants sit in the 'Participant's room'. Usability analysts can see the participants working on the application from their computer screens, while the participants cannot see or hear the usability analysts (Fig. 2).

The desktops of the usability analysts are linked to the desktops of the participants. Sound insulation and one-way mirror helps the participant work without being disturbed by the discussions of the usability analysts in the 'Observation room'. Web camera installed on the participant's desktops capture the facial expressions of the participants and the same can be viewed real time by the usability analysts. The captured video is stored for analysis.

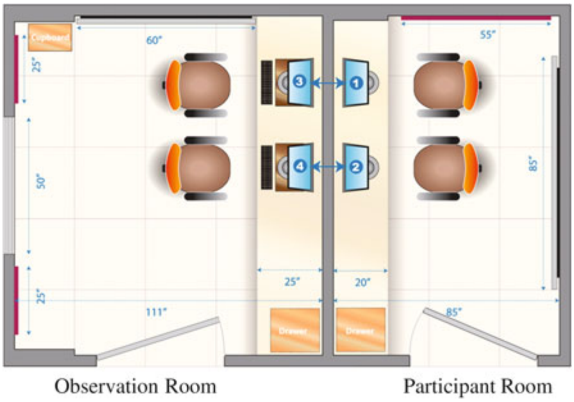


Fig. 1 Plan of usability lab set-up for testing two participants

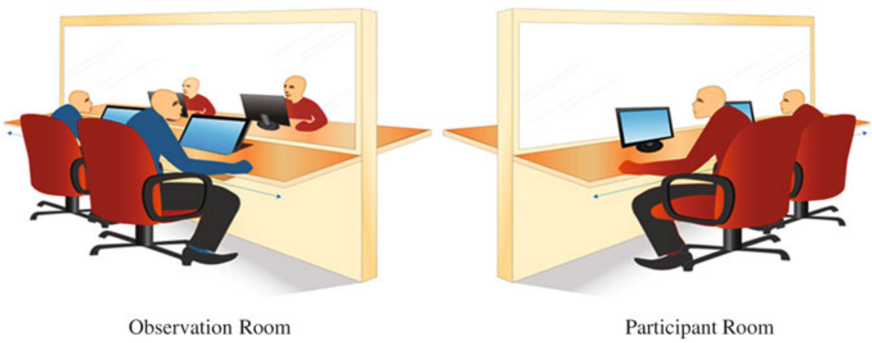


Fig. 2 Elevation of usability lab set-up for testing two participants

2 Questions to be Answered

Before setting up the Usability lab, most companies deal with numerous questions regarding its need and viability of the venture. Most usability practitioners and managers vouch for the need of a usability practice. Usability practitioners and managers would have answered questions related to usability practice and justification of having a usability lab. Most practitioners dig into research papers and articles to retrieve business justifications and ROI of usability lab infrastructure. Lets us look at some of the most frequently asked questions related to usability practice and usability lab infrastructure:

- Why do we need a usability lab?
- What are the benefits of having a usability lab?
- What do we get out of a usability lab as a deliverable?
- Which organizations should have it?
- Will client pay for usability Lab usage?
- Why we need usability lab usage when we are not a research organization?
- Are there cases when usability lab is not required?
- Are there scenarios when clients do not want the services of a usability lab?
- Can we use of some makeshift usability testing techniques and still show value to clients?

This paper will look at an IT company's business models, business focus and maturity of processes to determine if the conditions are ripe to set-up usability lab or not. One need not elaborate the benefits of a usability lab but in its absence, one needs to find ways and means to conduct usability tests and research to help UX practitioners produce user-friendly and innovative solutions. There are tools and techniques which can be used to conduct usability tests and measurements in absence of a usability lab.

Let us look at the factors which help decide the need of a Usability lab infrastructure.

3 Factors Governing Usability Lab Set-Up

There are several organizational aspects that play an important role in determining how the UX practice shapes-up and whether approval will be received to set-up usability lab infrastructure or not. Usability practice needs blessings from the senior management to stand on its own feet [1].

Lets us look at the business models and some of factors that can determine usability lab set-up within each business model.

3.1 IT Business Model: Product Companies

Most product development companies have usability labs to conduct usability tests for applications. With application customizations and new feature development, the bucket is usually full for the usability analysts. The product development companies also have the budgets and plan in place to account for usability inputs and recommendations. The prevalence of well-organized Usability labs can be seen in those product development companies where there is reasonable understanding about the importance of usability processes and its benefits.

Another important factor is the maturity of the companies with respect to having an integrated "Product Development Lifecycle" (PDLC). There are a very few companies in the Indian IT sector, where the "User Centered Design" (UCD) process has been successfully integrated with PDLC [1]. In these companies, we can see the maximum benefits of an integrated process where usability is a part of the overall product development process.

The first task for the usability practitioners is to sell usability to the senior management to get their attention and approvals to set-up usability lab. In most cases, it does not happen in the initial years of setting-up the usability or user experience design practice. One needs to engage with the existing processes and workflows for a couple of years to get noticed and get the budget to set-up a full-fledged usability practice where usability lab is an integrated part of the landscape.

But what does the usability practitioner do in the initial years of their practice without a usability lab? The usability practitioner needs to rely on their experience and the experience of the sales and marketing teams. There is a huge dependency on the sales, marketing and product management teams for approval of usability proposals. The main issue is that the usability teams do not have the tangible data like number of clicks and time savings without the usability lab set-up.

What does the usability team do in such scenarios? There are many possible ways to sell usability and get funding from the product owners. The most important step is to start engaging with clients and the senior management to influence the integration of usability as an integrated part of the PDLC [1].

In many IT companies, the usability practice needs the blessings of the senior management to flourish. Usability practice survives with a top down approach [1]. The main reason is the maturity of the UX practice in the IT company.

If the usability team is able to show the ROI of usability practice to the senior management and the clients, it is easier and faster to institutionalize it. There is always resistance to change and there are issues with sharing decision making powers from the product development teams with UX team [1]. Product development teams believe that the usability team is away from the real world and that they may not be able to provide solutions which need less time and effort to implement.

For small and mid level IT companies, usability lab is not seen as a very critical requirement. This is due to focus on specific areas of software development and delivery. However, for the companies which are working higher-up in the value chain of product development and IT services, usability is seen as a critical and game changing practice. We see a full-fledged usability lab with regular use in such companies.

3.2 IT Business Model: Service Companies

IT service companies have a different kind of problem and solutions as far as the usability practice and setting-up of usability lab is concerned. The work culture in IT services model is more volatile compared to product business.

IT services companies and their infrastructure set-up is driven by the business and client requirements. As far as the usability practice is concerned, the situation is very similar to product development companies. Usability practice and lab infrastructure needs support from senior management or it is mostly driven from client requirements.

However, there are some differences in service companies and product companies with respect to usability lab infrastructure. IT service companies need to sell capabilities to bid and win deals. Most IT service companies do not offer usability practice as service which would require specialized services of a usability lab. However, tier-1 and tier-2 IT companies do have usability labs and leave no stone unturned to show them off. But having usability lab infrastructure and having a functional and effective lab infrastructure are two different things.

3.3 Organizational Factors

Usability budget in an IT company is steadily growing. The budgets allocated for usability engineering was about 6 % of cost of the development projects in 1993. Based on visible benefits of usability methods to improve products, an IT company starts investing on usability practice and usability lab infrastructure [5].

The organizational structure of an IT company also impacts the growth and development of usability practice. Some IT companies distribute the usability resources into individual development projects, where as some other place the usability resources into a horizontal resource group which cuts across all the verticals/projects and development teams. A centralized usability practice benefits from the permanent lab infrastructure [5].

3.4 Usefulness of Discounted Usability Methods

When a company decides to improve the usability of its products, the immediate requirement is not to start building a usability lab. It is possible to get started with simpler usability methods, referred to as "discount usability engineering" [5].

In absence of usability lab, one needs to make use of methods like GOMS analysis and heuristic evaluation. Heuristic evaluation is used by individual UX practitioners to find usability issues and gaps. Heuristic evaluation is conducted based on established usability principles like learnability, efficiency, memorability, error prevention and satisfaction.

4 Cost Benefit Analysis: To Have or Not to Have

Many businesses and clients do not feel the need of having a usability lab. Many others do not have the budget and focus to engage the services of a usability lab. IT services companies rely on the off-shoring model where UX resources are budgeted and their efforts are tracked. The process followed by UX resources is usually not tracked.

In absence of usability lab, the designers and usability specialists start believing that they know what how the application is being used and what is required to be resolved. This gives them confidence and sometimes over-confidence that they know how to deal any kind of problem and can come up with the solution to meet end user needs. The designs produced out of this quick and dirty UCD process looks good but may not be effective when it comes to intuitiveness and ease of use.

Table 1 compares several parameters to evaluate the need for a Usability lab and what is its impact on business and clients. The study is based on the experience and feedback from ten UX professional over a period of last 10 years (2000–2011). The UX professionals have experience in various IT companies which range from start-ups, mid-tier and the top IT companies in India.

5 UCD Process: How Much Can We Achieve Without Usability Lab Set-Up?

The importance of usability lab for UX practice is well accepted by the academic circles and research levels, what we need to discuss specifically is how much can we achieve for a UX practice without having a usability lab in a business set-up. It can also be stressed that to evaluate the specific usability oriented data, whether it can be collected without a usability lab. Whether the data is collected through a usability lab or not, the target is to analyze the collected data and design/redesign a task in way that it becomes more effective [6].

Table 1 Usability lab: to have or not to have

Parameters	Without usability lab	With usability lab
UX services offered	80 %	100 %
Client impact	Less	High
Overall business impact	Low	High
IT product company	Low impact	High impact
IT services company	Low impact	Very high impact
ROI for delivery acceptance	Limited impact	Very high impact
ROI for business development	Limited impact	Very high impact
Customer focus	Less	High
Learning and innovation	Limited	High
Data collection and research	Limited	High
Initial set-up cost	Less	Very high
Incremental overhead user testing cost	High	Negligible cost
Running cost	Less	High
Ease of hiring and talent retention	Low contribution	High contribution
Satisfaction levels of UX team	Limited	High
Learning and customer focus for UX team	Limited	High
Learning and customer focus for product management	Limited	Very high

Various usability metrics are employed to measure usability dimensions like effectiveness, efficiency and satisfaction [7]. These dimensions are also pointed out in the ISO 9241.11 standards. The four important metrics which represent these dimensions are: task completion, error counts, task times and satisfaction scores [8].

Usability tests are devised to collect data on the usability metrics. A formal usability lab set-up is useful but not necessary. The effectiveness of the usability tests depends on the chosen tasks, the methodology and the person in-charge of the test [9].

Many researchers argue the suitability of results achieved through field study versus usability lab. The data collected through detailed usability lab set-up and through field studies differ in quality and focus. One major factor in favor of the usability labs is that the environment in usability lab is peaceful space where the participants can focus on given tasks [10]. There are interruptions, movement and noise issues in field studies [11].

The only benefit of field studies is to get understanding of real working conditions of the end user which may not be achievable in a usability lab set-up. Steve Krug has compared the cost saving benefits of "Lot-Our-Lease Testing" [12] with traditional testing. He suggests that one can achieve equivalent results with 3–4 participants in an office or conference room set-up compared to 7–8 participants in a usability lab.

Table 2 compares various usability parameters to evaluate if we can live without a usability lab and still gather all the relevant data required for understanding users and design better software. The study is based on the experience and feedback from ten UX professionals over a period of last 10 years (2001–2011).

Table 2 How much can we achieve without usability lab set-up?

Usability parameter	Without usability lab	With usability lab
User study and persona development	Yes	NA
Scenario building	Yes	NA
Competitor analysis	Yes	NA
Task analysis	Partially	Yes
Study of existing application usage and issues	Partially	Yes
User behavior and need analysis	Yes	Yes
Heuristic evaluation	Yes	NA
Iterative testing	Partially	Yes
User testing	Partially	Yes
Mouse and keyboard click analysis	Partially	Yes
Mental load analysis	Partially	Yes
Idle time analysis	Partially	Yes
Eye tracking analysis	No	Yes
Facial expression and satisfaction/ frustration levels	Partially	Yes
Time taken for click and satisfaction level analysis	Partially. Cumbersome	Yes
Preparation time for usability report	Very high	Low
Participants fear and anxiety toward hidden observation areas	Low. Since there is not partition and the observers can sit along with the participants and the participants can see what is happening during the user test.	High. One needs to spend time and effort to make them comfortable
Flexibility and portability	Can set-up a makeshift lab easily at client location	Cannot take the lab to client location
Controlling observers	We need to brief the observers not to talk and disturb the participants	It is easy to handle many observers at the same time due to partition and sound proofing
Time and effort	Less time and effort is required to quickly gauge the issues and user feedback. This is because there is less data to be analyzed.	Lot of time is required to analyze the data collected in the form of video recordings. One needs to derive the clicks, time taken and so on. This time can be reduced with specialized usability testing software

(continued)

Table 2 (continued)

Usability parameter	Without usability lab	With usability lab
Data collected	Less data is generated. Suitable for development projects	More data is generated. Suitable for research activities
Range of analysis and results	Most details like issues and pain points can be discovered	All the details and issues can be identified and analyzed
Measuring end user satisfaction	Partially	Yes
Data/video availability for reference and training	Data not readily available	Data readily available in the form of video

6 Conclusions

Usability lab set-up helps the usability team learn more about user behavior and his preferences. Usability labs are expensive to establish and maintain. Factors like maturity of usability processes and integration of UCD with PDLC in an organization, type of projects taken and delivered, user focus and budget allocation determines whether to set-up a usability lab or not.

A usability lab can be used as a common platform where various levels of researches can be carried out with representations from various industries along with academician-researchers. This arrangement can even be made for a specific context and requirement. The data collected can be used by the concerned stake holders.

With the ever changing IT working and delivery models, the relevance of a traditional usability lab is slowly fading away and giving way to a portable lab. Usability professionals have also realized over a period of time that there are other ways and means to conduct usability tests which do not demand high investment and do not take too much time in data collection and analysis. Guerrilla and discount usability methods are quite popular, but we do not need to measure usability to improve it [13].

For product development organizations, traditional usability labs do make sense. For IT service focused organizations, a make-shift or a portable usability lab will be very useful. Usability professionals are also trying out discount usability testing methods which yield similar results with minimal effort, cost and time. When a company decides to improve the usability of its products, the immediate requirement is not to start building a usability lab, but to start using 'discount usability engineering' methods [5].

Acknowledgments I would like to thank Anish Shah and Kiran Pai for enabling the UX practice and providing an environment of freedom for UX research activities. Thanks to Vinayak Hegde for the images. I would extend my thanks to Aneesha Sharma for helping me with insights into research process.

References

1. Sharma A (2011) Institutionalization of usability in banking software environment: tasks and challenges. In: International conference on research into design (ICoRD11), ISBN: 978-981-08-7721-7, 2011
2. Tara S (1999) Usability labs: our take, user interface engineering. http://www.uie.com/articles/usability_labs/. July 1999
3. Spool Jared M (2011) Bending the protocols: useful variations on usability tests. User interface engineering. http://www.uie.com/articles/bending_protocals/. Dec 2011
4. Bevan N What is the difference between the purpose of usability and user experience evaluation methods? www.nigelbevan.com
5. Nielsen J (1994) Usability laboratories: a 1994 survey. J Behav Inf Technol 13:1–2
6. Bevan N, Kirakowski J, Maissel J (1991) What is usability? 4th international conference on HCI, Stuttgart, Sept 1991
7. Ergonomic requirements for office work with visual display terminals (VDTs)—Part II: guidance on usability, ISO 9241-11:1998 (E), Geneva, 1998
8. Sauro J, Kindlund E (2005) A method to standardize usability metrics into a single score. In: CHI 2005, USA, 2–7 April 2005
9. Molich R, Ede M, Kaasgaard K, Karyukin B (2004) Comparative usability evaluation. Behav Inf Technol
10. Kaikkonen A (2005) Usability testing of mobile applications: a comparison between laboratory and field testing. J Usability Stud 1(1):4–16
11. Tamminen S, Oulasvirta A, Toiskallio K, Kankainen A (2004) Understanding mobile contexts. Spec Issue J Pers Ubiquitous Comput 8:135–143
12. Krug S (2005) Don't make me think: a common sense approach to web usability, 2nd edn. New Riders, USA
13. Nielsen J (2006) Quantitative studies: how many users to test? Jakob Nielsen's Alertbox. http://www.useit.com/alertbox/quantitative_testing.html. 26 June 2006

Muscle Computer Interface: A Review

Anirban Chowdhury, Rithvik Ramadas and Sougata Karmakar

Abstract A new kind of human computer interface using electrical activity of muscles, known as Muscle computer Interface (muCI) has been developed by researchers. With an intention of unfolding current status of muCIs, original research articles, review articles, reports, books, news etc. from authentic printed and online sources involving different search engines and libraries have been searched and critically studied by authors of present paper. This review has successfully highlighted developments of different sEMG based interfaces such as hand movement/gesture recognition interfaces, facial gesture recognition interfaces, myoelectric prosthetic arms, muscle fatigue analysis and other sort of interfaces. It has also covered the comparison between muCI and BCI, methodologies used for signal classification for muCI and the various shortcomings of the current muCIs. As muCI is still at its initial stages of development, it has been envisaged by the authors that present paper would help researchers to explore new ideas in emerging areas of muCI's.

Keywords Human computer interface · Brain computer interface · Muscle computer interface · Signals processing

A. Chowdhury · R. Ramadas · S. Karmakar (✉)
Department of Design, Indian Institute of Technology Guwahati, Assam, Guwahati 781039, India
e-mail: karmakar.sougata@gmail.com

A. Chowdhury
e-mail: chowdhuryanirban14@gmail.com

R. Ramadas
e-mail: rithvik.firebird@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_33,

1 Introduction

Many human computer interaction (HCI) technologies are now well established. Among different developmental phases of HCI, researches on brain computer interaction (BCI) are very popular. Brain computer interfaces are very much helpful to overcome many human limitations such as assisting, augmenting or repairing human cognitive or sensory-motor functions [1–3]. In recent years a new means of HCI is focused on Muscle Computer Interface (muCIs). Muscle computer interface is a user interface in which user employs electrical activity of their muscle as an input while they are executing various tasks. In other words in such interaction people may control devices using their myoelectrical signals. Though the term Muscle Computer Interface is relatively new, usage of myoelectric devices employing sEMG electrodes has long history. From the past, EMG signals have been successfully used in several fields such as medicine [4, 5], understanding neurophysiological disorders (e.g. neuropathy, myopathy etc.) [1], development of prosthetic arm [6, 7], fatigue detection devices [8–10] etc. Only few articles state information about muCI in details. On contrary, there is a lot of information available on subjects which are related to muCI like electromyography and muscle signal processing [6, 7, 11–22], HCI [1, 23], BCI [1–3, 16] etc.

In the present paper an attempt has been made to review the current status of muCI for understanding EMG signals and muCI, differences between muCI and BCI, as well as the future direction of muCI development.

2 Methodology for the Review

Authors of this paper have gone through several research articles, review papers, books and book chapters from various authentic search engines with the help of internet as well as institute library. The search engines used for this present review include Google, Google Scholar, PubMed-NCBI, ACM digital library, IEEE Xplore and other digital libraries. Following thorough study of the available literatures, analysis was made and findings were reported systematically. Apart from this, authors have tried to build connections between muCI and other related fields and have been able to give some state of the art ideas for future generation of muCI.

3 Development of muCI

Although the concept of muCI is very recent, it is actually a further improvement of HCI rather it is the general physical transducer (e.g. mouse, keyboard etc.) mediated HCI. The term muCI is relatively new to many of us but the usage of sEMG signals for developing devices is well known. Previously, EMG signals have been used for development of prosthetic arms [6, 7, 24–27]. The term muCI was first coined by Saponas et al. [28] while demonstrating the feasibility of muCI using forearm electromyography. According to them [28], muCIs are an "Interaction methodology that directly senses and decodes human muscular activity rather than relying on physical device actuation or user actions that are externally visible or audible". They were able to differentiate and classify EMG signals for change in different positions of fingers and pressure of finger presses, as well as they classified tapping and lifting gestures across all five fingers. Moreover they have concluded their work for future muCI designs [28]. Recent muCI systems include EMG sensors which are placed over muscles of interest related to a particular movement of body parts or gestures. There are varying number of EMG sensors which can be used for capturing muscle signals to develop muCI e.g. 6 sensors [10] 8 sensors [29] or 10 sensors [28] etc. Based on their previous work Saponas et al. [29] classified finger gestures on a physical surface. They introduced a bi-manual paradigm that enables use in interactive systems. Their experimental results demonstrated the classification accuracies of four-finger averaging 79 % for pinching, 85 % while holding a travel mug, and 88 % when carrying a weighted bag. Additionally, they showed feasibility of generalization across different arm postures with exploring the tradeoffs of providing real-time visual feedback. After that authors have studied and presented methods of making these interfaces more human friendly, cost effective and developing arm bands which are easy to wear without the adhesive gel. In addition, Saponas et al. reported about more practical applications of muCI in which system needed not be calibrated over and over again when removed and worn [30]. They have reported that accuracy existed in the system of about 86 % for activities like

Table 1 Different EMG signal classification methodologies and their accuracies

S.no	Methodology used	Author	% Accuracy
1	Artificial neural network (ANN)	Putnam et al. [44]	95
		Rosenberg et al. [45]	14
		Tsenov et al. [21]	98
		Jung et al. [46]	78
2	Back propogation neural network (BPNN)	Itou et al. [47]	70
		Naik et al. [17, 34], El-Daydamony et al. [12]	97
3	Log linearized gaussian mixture network (LLGMN)	Tsuji et al. [48], Fukuda et al. [49]	Not mentioned
4	Recurrent LLGMN	Tsuji et al. [50], Fukuda et al. [51]	Not mentioned
5	Fuzzy mean max neural network	Kim et al. [52]	97
6	Hidden markov model (HMM)	Wheeler [36], Chan et al. [53]	Not mentioned
7	Bayes network	Chen et al. [33], Kim et al. [15]	94

Table 2 Comparisons between BCI and muCI

S·no	BCI	S·no	muCI
1	Computer is controlled via signals sent from the brain directly. Signals are acquired as EEG signals, MRI signals etc.	1	Computer is controlled via signals received from the muscles during various activities. muCI only involves only EMG signals
2	It is generally non invasive. Electrodes used are generally specialized for EEG	2	It can be invasive as well as non invasive and EMG electrodes (with 2 to 10 channels) are used
3	Some applications of BCI include BCI based gaming interface, device interface for paralytic patients etc.	3	Some of the application of muCI includes gesture based gaming interface, prosthetics etc.

pinching across three fingers. Whatever, basic steps that need to be followed for development of muCI are: (1) Detection of EMG signals for a particular body movement; (2) classification of EMG signals and develop machine learning algorithm; and (3) use those EMG signals of a particular body movement as an input for controlling any devices. Among these steps EMG signal classification is most important.

4 EMG Signal Classification

People use EMG signal classification method for several purposes such as development of myoelectric hands [31, 32], gesture recognition interfaces [15, 17, 23, 33–37] (e.g. face and hand), blink recognition interfaces etc. Even there are various methods for EMG signal recognition process which range from ANN to Bayes Networks. All these methods have different accuracy levels. Signal classification is very crucial in the development of muCI as the machine is only able to understand/recognize right signals/signal of interest from the muscles after signal classification. Details of the various methods and their corresponding accuracy levels are furnished in Table 1.

5 Comparative Analysis Between muCI and BCI

A comparative analysis is necessary to know pre-existing and existing similar technologies for better understanding of present technological progress in the field of muCI. In this context, it is important to mention that supporting technology for Brain computer interface (BCI) is much similar to muscle computer interface technology. Brain computer interface can be defined as an interaction medium which allows the brain to directly control the computer instead of relying on direct physical interaction with computer. BCI is using electrical activity of the brain and it is independent of neuromuscular pathways. So, its application is very popular in communication of patients of neuromuscular disorders [1]. On the other hand muCI is a field where human computer interaction is based on muscular activity. Thus, muCI does not incorporate paralytic muscles and people with neuromuscular disorder(s) are unable to use muCI based communicative/interactive device. In both BCI and muCI, signals are decoded using similar methods like ANN, HMM etc. Although the approach in development of muCI and BCI is similar, still these are different in several aspects. Here, 'Table 2' is summarizing comparative analysis between BCI and muCI. This table will be helpful to have basic concepts of muCI and BCI for budding designers/researchers.

6 Present Status and Future Scopes of muCI

Muscle computer interface has a high potential for various applications to develop muscular activity based interactive devices for different purposes. How muscular signals can be used for different purposes is discussed in the subsequent sections.

6.1 Hand Gesture Recognition Interfaces Versus. Gaming Interfaces

Wheeler et al. [36] reported about neuro-electric interfaces for virtual device control. Different hand gestures were classified by them using HMM. Moreover, they conducted two experiments: one replicating a joystick and other with a keyboard, to examine their feasibility. In 2009, Xiang et al. [37] developed hand gesture based interfaces depending on American and Chinese sign languages using 6 channel electrodes for classifying various gestures. This kind of technology can further be developed as gesture based communication language tool with the help of muCI. These devices can even be interfaced with a bluetooth/wireless network for mobile applications [35] which might be helpful for differently-abled people (deaf and dumb) to communicate with ease. Kim et al. [15] has highlighted the development of an EMG based interface for hand gesture recognition with 94 % accuracy. In their experiment a single channel EMG sensor was used inside the forearm. Based on gesture recognition technology, they controlled a robot car. Similar techniques can be used to play car race. One can play such games using different gestures which would make the current games more interactive rather than the traditional joystick based control. Tang et al. [20] designed a ring like sEMG device which can be worn on the forearm easily. Their device was used for development of another device called 'Possessed Hand' where electrodes were employed for giving small harmless currents to the hand and this current helped to form various gestures. This device has been found to be helpful in training users to play string instruments like guitars. Further development of above mentioned device can replace the current device used in the 'Game Guitar Hero' which has only 5–6 buttons and one flipper. Presently 'Game Guitar Hero' can only recognize the gestures and train users to play instruments with ease. Additionally, muCI enabled device has recently been used in an application for drawing within a large scale virtual environment. Electrical changes due to muscular activity of user is acquired by the device and used by the application for controlling dimensions and colors of the brush [24].

6.2 Prosthetics and muCI

The application of surface EMG and invasive EMG in prosthetics is not new to us. Zecca et al. [22] reported traditional methods to control prosthetic hands by EMG in both clinical and research context. In their work, Chu et al. [31] used principal component analysis, self organizing feature map and multilayer perception for extracting features from the EMG signals. This was used in upper limb prostheses.

Khezri and Jahed [38] reported about current systems employed to control prosthetic hands which have limited functions or can be used to perform simple movements, they proposed to use an intelligent approach based on adaptive neuro-fuzzy inference system (ANFIS) integrated with a real time learning scheme to identify hand motion commands. The hybrid method for training the fuzzy system consists of back propagation (BP) and LMS. To design an effective system they considered the conventional scheme of EMG pattern recognition [39] system namely time domain (TD) and frequency representation. The results showed 96.7 % average accuracy and six unique hand movements were considered which include hand opening and closing; thumb pinch and flexion; wrist flexion and extension. More patterns of movements are still needed to be explored for further development of prosthetics. Emphasis should be given for detailed research in complex movements of body parts (e.g. rotation of hand), range of movement of body joints, torque analysis during movement, etc. to make the devices more accurate.

6.3 Facial Expression Recognition Based muCI

In their earlier publication Naik et al. [34] demonstrated an ICA based hand gesture recognition system for HCI using 4 s EMG sensors. Recently they have employed same method to study facial expressions. Their results reported near about 100 % accuracy excluding small errors over 360 experiments. This EMG based facial recognition system has very wide range of applications. If we can classify EMG signals for each different facial expression then we can control different devices by means of facial expression. So, it will be helpful in emotion based product design. For example, favourite music can be played by music player when got stressed. In this context input may be tensed expression based facial muscular activity. In addition, in near future one can interact with large scale virtual environment with the help of facial expression based muCI. Now, differently abled persons would be able to access mouse with the help of facial expression based muCI technology [40]. So, this facial expression based muCI technology has great potential in different application areas, researcher/designers just need to explore.

6.4 Fatigue Detection and muCI

There are several reports about muscular fatigue detection using EMG. Peper et al. [41] reported how sEMG could be used to assess several workstations to prevent repetitive strain injuries [42]. Singh et al. [9] reported about muscle fatigue detection during cycling via sEMG and this was a grand success for this methodology because it was also verified using muscle biopsy tests and blood tests. In another report, Subasi and Kiymik [10] mentioned about fatigue detection by sEMG using time frequency methods, ICA and neural network methods.

It is expected that in near future muCI based alert systems and/or health care devices would be able to detect muscular fatigue of workers who are working for long time at a stretch or repetitively in workstations. Probably this kind of alert system can be helpful to prevent musculoskeletal disorders including repetitive strain injuries.

7 Limitations of muCI

There are some limitations of muCI as it is very much dependent on sEMG signals. Locations of EMG electrodes are one of the important constraints. Hogrel et al. [43] reported how various parameters like muscular action potential, conduction velocity (CV) and mean power frequency (MPF) could vary with the electrode location, type of electrodes and their proper functioning. In addition, CV and MPF not only depend on location of electrodes but also on their initial values which change upon fatigue. This influence appears to be subject-dependent. Signal variability seems essentially to be due to the relative displacements of myotendinous and neuromuscular junctions with respect to the electrode placed. In addition to that, it is very often not possible to capture signals with the help of normal surface EMG from muscles which are very small (e.g. some facial muscles) or muscles which are located internally as placing of electrodes is itself very challenging. Researchers should take a challenge to design new kind of electrodes in this context. Even in prosthetics, current sEMG methods have proven to be inefficient and the users complained of early fatigue due to the high concentration required to executing simple tasks [7, 19, 22, 26].

However, Hargrove et al. [13] have shown that there was no significant difference when decoding the accuracy of the intramuscular EMG compared to that of surface EMG signals. Hence, proper placement of EMG electrodes, accuracy of capturing EMG signals and proper/more accurate classification of EMG signals, incorporation of Bluetooth/Wi-Fi facility for making this kind of devices more mobile [35] are still limited for better development of new muCI.

8 Summary and Conclusions

It can be summarized that muCI is a current and interesting field of HCI. It is on the verge of being a very important means of interaction in our various lively works. Present paper highlights recent researches done in the field of muCI, advances made by researchers, and also what could be the future application of such interactive devices.

Observations have been made to understand how muCI's can be used for Gesture recognition which in turn can be applied for gaming interfaces as well as interfaces for communicating with differently-abled persons (e.g. deaf and the dumb). The ways how facial expressions can be read using muCI and how this methodology can be used for controlling devices by means of different expressions, have also been stressed in the present review. The way how muCI's have been successfully used in prosthetics and how muCI's can be used to make devices for fatigue analysis of workers at workstations, have also been looked into. Lastly, some limitations of muCIs have taken into consideration to complete the knowledge-base.

Technology of muCI can be applied in various fields such as various gesture based game playing like Spiderman, Road Rash etc. design of gesture based more accurate and interactive digital drawing tool; prosthetics for more complex body movement [54], emotion based interaction with virtual world, emotion based controlling of devices, gesture based typing tool for blind persons, gesture based examination system for blind students etc. Thus, it can be concluded that present paper would be able to open new doors toward several new design ideas and using this emerging technology in future for mankind.

References

1. Ahsan MR, Ibrahimy MI, Othman O (2009) EMG signal classification for human computer interaction: a review. Eur J Sci Res 33:480–501
2. Veron S, Joshi SS (2011) Multidimensional control using a mobile phone based brain-muscle computer interface. EMBS IEEE, pp 5188–5194
3. Veron S, Joshi SS (2011) Brain-muscle computer interface: mobile phone prototype development and testing. IEEE Trans Inf Technol Biomed 15:531–538

4. Crary MA, Carnaby GD, Groher ME, Helseth E (2004) Functional benefits of dysphagia therapy using adjunctive S-EMG biofeedback. Dysphagia 19:160–164
5. Disselhorst-Klug C, Schmitz-Rode T, Rau G (2009) Surface electromyography and muscle force: limits in s-EMG-force relationship and new approaches for applications. Clin Biomech 24:225–235
6. Park E, Meek SG (1995) Adaptive filtering of the electromyographic signal for prosthetic control and force estimation. IEEE Trans Biomed Eng 42:1048–1052
7. Zecca M, Micera S, Carrozza MC, Dario P (2002) On the control of multifunctional prosthetic hands by processing the electromyographic signal. Crit Rev Biomed Eng 30:459–485
8. Gonzalez IM, Malanda A, Gorostiaga E, Izquierdo M (2012) Electromyographic models to assess muscle fatigue. J Electromyogr Kinesology 22:501–512
9. Singh VP, Kumar DK, Polus B, Fraser S (2007) Strategies to identify changes in SEMG due to muscle fatigue during cycling. J Med Eng Technol 31:144–151
10. Subasi A, Kiymik MK (2010) Muscle fatigue detection in EMG using time frequency methods, ICA and neural network. J Med Syst 34:777–785
11. Chiang J, Wang ZJ, McKeown MJ (2008) A hidden markov, multivariate autoregressive(HMM-mAR) network framework for analysis of EMG (s-EMG) data. IEEE Trans Signal Process 56:4069–4081
12. El-Daydamony EM, El-Gayar M, Abou-Chadi F (2008) A computerized system for SEMG signals analysis and classification. In: National radio science conference (NRSC 2008), pp 1–7
13. Hargrove LJ, Englehart K, Hudgins B (2007) A comparison of surface and intramuscular myoelectric signal classification. IEEE Trans Biomed Eng 54:847–853
14. Khezri M, Jahed M (2007) Real time intelligent pattern recognition algorithm for surface EMG signals. EMBS 6:45
15. Kim J, Mastnik S, André E (2008) EMG-based hand gesture recognition for real-time biosignal interfacing. In: Proceedings of the 13th international conference on intelligent user interfaces, pp 30–39
16. Morris D, Saponas TS, Tan D (2010) Emerging input technologies for always-available mobile interaction. Found Trends Hum Comput Inter 4:245–316
17. Naik GR, Kumar DK, Palaniswami M (2008) Multi run ICA and surface EMG based signal processing system for recognizing hand gestures. 8th IEEE international conference on computer and information technology (CIT 2008), pp 700–705
18. Nan B, Hamamoto T, Tsuji T, Fukuda O (2004) FPGA implementation of a probabilistic neural network for a bioelectric human interface. In: The 47th midwest symposium on circuits and systems (MWSCAS '04), vol 3, pp 29–32
19. O'Neill PA, Morin EL, Scott RN (1994) Myoelectric signal characteristics from muscles in residual upper limbs. IEEE Trans Rehabil Eng 2:266–270
20. Tang X, Liu Y, Liu C, Poon W (2011) Classification of hand motion using surface EMG signals. Biologically Inspired Robotics, CRC Press
21. Tsenov G, Zeghbib AH, Palis F, Shoylev N, Mladenov V (2006) Neural networks for online classification of hand and finger movements using surface EMG signals. In: 8th seminar on neural network applications in electrical engineering (NEUREL), pp 167–171
22. Xiong FQ, Shwedyk E (1987) Some aspects of nonstationary myoelectric signal processing. IEEE Trans Biomed Eng 34:166–172
23. Naik GR, Kumar DK, Palaniswami M (2007) Real time hand gesture identification for human computer interaction based on the ICA of surface electromyogram. In: Proceedings of the HCSNet workshop on use of vision in human-computer interaction, vol 56, pp 67–72
24. Belluco P, Bordegoni M, Cugini U (2011) A techinque based on muscular activation for interacting with virtual environments, vol 1. ASME 2011 world conference on innovative virtual reality, pp 315–324

25. Farid M, Keyvan HZ (2006) A method for online estimation of human arm dynamics. In: 28th annual international conference of the IEEE engineering in medicine and biology society (EMBS '06.), pp 2412–2416
26. Kyberd PJ, Holland OE, Chappel PH, Smith S, Tregdigo R, Bagwell PJ, Snaith M (1995) Marcus: a two degree of freedom hand prosthesis with hierarchical grip control. IEEE Trans Rehabil Eng 3:70–76
27. Scott RN, Parker PA (1988) Myoelectric prostheses: state of the art. J Med Eng Technol 12:143–151
28. Saponas TS, Tan TS, Morris D, Balakrishnan R (2008) Demonstrating the feasibility of using forearm electromyography for muscle computer interfaces. In: Proceedings of the 26th annual SIGCHI conference on human factors in computing systems, pp 515–524
29. Saponas TS, Tan DS, Morris D, Balakrishnan R, Turner J, Landay JA (2009) Enabling always available input with muCI's. In: Proceedings of the 22nd annual ACM symposium on user interface software and technology, pp 167–176
30. Saponas TS, Tan DS, Morris D, Balakrishnan R, Turner J, Landay JA (2010) Making muCI's more practical. Proceedings of the 28th international conference on human factors in computing systems, pp 851–854
31. Chu JU, Moon I, Moon MS (2005) A real time EMG pattern recognition system based on linear-non linear feature projection for a multifunctional myoelectric hand. In: Proceedings of 9th international conference on rehabilitation robotics IEEE, vol 53. pp 2232–2239
32. Farry KA, Walker ID, Baraniuk RG (1996) Myoelectric teleoperation of a complex robotic hand. IEEE Trans Rob Autom 12:775–788
33. Chen X, Zhang X, Zhao ZY, Yang JH, Lantz V, Wang KQ (2007) Hand gesture recognition research based on surface EMG sensors and 2D-accelerometers. In: 11th IEEE international symposium on wearable computers, pp 11–14
34. Naik GR, Kumar DK, Weghorn H (2007) Performance comparison of ICA algorithms for isometric hand gesture identification using surface EMG intelligent sensors. In: 3rd international conference on sensor networks and information (ISSNIP 2007), pp 613–618
35. Seregni L (2010) ERACLE wearable EMG gesture recognition system. Masters thesis, department of electrical and computer science engineering, Politecnico, Milano
36. Wheeler KR (2003) Device control using gestures sensed from EMG. In: Proceedings of the 2003 IEEE international workshop on soft computing in industrial applications, SMCia/03, pp 21–26
37. Xiang C, Lantz V, Qiao WK, Yan ZZ, Xu Z, Hai JH (2009) Feasibility of building robust surface electromyography based hand gesture interfaces. Eng Medicine Biol Soc 2983–2986
38. Khezri M, Jahed M (2007) A novel approach to recognize hand movements via sEMG patterns. EMBS, pp 4907–4910
39. Nagata K, Ando K, Magatani K, Yamada M (2007) Development of the hand motion recognition system based on surface EMG using suitable measurement channels for pattern recognition. EMBS, pp 5214–5217
40. Huan CN, Chen CH, Chung HY (2006) Application of facial electromyography in computer mouse access for people with disabilities. Disabil Rehabil 28:231–237
41. Peper E, Wilson VS, Gibney KH, Huber K, Harvey R, Shumay DM (2003) The integration of electromyography (SEMG) at the workstation: assessment, treatment, and prevention of repetitive strain injury (RSI). Appl Psychophysiol Biofeedback 28:167–182
42. Sbriccoli P, Felici F, Rosponi A, Aliotta A, Castellano V, Mazza C, Bernardi M, Marchetti M (2001) Exercise induced muscle damage and recovery assessed by means of linear and non-linear sEMG analysis and ultrasonography. J Electromyogr Kinesology 11:73–83
43. Hogrel JY, Duchêne J, Marini JF (1998) Variability of some SEMG parameter estimates with electrode location. J Electromyogr Kinesiol 8:305–315
44. Putnam W, Knapp RB (1993) Real-time computer control using pattern recognition of the electromyogram. In: Proceedings of the 15th annual international conference of the IEEE engineering in medicine and biology society, pp 1236–1237

45. Rosenberg R (1998) The biofeedback pointer: EMG control of a two dimensional pointer, wearable computers. In: Second international symposium on digest of papers, pp 162–163
46. Jung KK, Kim JW, Lee HK, Chung SB, Eom KH (2007) EMG pattern classification using spectral estimation and neural network. SICE annual conference, pp 1108–1111
47. Itou T, Terao M, Nagata J, Yoshida M (2001) Mouse cursor control system using EMG. In: Proceedings of the 23rd annual international conference of the IEEE engineering in medicine and biology society, vol 2, pp 1368–1369
48. Tsuji T, Ichinobe H, Fukuda O, Kaneko M (1995) A maximum likelihood neural network based on a log-linearized gaussian mixture model. In: Proceedings of IEEE international conference on neural networks, pp 2479–2484
49. Fukuda O, Tsuji T, Kaneko M (1999) An EMG controlled pointing device using a neural network systems. In: IEEE international conference on man, and cybernetics (IEEE SMC '99 conference proceedings), vol 4, pp 63–68
50. Tsuji T, Bu N, Fukuda O, Kaneko M (2003) A recurrent log-linearized gaussian mixture network. IEEE Trans Neural Network 14:304–316
51. Fukuda O, Arita J, Tsuji T (2004) An EMG-controlled omnidirectional pointing device using a HMM-based neural network. In: Proceedings of the international joint conference on neural networks, vol 4, pp 3195–3200
52. Kim JS, Jeong H, Son W (2004) A new means of HCI: EMG-MOUSE, systems. In: IEEE international conference on man and cybernetics, vol 1, pp 100–104
53. Chan A, Kevin B (2005) Continuous myoelectric control for powered protheses using hidden markov models. IEEE Trans Biomed Eng 52:123–134
54. Carrozza M, Micera S, Massa B, Zecca M, Lazzarini R, Canelli N, Dario P (2001) The development of a novel biomechatronic hand-ongoing research and preliminary results. Adv Intell Mechatron AIM 1:249–254

Preliminary Analysis of Low-Cost Motion Capture Techniques to Support Virtual Ergonomics

Giorgio Colombo, Daniele Regazzoni, Caterina Rizzi and Giordano De Vecchi

Abstract This paper concerns the development of a computer-aided platform to analyze workers' postures and movements and ergonomically validate the design of device a man or woman may deal with. In particular, we refer to pick and place operations of food items on the display unit shelves. The paper describes three low-cost solutions that integrate two optical motion capture techniques (one based on web-cam and another on MS Kinect sensor) and two human modeling systems (Jack and LifeMod) with the main goal of determining the suitability of operators' working conditions and, eventually, providing a feedback to the design step. The solutions have been tested considering a vertical display unit as case study. Preliminary results of the experimentation as well as main benefits and limits are presented. The results have been considered promising; however, we have planned to perform an acquisition campaign in the real environment, the supermarket.

Keywords Human modeling · Motion capture · Virtual ergonomics · Pick and place

G. Colombo
Department of Mechanics, Polytechnic of Milan, Milan, Italy
e-mail: giorgio.colombo@polimi.it

D. Regazzoni (✉) · C. Rizzi · G. De Vecchi
Department of Engineering, University of Bergamo, Dalmine, BG, Italy
e-mail: daniele.regazzoni@unibg.it

C. Rizzi
e-mail: caterina.rizzi@unibg.it

G. De Vecchi
e-mail: giordano.devecchi@unibg.it

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_34, © Springer India 2013

1 Introduction

Virtual ergonomics permits engineers to create and manipulate virtual humans to investigate the interactions between the worker or the consumer and the product. For example, in product design, human factors such as positioning, visibility, reaching, grasping and lifting of weights can all be evaluated by using virtual humans, providing a feedback to designers in the early steps of product development.

This paper refers to this context and addresses commercial refrigeration industry; in particular those companies specialized in display units. It describes the use of virtual ergonomics techniques in the design process of display units commonly used in supermarkets.

In previous research activities we have experienced the use of virtual manikins specifically targeted for ergonomics to evaluate postures and movements respect to requirements established by international standards to reduce health risks [1]. In this work we try to enhance that approach to provide more precise results. For example, when filling the shelves of a display unit, the workers act quite differently one from another. To face this issue we introduce the use of motion capture systems to reproduce with virtual humans the real way in which operators behave. In particular, we have evaluated the possibility to adopt and integrate Motion Capture (Mocap) and Digital Human Modeling (DHM) systems to perform ergonomic analysis relying on real movements performed by operators in everyday activities.

The paper, after a brief description of the state of the art of adopted techniques, describes three technical solutions based on low cost Mocap devices integrated with human modeling tool. Then, the case study and preliminary experimentation are presented.

2 Related Works

The implementation of the proposed virtual ergonomics platform requires the integration of Mocap and DHM systems to acquire end-users' postures and movements to determine fatigue, stress and risk for workers' health. In the following we provide an overview of both techniques.

First DHM tools for ergonomics analysis appeared in late 60s, mainly in aeronautics and automotive industries. Nowadays, in literature we can find various tools of different complexity depending on the target application. We have classified them into four main categories [2–4]: *virtual human/actors for entertainment* used to populate scenes for movies and videogames production [5, 6]; *mannequins for clothing* used to create virtual catwalks, virtual catalogues, and virtual try-on show rooms and to design garments [7, 8]; *virtual manikin for ergonomic analysis* used to define complex scenes, analyze postures, simulate tasks and optimize working environments [9–11]; and, finally, *detailed biomechanical models* [12, 13] whose applications concern ergonomics analysis, study of safety in transport, and human performance during sports activities, and medical device, etc. [14]. For our purpose, we consider DHM tools belonging to the last two categories.

Mocap techniques appeared in the 70s as a branch of imaging techniques applied to biomechanical processes and several applications have been developed for different contexts such as military, entertainment, sports, and medical applications. According to the working principle four main categories can be identified [15]: optical, mechanical, inertial, and magnetic that can be used for testing and validation also in a combined way [16].

We focus the attention on optical systems, considered the high-end technology. They extrapolate the position of body joints by triangulation between images taken from different cameras. We can have systems with active or passive markers [17] or markerless [18]. In the first case markers are placed in the remarkable points of the body while in the second case a dedicated software module recognizes the human figure.

In literature, we can also find researches that integrate DHM either with Virtual Reality (VR) and Mocap systems to improve the level of interaction and realism within the virtual environment, to drive the virtual human and facilitate the evaluation of comfort and prediction of injuries that could arise when executing a task [19, 20].

In our work we consider low cost techniques, developed for video games and entertainment, to verify their usability and performance in industrial context. Actually, such technologies benefit from a huge investment on research that leads to a rapid evolution but on the same time they keep affordable prices because of the target market they refer to. Moreover, the capillary diffusion ensure the ease of sharing of information on pros and cons, tips and unusual use researchers may find worldwide.

3 Technical Solutions

As mentioned before, main goal has been to experiment the integration of low cost Mocap system and DHM to evaluate postures and movements of workers filling the shelves of a display unit. We considered two systems, both optical and markerless: the former based on Sony Eye webcams and the latter on Microsoft Kinect sensor. We have been using them to acquire the real movements and postures of operators so that the following simulation can be based on real data. Both solutions are not expensive and can be easily moved and, with some precautions, used also outside the lab in potentially any work environment we want to acquire.

Concerning human modeling, we adopted two different tools: Siemens Jack specifically targeted for ergonomics and LifeMod to generated detailed biomechanical model. Figure 1 shows the technical solutions adopted, which are described in the detail in the following paragraphs.

3.1 Webcam Solution

This solution includes three main components: webcams, a module for data exchange and LifeMod to create the human avatar and reproduce postures and movements. Figure 2 shows the acquisition system composed by:

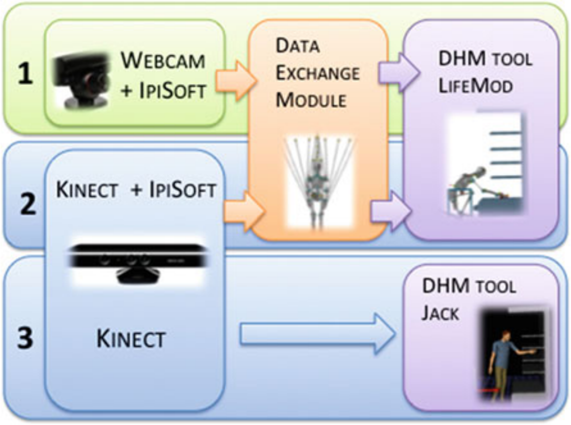


Fig. 1 Adopted technical solutions: *1*—webcam solution; *2*, *3*—Kinect solutions

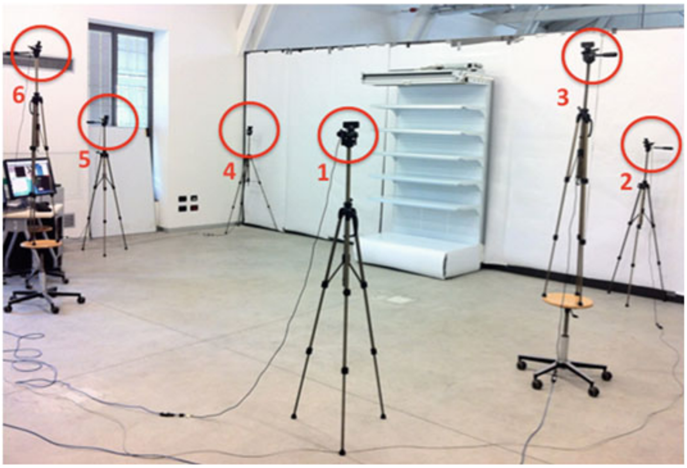


Fig. 2 Webcam solution

- Six Sony Eye webcams with a resolution of 640 × 480 pixels at 60 Hz mounted on photographic tripods.
- Portable workstation Dell Precision M6500.
- iPi Desktop Motion Capture™ (Ipi DMC) software.

iPisoft Software is a marker-less system developed to work with Sony Eyes webcams and its main features are:

- Possibility to use from 3 to 6 webcams.
- A maximum acquisition area of 7 × 7 m.
- Non real-time tracking.
- Input file format: MPEG.

The system acquires synchronized video sequences obtained with the cameras without having to apply any type of physical markers on the operator's skin. It automatically recognizes the different body segments and, then for each time step, calculates joints position and orientation. iPiDMC includes two main components: iPisoft Recorder for the motion capture phase that synchronizes images recorded from the six webcams and iPisoft Studio for the recognition and segmentation of body and tracking of movement. iPisoft Desktop Motion Capture output contains the recorded movement in Biovision Hierarchical Data (BVH) format. iPisoft adopts a skeleton made of 27 joints hierarchically organized, each characterized by proper d.o.f. and constraints. However, it has been necessary to develop a data exchange module to be integrated with the considered human modeling tool, namely LifeMod.

LifeMod is a biomechanical analysis software that permits to generate a complete biomechanical model of the human body. It is a plug-in of ADAMS software, a multibody analysis system. The creation of a model normally starts with the generation of a basic set of connected human segments based on the dimension contained in an anthropometric database; then, the joints, the muscles and the tendons are created and contact force with objects are defined. By the way, to reproduce the movement with the operators' avatar we need to exchange the data acquired from the Mocap system to the human modeling environment. This problem has been solved developing an ad-hoc conversion algorithm in Matlab. The algorithm translates the information relative to the joint hierarchy and to the motion contained in the BVH file to a SLF formatted file used by LifeMod. In order to complete the information required by a SLF file, anthropometric data are retrieved directly from user's data or from an anthropometric database (e.g., GeBOD [21], People Size [22] and US Army- Natick Database [23]).

Before proceeding in reproducing the operators' tasks using LifeMod, another issue must be faced. Actually, the conversion performed in the previous step does not take into account the fact that the information contained in the SLF file are related to the real position of the joints acquired subject while the biomechanical software use external markers placed on the skin surface. Once again to fix this problem an ad-hoc script has been created to relocate parametrically to model size the position of the markers. To reduce the number of operations necessary to run the analyzes, an automatic procedure and a CMD script have been implemented. The script is completely automatic and no user interaction is required because data relative to the markers initial position and the marker movements are produced by converting this information directly from BVH file.

Once the model is defined, simulation phase can begin. To obtain accurate simulations with the muscles and the articulations it's necessary to execute a first inverse dynamic simulation to drive the body with motion agents describing the movements to execute. Once the movements are stored a direct dynamic simulation is run to calculate the forces created by the muscles and the stresses the body is subjected to. The outcome provided by the system consists of forces and momenta acting on each joint in each time step of the analysis.

3.2 Kinect Solution #1

Similarly to the previous solution, also this one comprehends three main parts. The main difference is the Mocap system, which is composed by (Fig. 3):

- Microsoft Kinect with a resolution of 640 × 480 pixels at 30 fps, mounted on photographic tripod and connected via USB cable.
- Portable workstation Dell XPS.
- iPi Desktop Motion Capture software.

As in the previous case iPi Recorder manages the recording of images and depth videos coming from Kinect, while the iPi studio performs environment calibration and video analysis. In addition, MS Kinect SDK libraries are required.

The other two components of this solution, namely Data exchange and DHM modules, are exactly the same of the webcam solution.

3.3 Kinect Solution #2

This solution always uses a MS Kinect but, differently from the two previous one, Kinect sensor is fully integrated with Jack, a well-known human modeling system (Figs. 1, 3). It permits to define complex scenes with virtual manikins and objects, simulate many tasks and evaluate posture and ergonomics factors also using analysis tools such as Rapid Upper Limb Analysis (RULA) to investigate work-related upper limb disorders, U.S. National Institute for Occupational Safety and Health (NIOSH) lifting equations to evaluate lifting and carrying tasks, and Owako Working Posture Analysis System (OWAS) to analyze postures during work. Therefore, iPi DMC software is not necessary.

Fig. 3 Kinect solutions #1 and # 2

This solution requires:

- Mocap Toolkit, a module specifically developed by Siemens for Kinect sensor.
- MS KinectSDK v 1.0 libraries.
- SkeletalViewer sw to transfer data streaming acquired with Kinect sensor to Jack.

The skeleton used in the transition from Mocap to Jack is made of 21 joints whose positions and movements are tracked and there is not a hierarchy among them. This skeleton is less complex than Jack's one and some details cannot be taken into account (i.e., head rotation, fingers).

4 Preliminary Experimentation

In the following we describe the case study adopted for the experimentation and the preliminary results.

4.1 The Case-Study

The case study refers to a vertical refrigerator display unit typically installed in groceries or supermarket, with four or five shelves that could be placed at different heights (Fig. 4).

Different groups of people interact with the display unit: supermarket staff filling the shelves with goods, workers in charge of maintenance operations and customers picking up goods. In this paper we focus on the first category with the main goal of determining the suitability of operators' working conditions.

The task of loading a refrigerator is critical from the ergonomics point of view and may generate severe health disorders, mainly due to: repeated actions, holding and lifting loads, insufficient recovery times, uncomfortable postures, and uncomfortable environment (e.g., cold and humid).

To experiment the described solutions, we decide to focus the attention on pick and place operations of food items. We have conducted a preliminary study (interviews and direct observations) to analyze how operators really behave. This permitted to identify main operations to be reproduced in the lab and some occasional unacceptable practices such as assuming completely wrong and dangerous postures.

To acquire postures and movement we use a simplified version of the real unit (Fig. 4 right) more efficient because some elements of the complete display unit (e.g. lateral walls) may interfere with the operator during motion capture.

Fig. 4 Vertical refrigerator (image courtesy: www.costan.com) (*left*); simplified display unit (*right*)

4.2 Experimentation Results

Actors were asked to perform as much as possible as they were in the real environment and to follow a precise routine to produce comparable results with operators characterized by different anthropometric measures. The routine defines the initial and final positions of each movement to be performed. For each solution, the loading of a bottle of water in the four different shelves has been reproduced.

First the solution based on webcam has been tested. The system requires a first step of calibration that initializes the system and permits to correctly locate each camera in the space.

A semicircle disposition of the webcams at different heights around the operator is the best choice. Once calibration is done, it is possible to realize the acquisitions taking care to avoid fast movements and carefully execute the required task. It has been conducted recording ten loading routines with subjects of both genders and of different heights to evaluate if the motion capture system is affected by any problem. In particular, the conversion algorithm has been tested as well as different ways of automatically changing the position of joints depending on height and structure of subjects.

After having tested the system the real motion capture campaign has been performed and the data of the movement have been converted and analyzed with LifeMod. In Fig.5 one can see the representation of data related to the loading of the highest during the three main steps. The first one (Fig. 5a) refers to the environment in which the webcam images are captured and elaborated for each time step to gather joints positions shown in the second representation (Fig. 5b). The third representation (Fig. 5c) comes from the human modeling system where data have been converted, corrected and integrated with anthropometric databases.

The DHM tool provides different kinds of output data relative to biomechanical analysis; in particular it is possible to obtain results such as center of mass

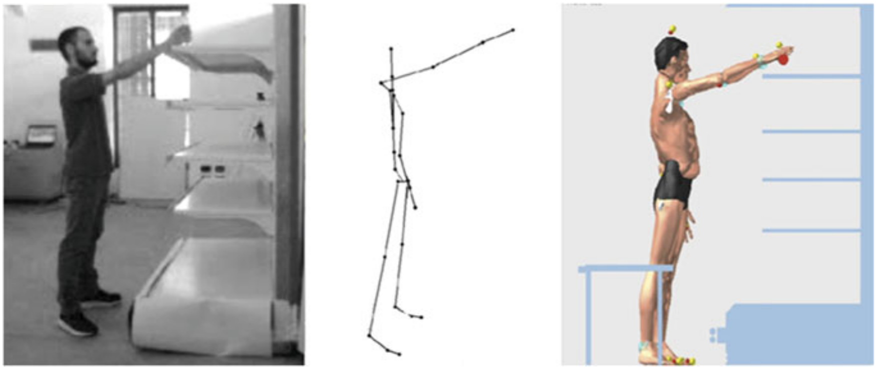


Fig. 5 Webcam solution: highest shelf loading

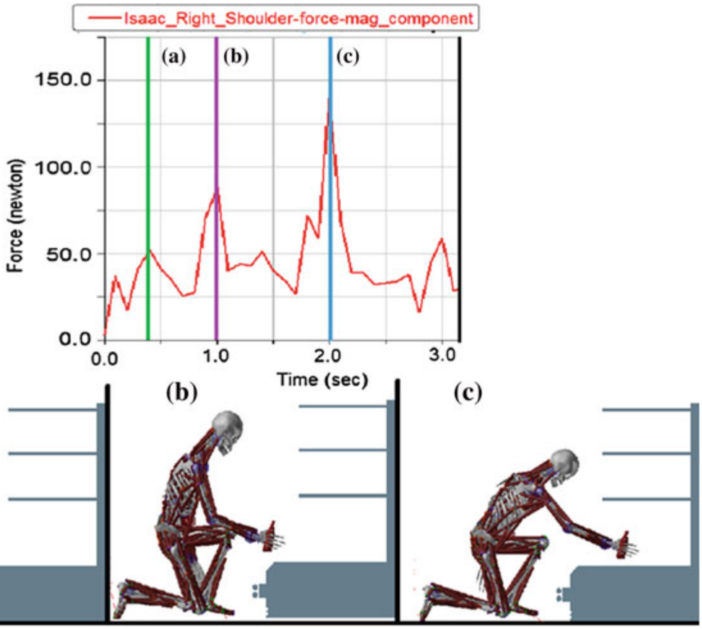


Fig. 6 Resultant force over time acting on right shoulder while loading the lowest shelf and three notable position

position, velocity and acceleration of segments, forces, torque and power for joints and additional information for soft tissues and environment interaction. Figure 6 shows an example of analysis results for the virtual human with one knee on the ground while performing the loading of a bottle on the lowest shelf. As an example the resultant force on the shoulder holding the bottle is plotted in the graphic and three screenshots corresponding to peaks are shown.

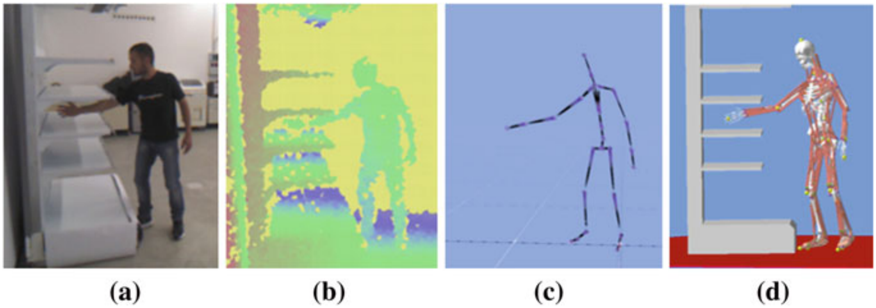


Fig. 7 Kinect solution #1: second shelf loading

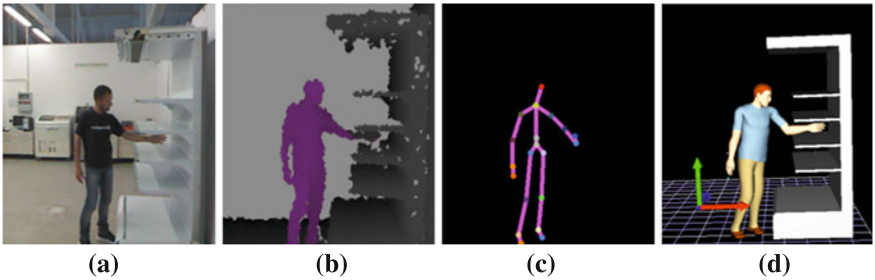


Fig. 8 Kinect solution #2: second shelf loading

Regarding Kinect solution #1 we proceeded similarly to the previous one. Figure 7 shows the results related to the loading of the second shelf. Figure 7a refers to the environment in which the Kinect images are captured, Fig. 7b shows the corresponding depth map, Fig. 7c the reconstructed skeleton and Fig. 7d the virtual avatar of the actor corrected and integrated with anthropometric databases. Results obtained were similar with those of the previous solution.

Finally we tested the Kinect solution #2, i.e. the Kinect sensor integrated with Jack. First, using Jack the virtual scene composed by the 3D model of the refrigerated unit and the operator avatar (in this case a virtual manikin 50th ile) is created; then, the Kinect plug-in and the SkeletalViewer software are launched and the acquisition session can start. Figure 8 shows the final step acquired during the loading of the second shelf. Precisely, Fig. 8a shows the image acquired, Fig. 8b the corresponding depth map, Fig. 8c the corresponding reconstructed skeleton and Fig. 8d the virtual avatar of the actor.

This solution has the advantage that the two environments, Mocap and the human modeling, are fully integrated; therefore Jack reproduces the operators' movements in real-time. For the other two solutions it is necessary to translate the data acquired with the Mocap system into a format readable by LifeMod and then reproduce the movements and postures of the actor/worker. Moreover Jack already includes dedicated modules that implement analysis tools such as RULA, NIOSH and OWAS to study and validate operator postures in order to avoid musculo-skeletal disorders.

Kinect used to track human body constitutes an interesting novelty in the instrumentation available for Mocap and virtual ergonomics at industrial level. Its low cost, broad diffusion and availability of libraries let us foresee it will be commonly used for Mocap application in near future. By the way, there are still some limitations affecting its performance when used with Jack. Actually, the skeleton does not always perfectly match the subject's posture; this is particularly true when body areas overlap. It is also recommended to acquire the entire actor so that Jack can make the posturing more robust, but Kinect limited working area, if compared to webcam solution, can constitute a limit. At the moment only one Kinect is supported for real time capture and this may cause occlusions and misunderstanding of actor position. Anyway, for the scene and tasks we consider in this paper and for most of ergonomic situations, these limitations can be acceptable and successful simulations can be carried out. Moreover, new versions of Jack that are going to be released shortly are expected to address these issues.

5 Conclusions

The goal of this work has been to verify the use of low-cost Mocap systems integrated with digital human modeling to evaluate ergonomics factors of industrial products, in our case refrigerated display units commonly used in supermarket.

Three solutions, based on two marker less Mocap systems and two different types of human modeling tools, have been preliminary tested considering the pick and place operations of a vertical display unit. The results have considered promising and interesting; however some limits have been highlighted and an acquisition campaign in a real environment, the supermarket, has been planned. In fact, starting from operators performing real tasks instead of standardized average tasks allows not only to be more precise in the final evaluation but also to consider unknown or incorrect postures or movements performed by operators in their everyday activities. In addition, data coming from acquisition campaign can be used to analyze performance variability and build a structured, domain dependant, database of real postures and movements to be applied to similar cases. This would allow benefiting from real data without the need of performing motion capture for similar cases.

The results gathered so far with the low cost Mocap techniques let us foresee a huge application in almost all industrial fields wherever a worker is asked to perform a manual operation and/or to interact with a machine. By the way, these techniques have a lower accuracy and precision of some well known and much more expensive solutions (e.g., Vicon) and this, at the moment, may limits their usage as, for instance, some medical applications.

References

1. Colombo G, De Ponti G, Rizzi C (2010) Ergonomic design of refrigerated display units. Virtual Phys Prototyping 3(5):139–152
2. Sundin A, Ortengren R (2006) Digital human modelling for CAE applications, handbook of human factors and ergonomics, 3rd edn. Wiley, New York
3. Magnenat-Thalmann N, Thalmann D (2004) Handbook of virtual humans. Wiley, Chichester
4. Rizzi C (2011) Digital human models within product development process innovation in product design. Springer, Berlin, pp 143–166
5. http://www.massivesoftware.com. Accessed July 2012
6. http://crowdit.worldofpolygons.com. Accessed July 2012
7. Wang CCL, Wang Y, Chang TKK, Yuen MMF (2003) Virtual human modeling from photographs for garment industry. Comput-Aided Des 35(6):577–589
8. Li SSM, Wang CCL, Hui Kin-Chuen (2011) Bending-invariant correspondence matching on 3D human bodies for feature point extraction. IEEE Trans Autom Sci Eng 8(4):805–814
9. Colombo G, Cugini U (2005) Virtual humans and prototypes to evaluate ergonomics and safety. J Eng Design 16(2):195–203
10. Mueller A, Maier T (2009) Vehicle layout conception considering vision requirements—a comparative study within manual assembly of automobiles. Digital human modeling for design and engineering conference and exhibition
11. Green RF, Hudson JA (2011) A method for positioning digital human models in airplane passenger seats, advances in applied digital human modeling. CRC Press, Boca Raton
12. Abdel-Malek K et al (2009) A physics-based digital human model. Int J Veh Des 51(3/4):324–340
13. http://www.lifemodeler.com. Accessed July 2012
14. Bucca G, Buzzolato A, Bruni S (2009) A mechatronic device for the rehabilitation of ankle motor function. J Biomech Eng 131(12):125001
15. Furniss M (2012) Motion capture. MIT communications forum http://web.mit.edu/commforum/papers/furniss.html. Accessed July 2012
16. Schepers HM (2009) Ambulatory assessment of human body kinematics and kinetics. Ph. d thesis, UniversiteitTwente, The Netherlands. Available at http://www.xsens.com/images/stories/PDF/ThesisSchepers.pdf
17. http://www.vicon.com. Accessed July 2012
18. Bray J (2012) Markerless based human motion Capture: a survey. Vision and VR Group, Department of Systems Engineering, Brunel University, available at http://visicast.co.uk/members/move/Partners/Papers/MarkerlessSurvey.pdf. Accessed July 2012
19. Colombo G, De Angelis F, Formentini L (2010) Integration of virtual reality and haptics to carry out ergonomic tests on virtual control boards. Int J Prod Dev 11(1/2):47–61
20. Spada S, Sessa F, Corato F (2012) Virtual reality tools for statistical analysis for human movement simulation. Application to ergonomics optimization of work cells in the automotive industry. Work 41:6120–6126
21. Cheng H (1996) The development of the GEBOD program. In: Proceedings of the 1996 fifteenth southern biomedical engineering conference, pp 251–254
22. People size database of anthropometric measure Available at http://www.openerg.com/psz/anthropometric_dates.html. Accessed October 2012
23. NSRDEC: US Army Natick Soldier Research Development and Engineering Center, http://nsrdec.natick.army.mil/ANSURII/index.htm. Accessed October 2012

A User-Centered Design Methodology by Configurable and Parametric Mixed Prototypes for the Evaluation of Interaction

Monica Bordegoni and Umberto Cugini

Abstract The research described in this paper presents a methodology for evaluating the interaction design in new consumer products, and specifically in electronic products. The methodology is supported by mixed prototypes, i.e. prototypes made up of physical and virtual components, which are parametric and configurable, and which can be used by target users of the future product, to verify aspects of usability and preferences, and to check the satisfaction in use with respect to their needs and expectations.

Keywords User-centered design · Interaction evaluation · Mixed prototypes · User interaction

1 Introduction

Experience in product design has made clear that the design of interactive products, i.e. products that are used by the users through interactive modalities, like the majority of consumer products, require the participation and involvement of users early in the elaboration of the concept, so that the final product fully meets the users' needs and preferences. Recently, it is becoming a widespread practice in the design of interactive systems the adoption of the so-called *User-Centered* Design (*UCD*) approach, which is a method for designing and developing applications,

M. Bordegoni (✉) · U. Cugini
Department of Mechanical Engineering, Politecnico di Milano, Milan, Italy
e-mail: monica.bordegoni@polimi.it

U. Cugini
e-mail: umberto.cugini@polimi.it

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_35, © Springer India 2013

components, systems or products that take into account the views and needs of the target users [1].

The UCD is actually a process consisting of multiple tasks of design and validation, based on the iterative application of various tools of observation, test and analysis. In the context of practices and standards for interactive product design, the standard ISO-9241-210 addresses the Human-centered design processes for interactive systems [2]. Human-centered design is an approach to the development of interactive systems that focuses specifically on making systems usable. This means designing systems that meet user needs better. According to this standard, systems designed on the basis of a UCD approach have the following characteristics:

- are easier to understand and use, thus reducing training and support costs,
- improve user satisfaction and reduce discomfort and stress,
- improve the productivity of users,
- improve product quality, and appeal to the users.

The design process based on the Human-centered design standard includes four main activities. The first activity concerns the specification of the context of use, which is necessary to identify which users will use the product, what they will do with it, and how it will be used and under what conditions. The following activity regards the specification of the requirements. The requirements focus on the tasks that the users will need to complete, and on any possible business goals of the product, as the cost. The creation of design solutions follows this phase. In fact, only after the requirements have been defined, the design team can start to conceive and design the product. Various design solutions may be proposed, in the form of sketches, scenarios, and prototypes, up to a complete model. The next step of extreme importance for interactive products is that one concerning the validation of the design, made by a panel of real users through tests, interviews, questionnaires and analyzes. The involvement of users is indeed beneficial in order to verify the fulfillment of the requirements previously identified, including usability, which is a central aspect in the interaction design. Usability is defined as the effectiveness, efficiency and satisfaction with which certain users achieve certain goals in certain contexts [3]. In practice, it relates to the degree of satisfaction of users when interacting with a new product. Usability testing is a common technique used in user-centered interaction design to evaluate a product by testing it on users.

Following this ISO standard, only when the design solutions reflect the requirements of the product, the design can be released and fully implemented as market product. This approach reasonably guarantees that the designed product is appreciated by a large group of users.

The research described in this paper presents a methodology for evaluating the interaction of new consumer products, and specifically of electronic products. The methodology is supported by the use of mixed prototypes, i.e. prototypes made up of physical and virtual components [4], which are configurable and parametric, and which can be used by target users of the future product, to verify aspects of usability and preferences, and to check the satisfaction of their needs and expectations.

2 Interaction Design and Assessment

During the design of a new interactive product, several components and interaction aspects of the product are defined. These aspects have to be evaluated and assessed during their development, by using the most appropriate assessment methods.

An interactive product, such as an electronic product, consists of many components, which can be grouped as:

- outer shape (cover)
- interaction physical components
- display
- Graphical User Interface (GUI)

Many products in the consumer market are characterized by such a configuration, such as mobile phones, handheld devices, video cameras, and many others. Therefore the design of such devices comprises the creation of the overall shape and style of the device, the selection of materials and colors, the definition of the various components, as buttons, and of the layout, which includes the arrangement of the components, the definition of the graphical interface including icons, functions, etc.

In order to develop a product that is likely to be successful, these items need to be assessed at some point in time in the product development process. In case the design adopts a UCD approach, these items must be validated sooner and often with users. In the early stages of the design and development process, changes are relatively inexpensive. The longer the process has progressed and the more fully the product is defined, the more expensive is the introduction of changes [5]. It is therefore important to start the design evaluation as early as possible.

The validation of the design features, in case of interactive products, has to be performed with the target end users, with respect to a set of assessment parameters, which are specific for the type of feature. The assessment parameters relate to esthetics, ergonomics, usability, functionality, performance, reliability, etc. Many methods for the validation of product concepts are based on the use of prototyping, which can be defined as that activity aiming at testing the design solutions and that is based on the use of prototypes.

In a user-centered design approach, prototypes are not simply demonstrations to show to users a preview of the design, but are used to collect *user feedback* that is then used to drive the design process. Early in design the emphasis is on obtaining feedback that can be used to guide design, while later on -when a more complete prototype is available- it is possible to measure whether user objectives have been achieved. The expected feedback from design can be used to select the design option that best fits the functional and user requirements, and also to elicit feedback and further requirements from the users.

3 Prototyping of Interactive Devices

Prototyping includes static prototypes as sketches, scenarios and storyboards, or dynamic representations of the product made using 3D models and virtual prototypes (VP), or even through interactive prototypes, virtual or physical, that can be used by users, and which have a variable degree of realism. The various kinds of prototypes are suitable to evaluate several features of the interactive products, as shown in Table 1.

In a context of UCD, the various proposals of a new product are evaluated from the outset of the design with users, coming gradually to be reduced to a limited number of selected prototypes, which will eventually lead to having only one, which will be selected for the subsequent stages of design (Fig. 1). As said, the validation methodologies are different, with different complexity and different validation and assessment targets. For example, sketches can be used at the beginning of the design, as a simple technique to show the overall idea about the product (shape, layout, etc.), and allow us to start eliminating the solutions less pleasant and appreciated by the users.

Then one can use dynamic scenarios and storyboards, for example realized by sequences of screens or videos, to show the product components and interactive sequences.

3D models and virtual prototypes (VR) are suitable to evaluate the esthetics and functionality of the products. Finally, more complex and complete prototypes are the interactive Virtual Prototype (iVP) and physical prototypes, which can effectively be used to simulate the real use of the product [6–8].

Some aspects of the product, such as its ergonomics, can be evaluated using physical prototypes. Other aspects such as usability can be evaluated by using interactive virtual prototypes. Each of these two techniques has benefits and deficiencies. The virtual prototype does not allow a complete validation of the

Table 1 Types of prototypes used to evaluate the various product design features

	Sketch	Scenario/ storyboard	3D model/virtual prototype	Interactive virtual prototype	Physical prototype
Esthetics	X		X		X
Ergonomics					X
Usability		X		X	X
Functionality			X	X	X
Performance					X
Reliability					X

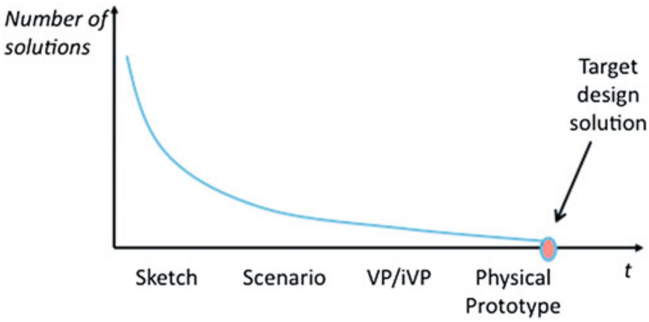


Fig. 1 Methods used to evaluate and assess the design of new products

product. Conversely, it is difficult to build a physical prototype that is very similar to the product, especially in the early stages of design; in addition the physical prototype is rigid and not easily modifiable.

A solution proven effective in other research works is based on the integration of virtual and real components [9]. Still, an open issue is that the physical components, once developed, are difficult to modify and re-submit to users for the evaluation. This research proposes the use of a mixed prototype, including virtual and physical components, where the virtual components are parametric, and the physical ones are configurable.

3.1 Classification of Prototypes

Simple prototypes are valuable at an early stage to explore alternative design solutions. Although there is benefit in making the design solutions as realistic as possible, it is important not to invest so much time, money or commitment on realistic prototypes, that there is reluctance to change the design. The effectiveness of a prototype can be evaluated in respect to several characteristics [10]. Hereafter the main ones are listed.

- *FIDELITY*. This characteristic defines the level of fidelity of the prototype in general, or of the various aspects of the product such as its visual representation, its haptic behavior, or its auditory features.
- *COMPLETENESS*. This characteristic identifies which is the degree of implementation of the product design that the prototype covers. In fact, typically a prototype implements some parts, but not all, of the product design, also in relation to the kind of evaluation and test that we intend to carry out.
- *FLEXIBILITY*. This characteristic identifies how easy and quick is to implement changes in the prototype features. For example, it indicates if it is possible to change colors and textures of the interior of a car, or if is possible to change the haptic behavior of a door handle, quickly and easily as soon as a user asks for it.

- *COMPLEXITY of REALIZATION*. This characteristic defines the complexity of developing the prototype. It depends on the technologies that are used, on the ad hoc components that need to be specifically developed for the realization of the prototype, on the software code that has to be specifically implemented, etc.

4 Mixed (Virtual and Physical) Prototypes

In order to perform an effective assessment of the design of a new interactive product, the focus is on the development of an interactive prototype that has the following characteristics: high fidelity, completeness, flexibility to configure, and easiness to implement. All these characteristics are not easily achievable in a virtual prototype.

The methodology we used for optimizing these aspects and build an effective prototype was based on the implementation of a prototype consisting of a proper mix of virtual and real components. Mixed prototyping has been proposed in some other research works [4, 11, 12]. The work presented in this paper proposes very flexible mixed prototypes where it is possible to configure both the virtual and physical components of the mixed prototype.

Therefore, it has been defined a flow of activities for the development of mixed prototypes. The definition of the activities is related to the structure of the target products. So, with reference to the typical components of products covered in this research, i.e. electronic products for the consumer market, it has been decided the hypothesis that a corresponding interactive prototype would consist of:

- virtual components
- physical components
- Graphical User Interface and interaction functional model

The initial activity plans the construction of the 3D model of the product, which comprises a set of subcomponents. It is possible to create a realistic rendering from the 3D model, which allows you to view the product as if it were real. Some parts can be developed physically for example by using fast rapid prototyping techniques, which are nowadays wide spreading rapidly [13]. For example, one can create the external cover and the interactive components, such as buttons. Typically, this type of products includes a display with which the user can interact via touch screen, buttons, interaction wheels, etc. The information is displayed on the screen through a GUI, and can be called according to sequences defined by an interaction functional model. The flow of activities for the creation of a mixed prototype is shown in Fig. 2, and includes the production of the components mentioned above (hardware and software), and a physical layout where to install the various physical components.

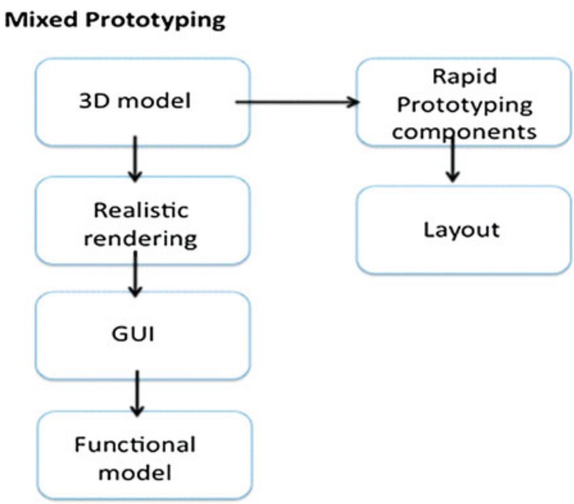


Fig. 2 Flow of activities for the development of a mixed prototype

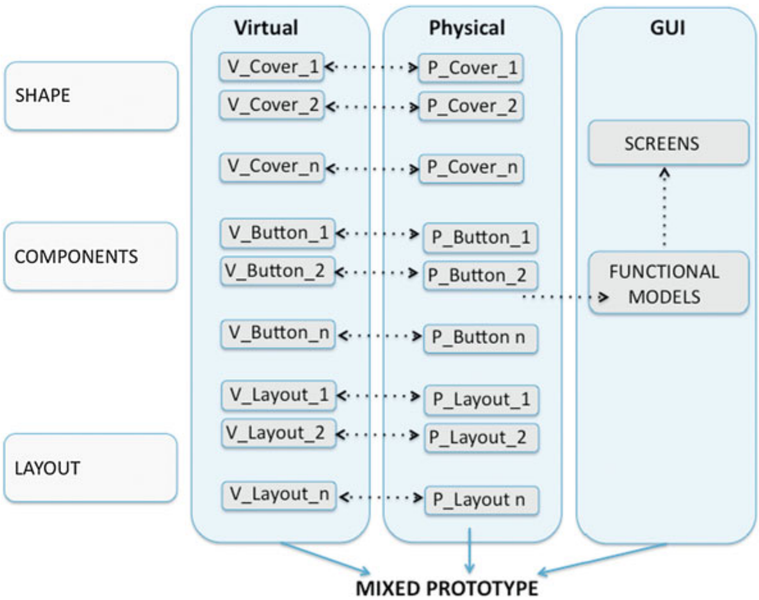


Fig. 3 Mixed prototype consisting of parametric virtual components and configurable physical components conveniently integrated

When developing a mixed prototype there is the necessity of linking and seamlessly integrating the virtual components with the physical ones (Fig. 3). Therefore, it is necessary to create a correspondence between the virtual and the physical components. In order to quickly change the virtual components, a solution can be implementing them as parametric, as well as developing the physical ones so that they are easily interchanged.

The resulting mixed prototype is highly configurable. It is possible to change the shape of the device and of the components, change the material and color, and also change the position of the interactive components as well as their behavior.

5 Case Study

One of the case studies selected to apply and test the methodology concerns a handheld device for domotics, implementing functions for the control of house equipments. The device can be placed on a holder attached on the wall, or held. After defining the device functions, we began developing the first sketches of the device, focusing on the button layout and esthetics, which were shown to a selected group of users. Then, we have developed a dynamic scenario consisting of a sequence of images (screen snapshots) that can be browsed through a hypertext structure, thus simulating the interaction with the GUI of the product. The prototype hypertext can be easily implemented by using various tools, with a limited effort, for example by using the MS PowerPoint application. These two prototypes have allowed us to select the configurations that at best suite the target users. Subsequently, we have developed a mixed prototype, as described hereafter.

5.1 Mixed Prototype Development

In order to test more accurately with users the esthetics, ergonomics, usability, and functionality of the variants of the handheld device, thus further converging to the preferred solution and configuration, we have implemented a mixed prototype. According to the methodology described in the previous section, first we have developed a 3D model of the device cover and of the interactive components (buttons), in their various shapes. Then, we have manufactured the corresponding physical components.

In order to connect the physical buttons with the functional model of the graphical user interface, and to enable user interaction with the functionality of the device, the components are connected to electronic circuitry. For that, we have used the Arduino system, which is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software [14]. Arduino is intended for designers and anyone interested in creating interactive environments. It can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. Specifically, the mixed prototype has been built using the Arduino One. The circuitry for the control of the interface has been obtained by welding on a breadboard the various

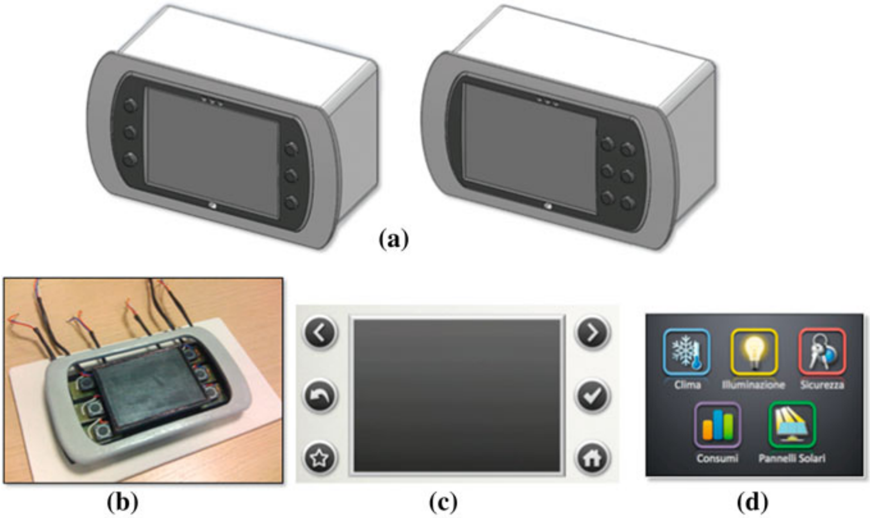


Fig. 4 Mixed prototype of the handheld device

selected electronic components, which consist of pushbuttons that detect the pressures exerted by the user, returning 5 v tension when pushed, and 0 v when released. The interaction with the buttons is controlled by a program implemented using the MenuBackend library, which allows a very flexible management of the menu, through a simple tree structure implementing the interaction functional model.

The layout has been developed by positioning some strips of velcro under the cover. Pieces of velcro has been also put under the physical buttons, so that the buttons can be conveniently repositioned. In this way it is possible to compare various variants. For example, it is possible to position six buttons on the right hand side, or three buttons on both sides. The final prototype is shown in Fig. 4. Figure 4a) shows the virtual prototypes, Fig. 4b) the mixed prototype, Fig. 4c) shows one of the functional buttons configuration, and Fig. 4d) one of the screen shots.

5.2 Evaluation of the Mixed Prototyping Methodology

After building the Mixed Prototype we have performed some tests with potential end users of the handheld device in order to validate the proposed methodology based on mixed prototyping.

The users test has been performed according to the ISO standard about ergonomics of human system interactions [2], where it is planned to consider seven characteristics that an interface between a user and an interactive system should

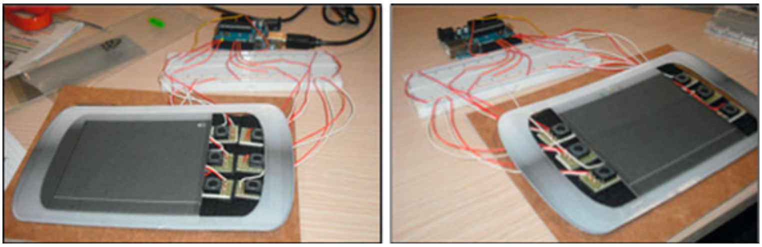


Fig. 5 Two different configurations of the device

have, for the analysis and evaluation of the functioning of the system: suitability for the task, self-descriptiveness, conformity with user expectation, suitability for learning, controllability, error-tolerance, suitability for individualization.

The objective of the user assessment was to evaluate the positioning of the interactive buttons in the layout, which have been arranged in two different configurations (Fig. 5): (1) all buttons placed on the right hand side, (2) three buttons placed on the left and three on the right side.

After a brief introduction to the functionality of the device under test, we allowed the users to use the control device for about ten minutes. The users were able to learn and test the functions of the device. The two configurations were presented to the participants in a quick sequence. In fact, the prototype set-up allowed us to quickly switch from one configuration to the other. At the end of this phase, an evaluation questionnaire has been submitted to each participant.

The questionnaire is divided into sections and provides an evaluation of the device according to the criteria of the followed ISO standard. For what concerns the section about the system usability and functionality, the users have been asked to assess the location of buttons and the functions associated with them.

At the conclusion of the test, according to the preferences expressed by the users, the preferred configuration is one in which the functions for the navigation are placed on the two sides of the device. Then, we have performed a second test for evaluating the position of the functions for browsing in the menu. The functions have been associated with the buttons, which configuration was varied as follows: (1) first buttons at the top, one on the right and one on the left, (2) two buttons on the right hand side, one below the other. The protocol used for the evaluation is similar to the previous one. At the end, again we were able to detect the user preferences concerning the functions arrangement.

Finally we have also asked the participants to evaluate the fidelity of the prototype, with respect to a real product of the same type. The perception of realism reported by the participants was quite high and satisfactory.

The tests have allowed us to evaluate the benefits of using configurable and parametric Mixed Prototyping for the evaluation of new interactive products. The tests have shown the following:

- the realism of the Mixed Prototype was considered good by the final users

- it was quick and easy to change configurations
- the configurations were switched in 2–3 min, reducing the time from one trial and the following one
- it was possible to test the esthetics of the cover and components, as well as the ergonomics and usability.

6 Conclusion

The paper has presented a methodology developed for the evaluation of interaction of new products, which is based on the use of mixed prototypes that are parametric and configurable. The methodology developed has been evaluated through the development of a case study presented and discussed in the paper.

The use of mixed prototype has allowed us to refine the evaluation previously performed with users by using other prototyping methodologies, as sketches and dynamic scenarios. The prototype has revealed to be very flexible, both for the virtual components, defined parametrically, and the physical components, which are highly configurable. The realization of the prototype includes the development of the virtual model, of the GUI and of the functional model, which can be re-used later on in the subsequent phases of the product design. The major effort has been put on the development of the correlation of the physical component with the functional model, which can rely on circuitry and modules that can be easily re-used for the development of several similar applications.

Acknowledgments The authors would like to thank Samuele Polistina, and the students Alessandro La Rosa, Luca Marseglia for their contribution to the development of the case study.

References

1. Norman DA, Draper SW (1986) User-centered system design: new perspectives on human-computer interaction. Lawrence Erlbaum Associates
2. ISO DIS 9241-210 (2008) Ergonomics of human system interaction—Part 210: human-centred design for interactive systems. International Organization for Standardization (ISO). Switzerland
3. Nielsen J (1994) Usability engineering. Academic, Cambridge
4. Bordegoni M, Polistina S, Carulli M (2010) Mixed reality prototyping for handheld products testing. Research in interactive design: proceedings of virtual concept 2010, Springer Verlag
5. Dixon JR, Poli C (1995) Engineering design and design for manufacturing, a structured approach. Field Stone Publishers, Conway
6. Kawaguchi K, Endo Y, Kanai S (2009) Database-driven grasp synthesis and ergonomic assessment for handheld product design. In: Duffy VG (ed) Digital human modeling, HCII 2009, Springer, Berlin

7. Kanai S, Higuchi T, Kikuta Y (2009) 3D digital prototyping and usability enhancement of information appliances based on UsiXML. Int J Int Des Manuf 3(3):201–222 (Springer, Paris)
8. Ferrise F, Bordegoni M, Cugini U (2012) Interactive virtual prototypes for testing the interaction with new products. Comput Aided Des Appl (in press)
9. Bordegoni M, Cugini U, Caruso G, Polistina S (2009) Mixed prototyping for product assessment: a reference framework. Int J Int Des Manuf 3(3):177–187 (IJIDeM, Springer)
10. Bordegoni M (2011) Product virtualization: an effective method for the evaluation of concept design of new products. In: Bordegoni M, Rizzi C (eds) Innovation in product design: from CAD to virtual prototyping, Springer
11. Costanza E, Kunz A, Fjeld M (2009) Mixed reality survey. In: Lalanne D, Kohlas J (eds) Human machine interaction, LNCS 5440, Springer, Berlin, pp 47–68
12. Bimber O, Raskar R (2005) Spatial augmented reality: merging real and virtual worlds. A. K. Peters, Massachusetts
13. Wright PK (2001) 21st Century Manufacturing. Prentice-Hall Inc, New Jersey
14. Arduino (2012) http://www.arduino.cc/. Accessed on Oct 2012

Study of Postural Variation, Muscle Activity and Preferences of Monitor Placement in VDT Work

Rajendra Patsute, Swati Pal Biswas, Nirdosh Rana and Gaur Ray

Abstract Various studies investigated sitting posture while working at VDT for muscle response, posture and preference, to deduce recommendations for design. The posture assumption is a dynamic activity and is often resulted out of continuous visual and physical feedback processed on cognitive level to maintain optimum comfort. The parameters that affect the work station design such as visual display terminal height directly affect the posture and comfort. This paper discusses the study of postural angles such as Head inclination, Trunk bending, Trunk inclination and sEMG muscle activity of Neck Extensors, Erector Spinae, Sternocleidomastoid and Upper Trapezius muscles when a Visual Display Terminal (VDT) user is working at a visual display terminal. The conditions were simulated on a test-rig which was developed on the basis of anthropometric data obtained. The experiment was performed on eight Indian male subjects and the VDT height was varied from 69.5 to 119.5 cm, monitor inclination was varied as 0, 30, 60°. Changes in the sitting postural angles was recorded using photogrammetry, simultaneously sEMG muscle activity of the defined muscles was recorded, also the preferred position of the VDT at each height as responded by the subjects was recorded including preferred VDT height. It was observed that the thoracic bending varied between 120 and 155° which increased with increasing VDT

R. Patsute (✉) · S. P. Biswas · G. Ray
Industrial Design Centre, Indian Institute of technology Bombay, Mumbai, India
e-mail: rajenp@iitb.ac.in; rajenpats@gmail.com

S. P. Biswas
e-mail: palswati27@gmail.com

G. Ray
e-mail: ggray@iitb.ac.in

N. Rana
Theem College of Engineering, Boisar, Mumbai, India
e-mail: ranank@rediffmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_36, © Springer India 2013

height. The trunk inclination with reference to horizontal varied from 96 to 65°. Similarly neck inclination was observed to change by a span of approximately 40°. The preferred monitor height was observed to be in the range of 89.5–99.5 cm. The Upper Trapezius and Sternocleidomastoid showed variation in muscle activity but not related to monitor height. The Erector Spinae and Neck extensors however responded to the variation in monitor height in exactly opposite pattern. It was observed that the point of intersection of the normalized sEMG ratio curves lies in the span of preferred VDT height responded by the subjects. The potential application of this research is in design of Sit down console, computer work stations/consoles with or without adjustability features in Indian context.

Keywords VDT height · Work station design · Sitting posture

1 Introduction

Visual display terminal height is known to influence posture and muscle during computer usage. Posture assumption is a dynamic activity and is often resulted out of continuous visual and physical feedback processed on cognitive level to maintain optimum comfort. Parameters e.g. display height directly affect the posture and comfort. The electromyographic response of the muscles is known to vary with the changes in display height. Posture is directly related to tissue loads and postural investigation associated with muscle activity reveals interesting facts. It has been the most commonly used indicator of musculoskeletal demand in studies evaluating VDT heights [1]. In design of work stations this issue of postural comfort has been partially resolved by providing flexibility of setting various work station parameters. It is but important to understand how various parameters that influence sitting posture and comfort behave in relation to each other. So that it adds to the designers knowledge base thereby affecting the outcomes. This study analyzes multiple parameters at varying heights and inclinations of VDT. The posture is studied by observing variation in defined postural angles and electromyographic response of involved muscles.

In the VDT work posture studies researchers have discussed the surface electromyographic response of the back muscles and the regions being primarily Cervical, Lumbar and Trapezoidal. The most important muscles taken into consideration are Neck extensors, Sternocleidomastoid, Upper Trapezius and Erector Spinae because of their prominent involvement in attaining the posture. The prime consideration in VDT workstation studies has been the placement of the viewing unit which is the point of information fixture around which the human body tends to manipulate and adjust itself. Since this study is about evaluation postural variation and muscle load variation in response to the changes in VDT height and inclination it is essential to take a overview of various other studies which have attempted to understand the underlying phenomenon.

It has been reported that surface EMG from electrodes located in the posterior *upper cervical region* reflected differences in VDT location, at least between extremes in location [2]. In the study carried out by Villanueva et al. [3] on ten subjects the muscle activity was recorded at c2–c3 level for the neck extensor muscles and over lateral portion of trapezius. The extensor activity normalized to maximum showed significant increase with more flexed neck and decreasing VDT height. A backward leaning trunk showed decreased trapezius muscle activity. Hamilton [4] observed that sEMG signal of Sternocleidomastoid and Neck extensor muscles changed in response to the position of the copy holder both in reading and typing task, the activity was more in the later. Turville et al. [5] compared the 15° and the 40° recommendations for VDT placement for muscle response of a set of back muscles. The 40° VDT placement or lower VDT position (LMP) showed significantly higher muscle activity for right sternocleidomastoid, right levator scapulae, right cervical erector spinae, left cervical erector spinae, right thoracic erector spinae and left thoracic erector spinae. In experiment carried out for bifocal conditioned subjects Kumar found that the trapezius and sternocleidomastoid sEMG was less by 30–40 % in the sunken VDT position [6]. On the other hand Aaras et al. [7] found no significant difference in trapezius EMG levels between high and low VDT position. They studied muscle load from the upper part of trapezius.

Hsio and Keyserling [8] in their pilot studies with three subjects evaluating posture behavior during seated tasks observed that postures were affected by target location, body size, and target size. Also the movement of the seat pan was seen as important for adjusting to a comfortable work posture. De Wall et al. [9] found that the position of the head in which neck muscle forces are minimal differs from the position of the head when some commonly accepted recommendations for VDU placement are used and further say that 15° above horizontal is better than the 15° below. Posture improved with increase in angle above horizontal. Villanueva et al. [10] studied the interrelationship between eye position and body posture and suggested that changes in body posture compliment the eye position in attaining a better view of the visual target. Viewing angle was mainly decided by neck and eye inclination and to a lesser extent by thoracic. Burgess-Limerick et al. [11] studied the head and neck posture influenced due to eye level and low VDT locations when subjects performed a word processing task. Lowering the VDT position did not cause changes in the posture of the neck relative to the trunk but did increase the flexion of the head relative to the neck.

Mandal [12] has displayed that with inclined seat and inclined desk a better sitting posture is achieved when the desk is inclined by 10° and seat by 15° reducing the bending that is required at the hip resulting in more comfort feeling. With horizontal chairs the same effect is achieved by users by resting only the buttocks on the seat. Fujimaki and Mitsuya [13] have discussed that backward tilt makes it difficult for the operators to keep their feet flat on the floor. Operators body posture keeps on changing and they respond in various ways like forward tilt, the reclining posture makes it difficult to keep feet flat on the floor. Operator behaviors are peculiar, in the study conducted by Ray et al. [14] it was observed that VDT operators (74 %) never adjusted their chair height even when the adjustment facility was provided, half of the users acquire forward leaning posture while working on VDT which makes the backrest practically useless.

Apart from the postural and muscular issues the visual accommodation and vergence capabilities tend to be in favor of Lower VDT placements. Since eyelids covered more region of eyeball in LMP it results in less eye dryness [10]. In quite a few studies that studied VDU placement with help of discomfort and preference the reports have been rather mixed. Kumar [6] studied the reported discomfort in three positions of VDT namely sunken, level and raised the reported rating was in the ratio of 1:2:4 respectively, informing that the discomfort was maximum in high VDT placement. In studies by Turville et al. [5] seven of the twelve subjects preferred 15° below horizontal placement whereas remaining preferred the 40° below horizontal position. Svensson [15] investigated the lowest loading height of the VDU on neck and shoulders of the operators. The study showed that to load the neck as little as possible during the VDU work, each individual should adjust the height of screen to obtain a suitable viewing angle for the eyes and one at which it is easy to keep the neck straight. The study shows that a viewing angle of +3° gave less load upon the neck than the −20° position.

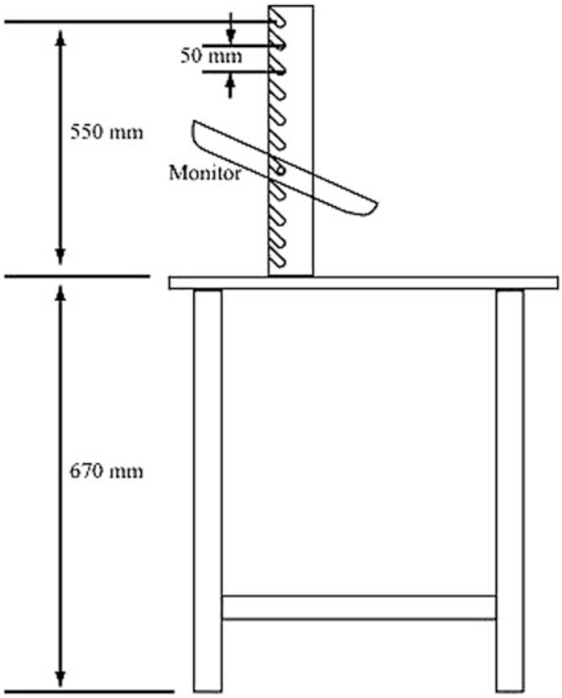
Optimal VDT placement is a compromise between visual and musculoskeletal system [16]. Much research has focused on identifying the optimal screen height and there is to this date no clear consensus. So often context based studies are more useful and recommend best options for the said context. And so while recommending guidelines for design it is very essential to carry out studies simulating the contextual user parameters and derive recommendations from the studies.

The task of working at VDT involves the neck muscles, shoulder muscles and the muscles of the lumber region. The angle of head, bending of thorax and trunk inclination are prominent in deciding the sitting posture. Experimentation discussed here covers the relative behavior of the muscles and corresponding changes in posture as the VDT height is varied from a very low to high position. The study here attempts to investigate the correlation between sEMG responses of a few selected muscles from the back and the corresponding variations in the posture triggered due to input variable such as VDT height. Also it is attempted to correlate this data with the preferred position of the screen. The results are discussed in light of earlier studies and it is attempted to get a comprehensive view of the play of different variables in sitting posture and sEMG activity of involved muscles while user works at VDT to a limited extent.

2 Method

To enable variation of VDT height and inclination, a test-rig was prepared (see Fig. 1) to simulate the conditions of the VDU work station and enable controlling variables like VDT height. Slotted supporting structures were fitted on the table (Fig. 1) which enabled shifting of the VDT vertically. The VDT could also be rotated about its axis which enabled changes in VDT inclination angle (A) at

Fig. 1 Schematic of the rig developed for the experiment



various heights (H). The height of horizontal surface on which keyboard rested was fixed after studying the anthropometric dimensions of Indian male adults in sitting position equal to 670 mm. The subjects were given to sit on a seat with adjustable height which was set to the popliteal height of the subject. It has been observed that the operators while working at VDT tend to sit forward in the chairs ignoring the backrest. The eyes of the operators are strongly fixed on the screen and hands are busy operating the keys or mouse. Considering these aspects no back support or elbow-rest was provided to the subjects. And subjects were asked to adopt a comfortable working posture on the rig with thighs horizontal and feet flat on the ground. The subjects were bare bodied with minimal clothing to facilitate sticking of electrodes and markers that were used to collect postural information by photogrammetry and the electrodes captured the sEMG signal of the muscles.

The height of VDT was varied in 11 stages from 69.5 to 119.5 cm and in each stage three angles of monitor that is 0, 30 and 60° were considered. To capture information on postural changes photographs of subjects were taken in each experimental state. These photographs were then imported into AutoCAD to measure the required postural angles. White markers were put on to the subject to mark various angular positions as shown in the Fig. 2. Position of the markers on the subjects body were fixed at 7th cervical vertebra, Angulus inferior scapula (AIS), Iliac crest, Temporal canthus, In proximity of the center of the outer canal of the ipsilateral ear.

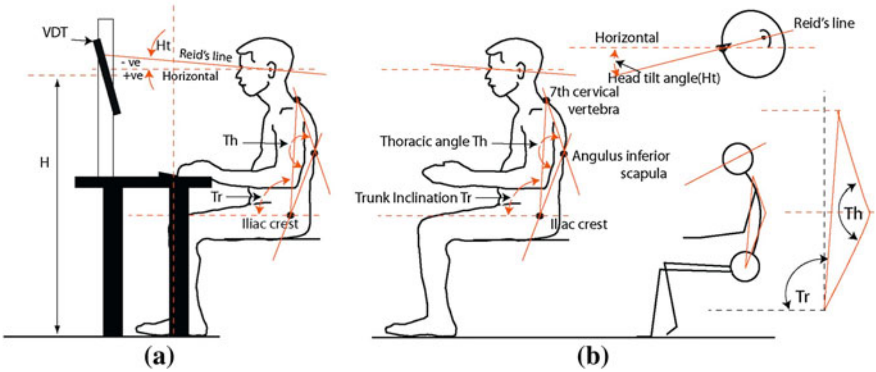


Fig. 2 Position of postural markers

Different variables considered for evaluation in the experiment were: Thoracic bending (Th) is the angle formed by the intersection of lines joining 7th cervical vertebra-AIS and AIS-Iliac crest which gave the thoracic bending of the subject. Head inclination (Ht) is the angle formed by the intersection of lines joining temporal canthus-proximity of the centre of the outer canal of ipsilateral ear and the horizontal. The angle is taken as positive when the former line is inclined and subject is looking below horizontal. Trunk inclination (Tr) is Angle formed by the intersection of lines joining Iliac crest-7th cervical vertebra and horizontal. In order to capture the sEMG signal of the neck extensor muscles electrode were placed at the level of second and third cervical vertebra, over the cervical portion of the descending part of the trapezius. To measure the activity of upper trapezius electrodes were placed at 2 cm lateral to the midpoint of the line between the 7th cervical vertebra and acromion and three cm below the processus mastoideus (Mastoid process) to measure activity of the Sternocleidomastoid. For Erector Spinae muscle the electrodes were placed at 2 cm lateral from the midline of spine at L5-S1 level.

A multichannel (16 Channel) data acquisition system MP100 from Biopac Inc was used for EMG signal recording from all the four muscles simultaneously. The electrodes used were of Ag/AgCl disc type. Before placement of the electrodes the skin was abraded to remove dead cells and was cleaned with 70 % ethanol. The data acquisition software Acq 3.7.3 was used to capture data. Figure 3 below shows the set up. The test was performed by keeping the amplifier gain 500 and sampling rate 2,000. Integrated RMS signal was obtained from the raw EMG signal for data extraction and analysis.

Eight male subjects of varying body sizes were chosen for the experiment. The subjects were asked to play an interactive game on the screen. The Sitting eye height of the subjects varied between 166 cm and 150 cm and weight varied between 49 and 81 kg. The detail statistics of subjects of subjects is shown in Table 1.

Fig. 3 Biopac MP100 data acquisition system

The task demanded the subject to keep attention continuously on the screen following the moving visual target and interact with the system via keyboard and mouse for control. Room illumination was maintained at 185 to 240 lux with partially natural and diffused artificial light. LCD VDT with display size 41.3 by 25.9 cm was used. The subjects were asked to play for approximately one and half minute in every data acquisition state the total duration therefore approximated 50 min. There were total $11 \times 3 = 33$ data acquisition states. The readings in each state were taken in the later half minute when the subject was fully engrossed in the game. The subjects were given intermittent rest after every height and was asked to relax when height of the VDT was changed. Figure 4 below shows experimental setup where subject is participating in the experiment.

Raw data was processed to be made interpretable. In every state data, average was found from the RMS signal. Normalization was carried out by dividing it by average RMS signal of reference state. In the reference state subject was asked to sit in normal posture with feet flat on the floor and hands held against trunk, bent at the elbows and palms straight (Fig. 2). This type of ratios was found for all the 33 states of a subject. These were then classified as variation of VDT height versus ratios for Upper trapezius, Sternocleidomastoid, Neck extensor and Erector spinae and the angles in respective states that is trunk inclination, thoracic bending, Head

Table 1 Subject details

Sub No	Age (years)	Weight (Kg)	Height (cm)	Eye ht (cm)	Popliteal ht (cm)	Sitting eye ht(cm)
1	34	60	165	154	48	112
2	25	57.36	168.5	155.2	47	117.5
3	28	49.5	169.5	157.8	45	118.9
4	22	63.8	164.2	150.6	43.9	112.7
5	30	56.7	170	158	46	119.8
6	25	56	164	150.7	45.7	112.7
7	25	81	173	161.4	44	122
8	22	77	176.5	166	48.5	122

Fig. 4 Experimental set up with subject

inclination for all three states on viz 0, 30 and 60° inclination. The ratios were also classified as variation of Inclination versus Ratios for Upper trapezius, Sternocleidomastoid, Neck extensor and Erector spinae and the angles in respective states that is trunk inclination, thoracic bending, neck inclination for all states for different heights.

3 Results

The responses of posture to changes in VDT height is revealed in the variation of angular data on the subjects. The trunk angle is observed to be generally in the zone of 72–93°. Table 2 displays the summary of trunk inclination data obtained, in column heads prefix Tr is for trunk inclination and suffix 1 represents the subject number.

All subjects showed either a steady or increasing trend. Increasing trunk inclination angle means the subject is swaying away from the monitor. However this increase is not continuous and often there is steep fall in the angle indicating the subject bending more towards the screen, and may then again tilt back increasing the trunk inclination angle. The Changes in monitor inclination doesn't seem to affect trunk inclination. The average for all the subjects of the angles at various heights shows increase with increase in VDT height for all three positions: A0, A30, A60. Figure 5 displays the average plot and trend using linear regression equation for angle A0, A30 and A60.

Table 2 Summary of trunk inclination data

Sub-	Tr1	Tr 2	Tr 3	Tr 4	Tr	Tr 6	Tr 7	Tr 8
At A0								
Max	86.21	91.32	90.56	84.29	92.27	85.56	80.10	85.61
Min	81.93	82.08	74.84	80.32	84.98	82.09	72.54	74.32
Av	84.38	87.62	81.36	82.56	89.77	84.16	77.11	79.77
SD	1.34	3.40	5.43	1.38	2.90	0.99	2.52	4.03
At A30								
Max	86.19	92.60	87.42	84.06	96.27	85.25	80.67	85.43
Min	80.80	83.11	65.92	79.07	85.12	82.84	72.98	76.93
Av	84.50	87.36	79.90	82.58	90.50	84.18	77.82	80.34
SD	1.59	3.23	6.60	1.61	3.35	0.67	2.66	2.93
At A60								
Max	86.71	90.71	90.37	85.48	95.01	84.82	84.77	91.40
Min	82.73	84.38	69.12	81.15	85.64	82.43	73.25	73.21
Av	84.69	87.64	82.26	83.45	90.39	83.88	77.72	82.47
SD	1.43	2.12	6.74	1.51	3.03	0.74	3.49	4.65

The increase in trunk angle means that the subject is swaying away from the VDT screen implying that increase in height of the VDT seems to make the subject bend away from the screen. The thoracic angle varies between 125 and 155°. Increase in thoracic angle increases the height of the sitting subject and indicates straightening of the body. Though the increase may not be consistent and every now and then steep fall is seen which is compensated in the next higher stages. Generally thoracic angle is observed to increase or remain almost same with increase in VDT height indicating decrease in thoracic bending or varying around constant with increase in VDT height. Table 3 below gives summary of Thoracic angle data obtained.

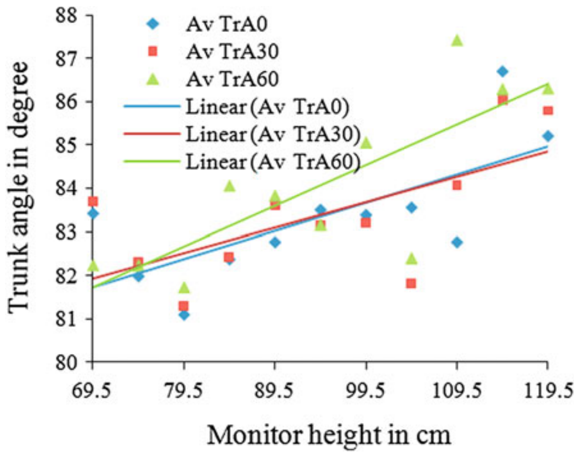


Fig. 5 Plot of Average Trunk inclination vs VDT height at VDT inclination A0, A30 and A60

Table 3 Thoracic angle variation

Sub-	Th1	Th 2	Th 3	Th 4	Th 5	Th 6	Th 7	Th 8
At A = 0								
Max	136.85	150.82	154.43	144.55	152.86	142.98	138.81	148.89
Min	127.10	123.78	124.24	141.11	133.79	138.20	131.11	139.59
Av	131.38	138.56	135.91	142.91	145.85	140.94	133.78	144.67
SD	3.26	8.62	11.76	1.02	6.44	1.70	2.24	2.59
At A = 30								
Max	135.14	149.37	152.86	145.37	151.53	142.71	136.94	147.22
Min	126.18	121.19	124.63	139.45	135.84	138.95	131.26	136.54
Av	131.00	137.50	138.85	142.96	146.29	141.03	134.03	143.80
SD	2.55	10.03	10.59	1.96	5.46	1.40	2.08	2.90
At A = 60								
Max	135.40	149.86	153.97	146.51	155.15	146.72	142.61	151.66
Min	126.76	134.12	125.26	143.22	134.23	136.27	130.71	140.20
Av	131.84	144.51	144.34	144.32	146.59	141.42	134.79	146.90
SD	2.82	4.73	11.71	1.03	6.84	2.43	3.23	3.79

The average of subjects' thoracic angles at various heights shows increase with increase in VDT height for all the three positions: A0, A30, A60. Figure 6 shows plot of Average Thoracic angle against VDT height at A0, A30 and A60 for all the subjects. The head tilt angle decreases with the increase in the VDT height, the angle below horizontal i.e. subject looking down is referred to as positive neck angle. The neck and effectively the head seems to be altered continually with changes in VDT height. The changes in VDT inclination appear to be compensated more by the eyeball movements. Following Table 4 shows summary of the head inclination variation. For all the subjects the head tilt angle is seen to distinctly vary with the monitor height. The neck bending reduces with increase in monitor

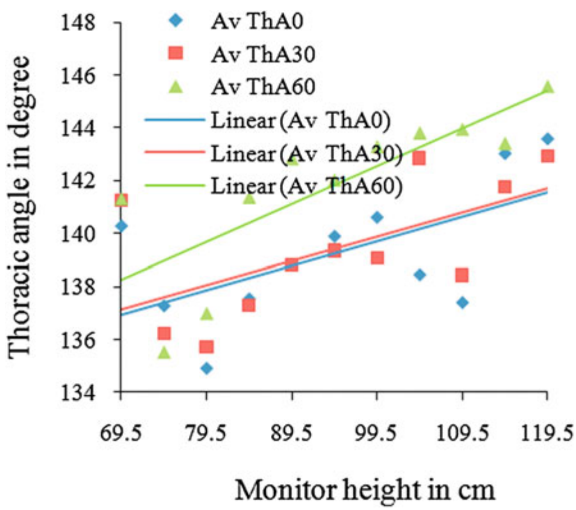


Fig. 6 Plot of average of subjects thoracic angle against VDT height at A0

Table 4 Summary of head tilt angle variation

Sub-	Ht1	Ht 2	Ht 3	Ht 4	Ht 5	Ht 6	Ht 7	Ht 8
At A = 0								
Max	0.16	22.38	3.17	−11.39	4.01	−6.62	−3.16	0.81
Min	−24.79	−13.35	−25.76	−45.21	−36.61	−20.11	−27.54	−21.73
Av	−11.52	6.25	−14.68	−24.66	−12.77	−13.18	−13.04	−10.67
SD	8.53	11.38	9.05	10.07	12.64	4.71	8.66	9.00
At A = 30								
Max	−1.14	23.41	0.18	−15.01	10.62	−4.26	−3.75	4.87
Min	−25.83	−13.49	−33.02	−40.58	−38.07	−19.20	−22.10	−33.10
Av	−12.07	6.82	−18.27	−25.63	−14.03	−13.20	−11.79	−14.69
SD	8.30	11.82	10.12	7.89	14.70	4.95	7.32	11.69
At A = 60								
Max	−2.41	17.24	−4.80	−14.32	6.47	−4.98	−1.84	4.91
Min	−22.79	−17.85	−34.03	−43.66	−36.27	−19.40	−27.93	−41.15
Av	−12.70	0.94	−17.58	−31.39	−15.75	−12.24	−15.68	−19.61
SD	7.37	11.37	10.40	8.76	13.55	5.05	9.48	13.92

height. Figure 7 below shows the plot of head tilt angle against VDT height at A0, A30 and A60. It was observed from the data that Upper trapezius activity did not show significant trend. The activity in arm and its positioning seems to introduce muscle activity which is strong but doesn't display any specific pattern.

Upper trapezius muscle was more susceptible to the movement caused by the subject in the hand arising out of adjusting to best position or better comfort and there was no specific trend observed common to all the subjects. Sternocleidomastoid also showed activity which is caused other than that due to changes in the VDT placement mostly influenced by voluntary stretching of neck muscles by the subjects and as such did not show a significant trend common to all the subjects. Table 5 below shows the summary of sEMG Ratios for Neck extensor muscles.

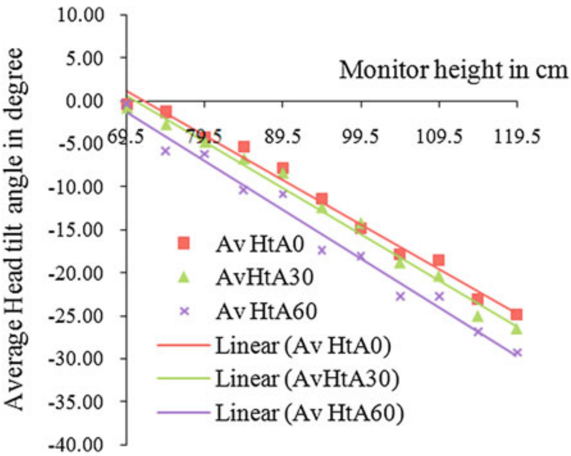


Fig. 7 Plot of average of subjects head tilt angle against VDT height at A0, A30 and A60

Table 5 Summary of results for sEMG ratios of Neck extensor

Sub-	Ne1	Ne2	Ne3	Ne4	Ne5	Ne6	Ne7	Ne8
At A = 0								
Max	1.70	1.63	1.98	1.53	1.61	1.37	1.79	2.42
Min	1.38	0.54	0.32	0.89	1.33	1.21	0.85	1.66
Ave	1.52	1.12	0.93	1.15	1.43	1.28	1.23	1.93
SD	0.11	0.33	0.46	0.18	0.10	0.05	0.39	0.24
At A = 30								
Max	1.72	1.41	1.28	1.45	1.79	1.39	1.78	2.50
Min	1.36	0.41	0.40	0.86	1.27	1.20	0.82	1.65
Ave	1.48	1.04	0.69	1.13	1.48	1.28	1.20	1.97
SD	0.11	0.36	0.24	0.17	0.19	0.06	0.36	0.25
At A = 60								
Max	1.64	1.29	0.94	1.37	1.70	1.41	1.92	2.29
Min	1.29	0.65	0.37	0.80	1.27	1.17	0.76	1.64
Ave	1.48	1.08	0.64	1.13	1.45	1.26	1.27	1.94
SD	0.11	0.22	0.21	0.19	0.13	0.08	0.44	0.23

Unlike Sternocleidomastoid and Upper trapezius the Neck extensors of all subjects tend to show a decreasing trend with increasing monitor height. Figure 8 shows plots of the average of Neck extensor values for the subjects versus the monitor height. The Av of neck extensor showed a decreasing trend with increasing VDT height.

Table 6 below shows the summary of Lumbar Erector Spinae sEMG ratios of the eight subjects. The trend lines show a pattern increasing with monitor height i.e. as the monitor height increases the Erector spinae shows greater sEMG activity. The preferred inclination of the VDT varies with height of the VDT. Table 6 gives summary of preferred monitor inclination at various heights of VDT. Following plot in the Fig. 10 shows the preferred VDT inclination at various

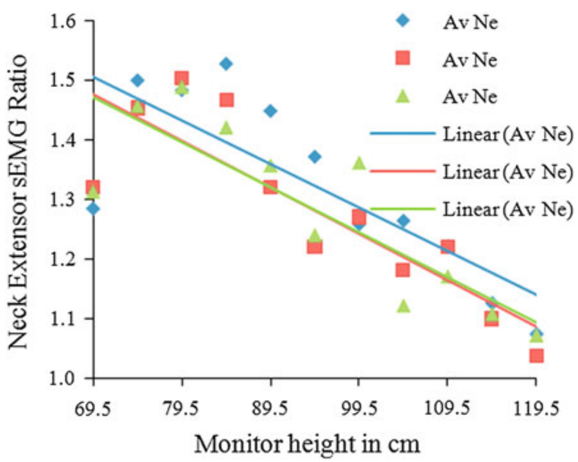


Fig. 8 Plot of average sEMG ratio of all subjects against VDT height at A0, A30 and A60 for neck extensor muscle

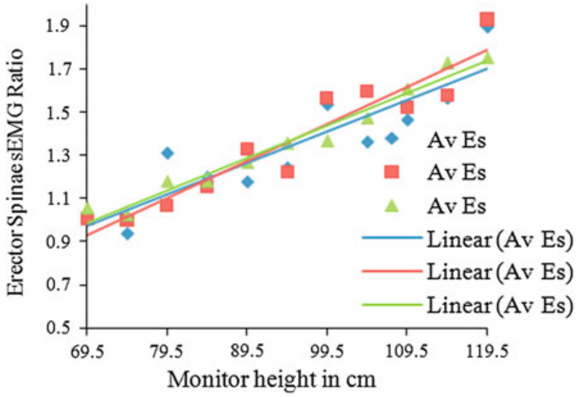


Fig. 9 Plot of sEMG ratio of different subjects against VDT height at A0, A30 and A60 for lumber Erector Spinae muscle

heights. Since the angle is measured from vertical and top edge of monitor away from subject as positive the preferred VDT inclination decreases as the height of the VDT increases (Fig. 9).

At lower heights the preferred inclination of the screen is observed to be is as high as 50°, as the height of the VDT increased the preferred inclination is seen to be decreasing and at extreme heights it has almost straightened to zero or negative values. The average of the preferred angles graph displays a steep declination as the VDT height is increased indicating that preferred VDT angle is function of the VDT height. The VDT placement preferred zone was 89.5 to 99.5 cm. Out of 8 subjects 4 preferred 94.5 cm height, 3 preferred 89.5 cm height and 1 preferred 99.5 cm height.

Table 6 Summary of results for sEMG ratios of Erector Spinae

Sub-	Es1	Es2	Es3	Es4	Es5	Es6	Es7	Es8
At A = 0								
Max	2.60	2.94	2.03	1.26	1.40	2.11	1.89	1.21
Min	0.82	1.17	0.87	0.77	0.57	0.90	0.84	0.73
Av	1.68	1.98	1.42	1.00	0.96	1.39	1.27	1.02
SD	0.59	0.63	0.40	0.16	0.27	0.38	0.30	0.14
At A = 30								
Max	2.74	2.86	2.29	1.31	1.56	2.15	1.97	1.23
Min	1.04	1.13	0.77	0.82	0.59	1.11	0.83	0.64
Av	1.82	1.99	1.39	1.00	0.94	1.40	1.30	1.04
SD	0.70	0.57	0.38	0.14	0.29	0.37	0.36	0.16
At A = 60								
Max	2.16	3.64	1.97	1.25	1.31	2.21	1.75	1.22
Min	0.64	1.28	0.91	0.84	0.59	0.97	0.88	1.00
Av	1.51	2.46	1.29	0.99	0.87	1.38	1.32	1.11
SD	0.55	0.64	0.37	0.14	0.20	0.37	0.29	0.07

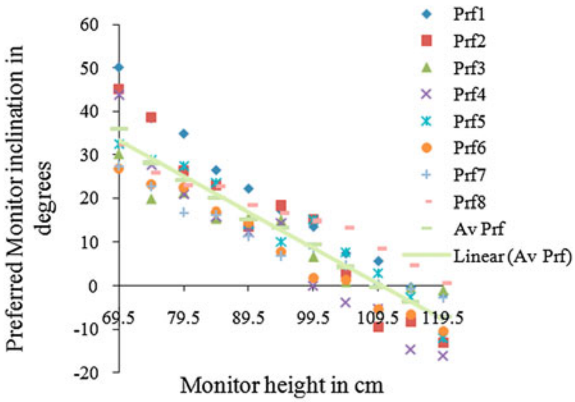


Fig. 10 Plot of preferred VDT angle against height

4 Discussion and Conclusions

Lower monitor placements increases the thoracic bending i.e. the thoracic angle reduces this coupled with thoracic inclination or the forward bend for lower monitor placements is the attained posture for viewing at lower monitor placements. The average trunk inclination angle shows increase with VDT height implying that subject bends away from VDT as height increases for viewing in higher VDT positions. The preferred VDT placement does not seem to contribute significantly to trunk inclination and subjects seem to take a suitable trunk inclination at a preferred height.

It is natural tendency to bend at the back leading to a natural preference for lower monitor placement. The average Thoracic bending angle for all three VDT inclinations show a distinctly higher thoracic angle that is less bending and more straightening of thoracic region with higher VDT positions. The variation of VDT height is distinctly reflected in head tilt however the changes in VDT inclination do not affect the same indicating that the required compensation is achieved through rotation of the eyeballs. This is supported by the observation of Villanueva et al. [10] that viewing angle was mainly decided by neck and eye inclination and to a lesser extent by thoracic inclination.

Postural changes are reflected in the sEMG activity of Erector Spinae and Neck extensors muscles. Erector Spinae was observed to show higher muscle activity with higher VDT positions. Kumar [6] also have reported higher discomfort in higher monitor placements. It may be the increase in stress in Erector Spinae that contributes due to the thoracic straightening and thereby the muscle activity.

The major response to the monitor height is by the head tilt which varies almost linearly with the varying monitor height. Lower monitor placements show a head tilt angle around horizontal and as the monitor position goes up the head moves up ward above the horizontal. The neck extensors respond to the variation by showing higher activity at lower monitor placements and it decreases as the monitor height goes up. This observation is supported by the study of Svensson and Svensson [15]

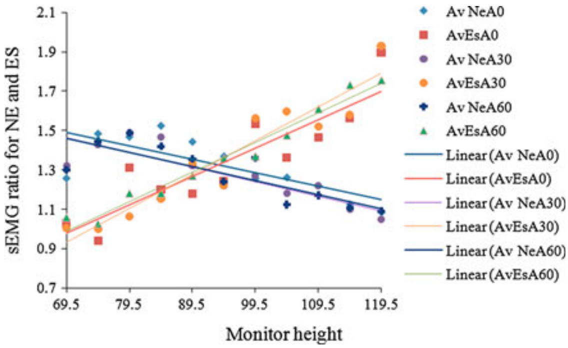


Fig. 11 Plot of average of preferred VDT angle against height

that a viewing angle of +3° gave less load upon the neck than the −20° position. Simultaneous plotting of Erector Spinae and Neck extensor ratio as in Fig. 11 shows the crossing of the two graphs as they depict two opposite trends. The crossing of the trend lines of the two graphs occurs at the H5 (equal to 94.5) which is approximate center of the preferred VDT placement zone that is 89.5 to 99.5 cm. This pattern is observed for all the three VDT inclination positions and the preferred monitor position appears to be a decision arising out of optimal muscle loading.

The plot of average preferred monitor inclination and monitor height yields the regression equation as $y = -0.8251x + 90.697$ where x is in cm and y in degrees. Using the regression equation the inclination of the monitor for a designated height of VDT can be generated. The designer may have to do finer adjustments or compensations which he may otherwise deem necessary to arrive at the final design.

The investigation attempts to answer as to what should be the position of the VDT i.e. its height and inclination. It tells the extent of influence of the VDT position on variables such as Thoracic bending and inclination which is serious concern for spine health in the long term usage. It elaborates that head tilt responds to the VDT height more directly and is reflected in the muscle activity of the Neck extensor muscles. Though the higher VDT placement tends to improve posture still it can be more fatiguing experience and cannot be adopted in design. Should we encourage lower monitor placements or to what extent the preferences should be given importance and be included in the design, how they relate to the muscular interplay has emerged.

Finally it is essential to mention that this study was carried out as part of evaluation studies of design of a sit down console that was developed for use in control rooms based on the anthropometric data of the user population in Indian context. Understanding of the preferences and muscle behavior improves the console design and increases its acceptability and creates an environment that has higher comfort levels.

References

1. Straker L, Mekhora K (2000) An evaluation of visual display unit placement by electromyography, posture, discomfort and preference. Ind Ergon 26(2000):389–398
2. Sommerich CM, Joines SM, Hermans V, Moon SD (2000) Use of surface electromyography to estimate neck and muscle activity. J Electromyogr Kinesiol 10(2000):377–398
3. Villanueva M, Jonai H, Sotoyama M, Hisanaga N, Takeuchi Y, Saito S (1997) Sitting posture and neck and shoulder muscle activities at different screen height settings of the Visual display terminal. Ind Health 35(3):330–336
4. Hamilton N (1996) Source document position as it affects head position and neck muscle extension. Ergonomics 39(4):593–610
5. Turville K, Psihogios J, Ulmer T, Mirka G (1998) The effect of video display terminal height on the operator: a comparison of the 15 deg and 40 deg recommendations. Appl Ergon 29(4):239–246
6. Kumar S (1994) A computer desk for bifocal lens wearers, with special emphasis on selected telecommunication tasks. Ergonomics 37(10):1669–1678
7. Aaras A, Fostervold K, Ro O, Thoresen M (1997) Postural work load during VDU work: a comparison between various work postures. Ergonomics 40(11):1255–1268
8. Hsio H, Keyserling MW (1991) Evaluating posture behaviour during seated tasks. Ind Ergon 8:313–334
9. DeWall M, Reil V, Aghina J, Burdorf A, Snuders C (1992) Improving the sitting posture of CAD/CAM workers by increasing VDU monitor height. Ergonomics 35(4):427–436
10. Villanueva M, Sotoyama M, Jonai H, Takeuchi Y, Saito S (1996) Adjustments of posture and viewing parameters of the eye to the changes in screen height of the visual display terminal. Ergonomics 39:933–945
11. Burgess-Limerick R, Plooy A, Fraser K, Ankrum DR (1999) The influence of computer monitor height on head and neck posture. Ind Ergon 23:171–179
12. Mandal A (1981) The seated man (Homo Sedens). Appl Ergon 12(1):19–26
13. Fujimaki G, Mitsuya R (2002) Study of the seated posture for VDT work. Displays 23:17–24
14. Ray G, Gupta N, Gupta S (2006) Experimental study to redesign visual display terminal work station for bifocal operators. J Sci Ind Res 65:31–35
15. Svensson H, Svensson O (2001) The influence of the viewing angle on neck-load during work with Video display units. J Rehab Med 33:133–136
16. Babski-Reeves K, Stanfield J, Hughes L (2005) Assessment of video display workstation set up on risk factors associated with the development of low back and neck discomfort. Ind Ergon 35:593–604

Relation-Based Posture Modeling for DHMs

Sarath Reddi and Dibakar Sen

Abstract Posture modeling for DHMs has significant effect on their usage in evaluation of product ergonomics. Direct manipulation schemes, such as joint level maneuvering for changing posture, are tedious and need more user intervention; complex scenarios are hardly simulated. This paper presents a high-level, relations based, description scheme for human postures and demonstrations for executing these descriptions using a digital human model (DHM). Here, *posture is viewed as a pattern of relations* of body segments among themselves and with the environment. These relations are then used as the criteria for the novel description based control. A few basic postures have been derived using the conventional principal planes. The basic postures and the composition rules enable description of complex postures in an easy and unambiguous way. We discussed the issues involved in the execution of descriptions and developed methods to resolve the conflicts due to link fixations. This scheme is effective for both lower and higher level control. Illustrative examples from the implementation of the concepts in our native DHM 'MayaManav' are included.

Keywords Posture control · Relations · Digital humans · Link fixations

S. Reddi · D. Sen (✉)
Centre for Product Design and Manufacturing, IISc, Bangalore, India
e-mail: dibakar@cpdm.iisc.ernet.in

S. Reddi
e-mail: sarathiisc@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_37, © Springer India 2013

1 Introduction

Digital human models (DHMs) both as avatars and agents shown in the Fig. 1 need to be controlled to make them manipulate the objects in the virtual world. DHMs are used for evaluation of product usability and identification of ergonomic issues in early stages of product design [1]. Present DHMs are technically sophisticated but difficult to use because of the low level control schemes. This in turn makes verification of DHM-based simulations in diverse platforms difficult to compare. The modeling of proper control schemes for digital humans has significant affect on their usage in the virtual environments. Several schemes are in existence to control the DHMs starting from lower level skeleton based control to higher level objective based control. The low level control schemes involve, manipulating the segments of the DHM directly using mouse or keyboard. This type of approach can be seen in commercially available modelers like Santos, Pro-E manikin [2] and DELMIA™ [3]. Though user gets the freedom to tailor the posture which satisfies the requirement, this type of control is of less use in realizing the behaviors. And also it is tedious as user has to manipulate each and every joint in a high degrees of freedom (d.o.f.) system as a DHM is. Another scheme which is being used by the above modelers involves presenting the user with a set of visuals of the posture (prototypes). In the similar lines, posture editor in the DELMIA contains predefined postures which are specified using names like stoop, squat etc. This approach is limited to situations where DHM has to be launched in the workplace in a posture, the user thinks suitable from the available predefined postures. These control schemes have limitations in realizing the postures driven by behaviors as there is little scope for autonomy. They become cumbersome in scenarios where anthropometry, scene and activity changes from the original context forcing the user intervention to readjust the configurations interactively. The idea of the predefined postures can also be seen in the scenario of hand grasp [4]. High d.o.f. of the hand poses significant challenge in its posture control. Taxonomy to simplify the description of hand posture for various everyday task scenarios can be found in [5–7]. Additionally, descriptions based type of control is seen in Jack [8] where a set of vocabulary is used to realize different kinds of behaviors for positioning the manikin and manipulating it in the virtual environment. In [9, 10],

Fig. 1 Digital human model interacting with environment

different specifications are proposed for full body gestural database and to describe the set of actions performed. To deal with higher level control in Jack [11, 12] a natural language based interface along with Parameterized Action Representation (PAR) is developed for giving instructions and connect these descriptions with actions of DHMs.

Though descriptive way of control is more efficient to the other control methods, unless a proper scheme/format is devised to construct a description, the processing cost for parsing and interpretation will be too high. And also there is no description based control scheme for posture modeling of DHMs. We developed a generic framework through which the postures are controlled by specifying only the relations between the actors (DHM and objects). Since a format is followed for descriptions; parsing and interpretation is much easy and does not involve tools to understand the intent in the description.

2 Relations Based Descriptions

There are several ways of describing the intent to be achieved. Either we can describe the actions necessary to fulfill the objective or we can describe the objective/intent itself. The second choice gives feasibility for DHM to select the actions on its own allowing it to realize the behaviors. The tasks are performed by changing the state of the objects in the virtual environment and the state of an object is usually defined with respect to other objects using its relative position, orientation and contact. Similarly, the state of the DHMs can be described using the relative position and contact between the body segments and the objects. Ability to describe these relations helps in conveying the intent and the way the tasks have to be performed. Therefore, *relations between actors* are chosen as a criterion for framing the descriptions and postures can be realized by the DHM when it satisfies the relations specified. Different cases arise pertaining to these relations between the actors (DHMS and objects); between Segment to segment, segment to object, object to object and combination of these three. As the descriptions in this scenario are expected to relate the objects, the structure of a relational description should contain the objects (segments and objects) of interest and the relation between them. It is also expected that the relation in the description should provide enough information about how to achieve the intended relation. Our intention here is to come up with a method to describe the intended relations and making the DHM act to realize the postures and also to investigate whether any finite set of descriptions (basic/canonical) are feasible combining which, will realize complex postures.

Human body comprises of segments connected with the joints. For the given number, there exist some finite combinations of relations between these segments. Suppose if the objective is to achieve a certain relation between two non adjacent segments, then that intended relation can be achieved in varieties of ways as there are many number of arrangements possible with the intermediate segments.

Therefore, numerous postures can be generated which can satisfy the intended relation between segments chosen. On the contrary if the segments are adjacent to each other, then posture attained when satisfying the intended relation between them is not influenced by the other segments as there are no intermediate segments. Therefore, the corresponding description of such a relation between two adjacent segments can be treated as basic. We consider a basic description as the one which specifies a relation that cannot be further expressed as a sequence of other basic descriptions. Basic descriptions can be used as the building elements of constructed ones following which can realize complex postures. Another important function of basic descriptions is that they can establish the links between one constructed descriptions with another.

2.1 Basic Relational Descriptions

The relations between the body segments are defined by the orientations of these joints. As the adjacent segments are finite, the relations between them can be specified using finite set of descriptions. To specify the relation we need a descriptor which relates the segments. Several terminologies are in use to describe the relative positions of the body parts, In the field of health sciences and ergonomics there is a tendency when describing a movement for it to be referred by some *dominating plane* and thus different planes and corresponding axes along with certain directions are came into existence to describe the human movements. The three planes of motion that pass through the human body are the Sagital plane, the Frontal plane and the Transverse plane. And to specify the descriptions, the literature in the field of ergonomics [13, 14] followed the convention of assuming a *reference posture* and describing only the *deviations* from this posture by specifying the magnitudes of the joint rotations between those body segment whose relations have changed. This approach is very effective in minimizing the effort needed for describing, interpreting and comparison of the postures. The idea here is to use the notions of *dominating plane* and *deviations* from a standard reference posture as the basis for specifying the basic relational descriptions so that the need of mentioning all the joint angles as is seen in the present modelers can be eliminated.

Regarding the dominant planes, these are in general defined with respect to the human body in standing posture. The sagital plane lies vertically and divides the body into right and left parts. The frontal plane also lies vertically however, divides the body into anterior and posterior parts. The transverse plane lies horizontal and divides the body into superior (above hip region) and inferior parts (below hip region), and all these planes intersect at the pelvic region. These three often termed as dominant planes as most of the human motions confines to these planes. Based on these three dominant planes, corresponding directions and axes are defined; *Anterior and posterior directions on sagital plane with reference to frontal plane; Left side and right side on frontal plane with reference to sagital*

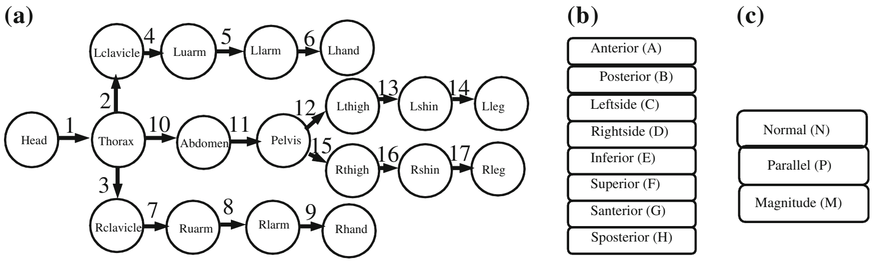


Fig. 2 **a** 17 pairs of adjacent segments. **b** 8 directions. **c** Magnitude of joint rotation. Combinations of these three elements with reference to standing posture form the basic relational descriptions

plane and Superior and inferior on traverse plane on either sides of traverse plane. The format of our descriptions is a quadruplet which consists of the objects to be related, a descriptor to specify relation and the magnitude. Following the above notations, our basic description typically consists of two adjacent segments, a direction and magnitude of the joint rotation connecting them as follows: *segment1 direction magnitude segment2*.

Though it is not uncommon to see the multi-plane movements in the daily activities of life and sports, we hardly see any naming conventions for those directions which are not in dominant planes. Our idea is to use the same dominant planes as basis to differentiate the regions such that new set of planes can be defined between the dominant planes. Plane obtained by rotating the sagittal plane about the vertical axis till it coincides with the frontal plane is referred to here as a *Sag-front plane*; a rotation $\theta < \pm 90°$ covers all possible planes. The anterior portion of a Sag-front plane is represented as Santerior-θ, and the posterior portion as Sposterior-θ. Figure 2 shows the format for basic relational descriptions. Figure 2a shows the directed graph of the adjacent segments starting from head. If the relationship between the adjacent segments is in line with the directed graph, then format is 'Adjacency INDEX'-DIRECTION-'MAGNITUDE indicator'. If it is against the directed graph, then it is 'Adjacency INDEX'-DIRECTION-'MAGNITUDE indicator'.

2.2 Postures as a Set of Basic Descriptions

In the context of relations between segments, we can understand a posture as human body segments satisfying some relation in terms of their position and orientation with respect to one another. Here the idea is to describe the postures intended using the above basic relational descriptions following the notion of describing only the deviation from reference posture [14]. The right half kneel and squat postures shown in the Fig. 3a and b are described using set of basic relational descriptions.

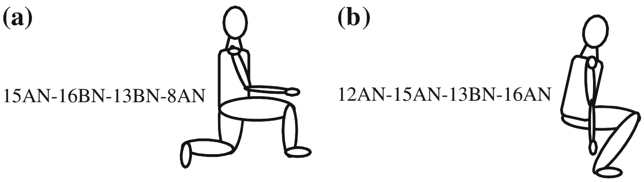


Fig. 3 **a** Right half kneel **b** squat. Describing complex postures as set of basic relations

Thus wide varieties of postures ranging from simple to complex can be described using a set of basic descriptions. The satisfaction of these relations in a DHM needs variations of direct kinematics. Advantage of representing each posture using set of basic descriptions is the transition from one posture to the other can be achieved with less effort as it is easy to compute necessary changes required in the basic relations which can bring the current posture to intended posture.

2.3 Relations Between Nonadjacent Segments

Unlike the relations between adjacent segments, the relations between non adjacent segments can be achieved in varieties of ways. Therefore, we need to specify some constraints in the description along with the segments to be related. Here the idea is to use the postures derived from set of basic relations as constraints to achieve the intended relation. If we consider the case of "hands on toes" as shown in the Fig. 4; the specified relation between hands and toes can be satisfied through many ways. Therefore, we can add a posture name as a constraint to the intended relation and in that way the relations between the intermediate segments also gets assigned. In this case the constraints can be specified using the descriptions "hands on toes by squatting" or "hands on toes by stooping" as shown in the Fig. 4a and b.

Though the exact magnitudes pertaining to the relations are specified in the basic descriptions, in this scenario they get changed to conform to the requirements posed by constraints. For example, while defining the stoop posture using the basic relational descriptions, the torso might be normal to femur; but that may not be sufficient for the hands to reach the toes. Therefore, torso has to *adjust* the angle between femur and torso as shown in the Fig. 4b.

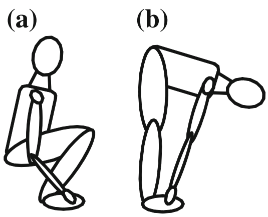


Fig. 4 **a** Reaching toes by squatting. **b** Reaching toes by stooping. Using postures as constraints to achieve relations between non adjacent segments

The format for description in this scenario is different than basic relational descriptions for it consists of a posture name to specify the constraint. The description contains the two segments involved, a relation and the posture name. The relations in this case are place prepositions such as ‘on’, ‘under’, ‘beside’ and ‘inside’ etc. These place prepositions helps in identifying the landmarks on the segments while executing the descriptions. The satisfaction of these relations in a DHM needs variations of inverse kinematics. The descriptions specify the relations using place prepositions and using inverse kinematics techniques the joint variables are determined which satisfies the relations. Thus format for describing relations between non adjacent segments: *Segment1-(place preposition)-segment2-constraint*.

2.4 Relations Between Segment–Object and Object–Object

This scenario is similar to the non adjacent segments with only difference being one of the segments is replaced by object in the environment. The description consists of a segment and object and relation between them. The relation is typically be a place preposition similar to the above scenario. Through these descriptions user can actually specify the direction to approach the object using the place prepositions. Similar to the case of relation between non adjacent segments, execution of descriptions involves employing the inverse kinematics techniques. The format is as follows: *segment-(place preposition)-object*, *object-(place preposition)-object*.

We developed the relations based control scheme with the objective of realizing behaviors. Behavior in the context of human activities can be interpreted as, out of many possible ways, choosing a particular way to accomplish a given task. Here in our scheme we are specifying only the intended relation between DHM and objects or between object and object. This approach offers lot of room to satisfy the relation governed by many aspects like human capabilities, task and initial posture etc. for example *Left hand on table*, can be accomplished in varieties of ways posing constraints on elbow, torso and orientation of hand. And also user can specify the constraints based on his understanding of the task by extending the description similar to the description of non adjacent segments. The above format in the scenario of constraints is modified as *Segment-(place preposition)-object-constraint*.

3 Resolving the Conflicts During Execution of Descriptions

The descriptions specified above are based on intended relations between segments and objects without concerning whether those relations are possible to achieve or not in presence of prevailing environmental constraints. There is no indication of how to overcome the effect of these constraints. Therefore, the responsibility of checking the feasibility and resolving the conflicts lies on the DHM itself.

The main constraint for the execution of the intended relations comes from the present configuration of the DHM. It influences the way the descriptions are executed as it determines the feasibility. The configuration of the DHM is not only a set of relations between body segments but it is defined based on the fixation of the links (links that are grounded). This aspect brings difference in the execution of relations for two different link fixations. Consider the case where the DHM is initially in standing posture, fixing its legs on the ground, and the objective is to achieve a relation between tibia and femur.

Following the format proposed above, it can be described as "$16'$ AN" (*right tibia posterior normal to right femur*). But as the legs are fixed, the movement of tibia is arrested and therefore the intended relation in the description cannot be satisfied. Only the relation "16AN" (*right femur posterior normal to right tibia*) as shown in the Fig. 5a can be realized with the given fixation. To satisfy the intended relation "$16'$AN", the fixation has to be changed to the pelvis or segments above pelvis as shown in the Fig. 5b. Therefore, when intended relations are described, first we need to check the feasibility conditions; whether the relation specified can be achieved in the existing posture with a given link fixation. If these conditions are satisfied then descriptions can be executed. The issues that arise due to change in link fixations like change in the global posture are resolved through our novel scheme developed to build the kinematic structure [15]. Extending the above discussion from basic descriptions to posture descriptions; we have seen that the postures can be described as a set of basic relational descriptions. From the above discussion we have also seen that for the same set of relations the way postures are realized is different (joints involved in moving segments) for different link fixations. Consider the case shown in Fig. 6, where attaining half right kneel posture from standing posture is the objective. Depending on the link fixations the sets of relations necessary are achieved with different joint rotations. When the right leg is fixed, the right knee rotates anticlockwise, torso rotates clockwise and

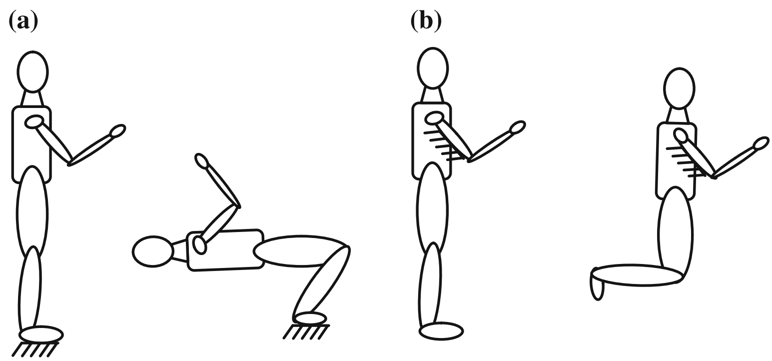
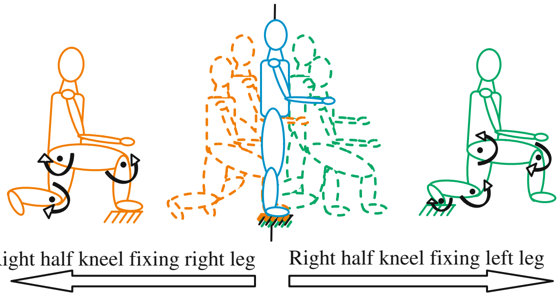


Fig. 5 Choosing the joint rotations based on link fixations. **a** Satisfying the relations between femur and shin when legs are fixed. **b** Satisfying the relations when upper torso is fixed

Fig. 6 Achieving the half kneel with different leg fixations



left knee rotates clockwise directions and to realize the same posture, the left toe in clockwise, left knee in anticlockwise, right femur in anticlockwise and right tibia in clockwise, are rotated fixing the left toe. Thus though the relations achieved are same, the execution differs considerably with different link fixations. The objective in this scenario of change in link fixations is, making the DHM compute the joint level solutions when it needs to switch over between two postures autonomously. Here two cases arise; one is achieving transition from one posture to another with same fixation and the other is posture transition between different fixations. Transition from squat (12AN-15AN-13BN-16AN) to stoop (15′AN) can be an example for the first case as legs got fixed for both the postures. The transition in this case is straight forward as there is no change in the link fixation. Each posture is a set of relations and only involves changing these relations by actuating respective joints.

The descriptions specified are actually the deviations from standing posture (base posture) where the principle planes and directions are described. The transitions involve first comparing the deviations in the two postures in the light of base posture and then bring the relations between segments to base posture which are not required while executing the new relations in the destination posture. In the case of "squat to stoop", the existing relations (12AN-15AN-13BN-16AN) are not required for stoop. Therefore, their relations can brought down to that of base posture and the new relation between torso and femur is executed to obtain stoop (15′ AN) posture. Regarding the second case where the link fixations are different between existing and destination postures, the link fixation needs to be changed while transition takes place. Consider the case of "halfkneel (15AN-16BN-13BN) to squat (12AN-15AN-13BN-16AN)" where one of the legs are fixed in existing posture while two legs are fixed in the destination posture. The procedure in this case is not straight forward and varies with leg fixation (right leg and left leg are fixed in the destination posture). Unlike the above case, the comparison is not only between the basic relations involved but also involves comparing the existing link fixation with that of destination posture. *The execution of transition starts from the existing fixed link by bringing the non relevant relations to the base posture and executing the new relations starting from the segment attached to the fixed link.* The satisfaction of relations in intended posture is carried out by first prioritizing the segments in the set of basic descriptions that constitutes the posture description with respect to the fixed link. As the link fixation of the intended posture determines the feasibility conditions, along with relationships, the link fixation also should be embedded in the description.

4 Demonstration Using DHM

The prerequisite for executing the descriptions by the DHM includes identification and naming of landmarks on the segments and the objects in the virtual environment. The first step in the procedure for reconstructive approach includes processing the scanned data to identify the location of the joints and body segments. This step is carried out interactively and different regions are rendered on the scanned data to identify the body segments and landmarks as shown in the Fig. 7a. Rendering is required to associate the segments with their respective joints. Segment lengths are then can be computed from the joint locations. Second step includes importing the scanned data (in the form of vertices and indices) and reconstructing the geometry to make DHM appear as a human. The computed link lengths are passed on to the kinematic structure module so that it can construct the skeleton from the scanned data. The vertices identified for each segment are stored separately to manipulate them along with the skeleton defined on the geometry. The third step involves applying the transformations to the segments obtained from the kinematic structure. Similarly the landmarks on the objects are rendered interactively based on their features of interaction as shown in the Fig. 7c. Each landmark can be named which is identified on the object for describing the relationship with respect to DHM. The naming can be done using the place prepositions so that if the description specifies a particular preposition, DHM will interact with the landmark associated with it.

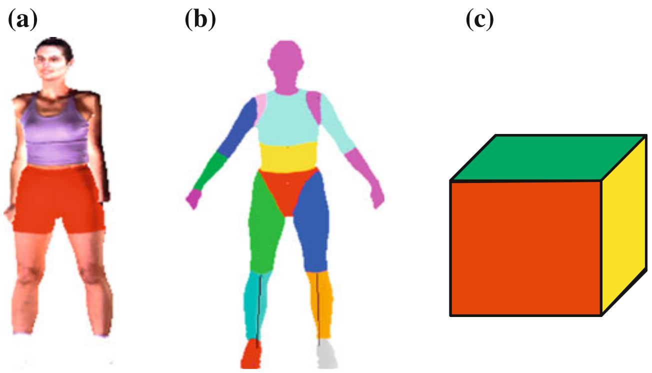


Fig. 7 **a** Scanned model of a human. **b** Body segments rendered to identify the corresponding vertices of the joints. **c** Object rendered to identify the landmarks

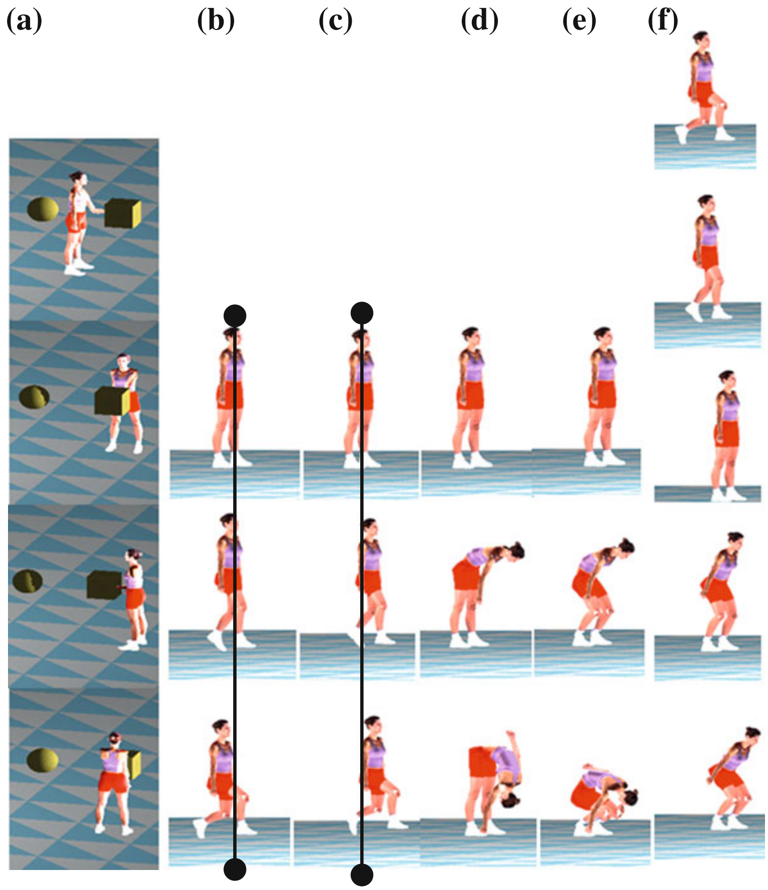


Fig. 8 **a** DHM satisfying relation "lefthand place preposition box". According to the place preposition DHM approaching the box in different directions. Prepositions used are, front side, backside, left and right side. **b** DHM realizing the half kneel posture fixing right leg. It moves backward from its initial position achieve the posture. **c** Realizing the same half kneel posture with left toe getting fixed. In this case DHM moves forward and joint angles are different from the previous scenario. **d** Depicting the relations between non adjacent segments. "right palm on right toe by stooping". Stooping is the constraint to achieve the specified relation. **e** "right palm on right toe by squatting". The squat posture is used as constrain to achieve the relation. **f** Posture transition from half kneel to squat by changing the link fixations from right toe to left and right ankles

The second step in the implementation of the descriptions is developing tools to make the DHM act to satisfy the intended relations. The execution of basic descriptions is a direct kinematics problem as it involves only rotating the joint to a magnitude and in the direction specified in the description. The execution of descriptions which involves non adjacent segments and segment-objects require inverse kinematics models to satisfy the relations between segments and objects specified. To execute the direct kinematics, kinematic structure is built [15] which can handle the posture alterations due to change in link fixations. Regarding inverse kinematics, a novel geometric based framework is developed to find the joint angles so that DHM can satisfy the relations (Fig. 8).

5 Conclusion

The descriptions to specify the relations and postures as a set of relations involve simple triplets and quadruplets. As the descriptions are to be specified according to the format devised, unlike existing modelers the parsing and interpretation aspects will not involve referring to complex grammars and meanings. As the descriptions constitute only the relations between actors, incorporating different behavior models while executing the relations is feasible through this framework. Along with the constraints imposed through behavior models, new constraints can be added using the postures defined as a set of relations. This framework gives the user feasibility to specify the relations intended in any order suitable to a task scenario. Both lower and higher level aspects of DHM can be controlled through this framework.

References

1. Chaffin DB (2005) Improving digital human modelling for proactive ergonomics in design. Ergnomics 48(5):478–491
2. Creo Manikin Extension http://www.ptc.com/products/creo-elements-pro/manikin/whats-new.htm
3. DELMIAErgonomics Evaluations http://www.3ds.com/products/delmia/portfolio/delmia-v6/v6-portfolio/d/digital-manufacturing-and-production/s/program-control-engineering/p/ergonomics-evaluation/?cHash=be2ef83cc230451ef0f39a010e68afb9
4. Cutkosky MR (1989) On grasp choice, grasp models, and the design of hands for manufacturing tasks. Robot Autom IEEE Trans 5(3):269–279
5. Sandra JE, Donna JB, Jenna DM (2002) Developmental and functional hand grasps, 1st edn. Slack Incorporated, Thorofare (ISBN-10: 1556425449)
6. Elliott JM, Connolly KJ (1984) A classification of manipulative hand movements. Dev Med Child Neurol 26(3):283–296
7. Iberall T (1997) Human prehension and dexterous robot hands. Int J Robot Res 16(3):285–299
8. Badler NI, Phillips CB, Webber BL (1993) Simulating humans: computer graphics, animation, and control. Oxford University Press, Oxford
9. Ianni JD (1893) A specification for human action representation. In: SAE technical paper series, 1999-01-1893
10. Hwang BW, Kim S, Lee SW (2006) A full-body gesture database for automatic gesture recognition. In: 7th international conference on automatic face and gesture recognition, pp. 243–248, Apr 2006

11. Bindiganavale R, Schuler W, Allbeck J, Badler N, Joshi A, Palmer M (2000) Dynamically altering agent behaviors using natural language instructions. In: Autonomous agents 2000, pp 293–300, June 2000
12. Badler N, Bindiganavale R, Allbeck J, Schuler W, Zhao L, Palmer M (2000) Parameterized action representation for virtual human agents. In: Cassell J, Sullivan J, Prevost S, Churchill E (eds) Embodied conversational agents, MIT Press, pp 256–284
13. Norkin CC, White JD (1995) Measurement of joint motion: a guide to goniometry, 2nd edn. FA Davis Co, Philadelphia (ISBN-10: 0803609728)
14. Cailliet R (1992) Soft tissue pain and disability, 2nd edn. FA Davis Co, Philadelphia (ISBN-10: 0803601107)
15. Reddi S, Sen D (2011) A novel scheme for modeling kinematic structures of DHMS with mutable fixations. In: International conference on trends in product life cycle modeling, simulation and synthesis

How People View Abstract Art: An Eye Movement Study to Assess Information Processing and Viewing Strategy

Susmita Sharma Y. and B. K. Chakravarthy

Abstract Perception of a form is primarily an individualistic experience. Viewing a product may involve perception of its function or an inherent coding of an idea in its form. Perception to an object or an artifact is like having a visual dialog with the form. The literature suggests that, the visual experience of a work of art, such as painting, is constructed in the same way as the experience of any aspect of the everyday world. Therefore, it is extremely difficult to analyze every aspect of the viewer perception. But, if the viewing aspect itself is observed, it may offer interesting insights, on how the visual dialog to an artifact or designed object is formed by the observer. In this research paper, we aim to explore some of the viewing aspects of viewers, observed through the eye movement research (EMR). The study has been done with 17 participants to establish an understanding in viewing strategy and information processing, while viewing select abstract paintings. Six paintings were used in this study. Selection of the paintings was done as a combination that included Abstract expressionistic paintings by Jackson Pollock and Willem DeKooning, which are spatially spread compositions. Mary Abbot and W. Kandinsky's directional and vigorous-movement stroke oriented paintings, and Piet Mondrian's neo-plastic, pure geometrical painting. Images were shown to the participants to investigate viewing strategy through visual attention and exploratory behavior: diverse or specific; in order to understand how abstract art is viewed. It was observed that spatially spread, uniform paintings offered maximum components of information for the viewer to process while pure abstraction evoked high visual search. We further discuss which paintings evoked

S. Sharma Y. (✉) · B. K. Chakravarthy
Industrial Design Centre, Indian Institute of Technology Bombay, Mumbai, India
e-mail: sharma.susmita@gmail.com

B. K. Chakravarthy
e-mail: chakku@iitb.ac.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_38,

high attention and discuss qualitatively the possible reasoning. One significant finding is that existence of high information processing may not necessitate a high diverse exploratory behavior.

Keywords Eye movement · Visual perception · Viewing strategy

1 Introduction

Visual response is one of the means to gauge the visual perception of an observer. Eye movement behavior (EMR), since the first works of Yarbus [1], has been used in various fields from reading, usability evaluation, cognitive psychology, artificial intelligence to object perception. Though extensive researches have been carried out in eye movement, the understanding is primarily based on viewer's response to usability, where s/he approaches with a destination or action in mind with response to time. On the contrary, viewing an art object, or a designed form, entails esthetic experience and personal involvement that may not aim to elicit an action on the part of the viewer. Therefore, it is also important to reinstate and re-contextualize the eye movement measures used for web-assessment to be seen in a new light and create meaning for visual assessment of art and form esthetics. Present Study with EMR aims to throw light on some of the viewing aspects of viewer strategies as observed in the eye movement behavior to establish an understanding of viewer viewing strategies and information processing trends.

A few areas have been studied in art, but mostly for studying the painterly way of thinking [2] analyzing representational or semi-representational art [3] and viewers in an art-Museum [4] for comparative study of diverse styles. Zeki compares artists with neuroscientists in their capacity to manipulate brain enabling the esthetic experience [5]. Exploration in displacement and slow revelation of pictorial element to enhance esthetic pleasure in art is also reported, [6] as well as preference and its relationship with typicality in paintings is explored [7].

Interesting insights are reported in comparison of Surrealist (Dali) and Baroque art (Caravaggio) for esthetic rating proposing that style of the painting also affects the viewing response [8]. Their results find that after the initial global exploration of the painting, specific visual scrutiny follows, and the style was observed to be an effecting factor for the viewing response. The study explored attention on compositional features like figures and other identifiable items in the figurative style selection. Also the effect of additional information to the paintings was sought, in consistence with previous studies [9]. In the studies, emphasis was laid on the effect of providing titles of the paintings as added information to visual experience [10]. This idea is based on the model that for the esthetic experience to be enhanced and engaging, it is important that the viewer understands the painting, in term of its projected meaning through its title.

Present study on the contrary, contextualizes the visual perception on non-identifiable components in the artwork. We developed the current approach to study visual response on Abstract art, where no added information is provided. The approach was to observe viewer inclination toward abstraction in art that propounds the viewer to create their own references and emergent meanings by unidentifiable compositional sources in the compositional space of a painting. This perception of art can be equated with first hand encounter of any art form or designed object that evokes and retains attention, as the esthetic evaluation of product form perception [11].

A viewer might just choose to see how a painting would have been painted, its compositional elements, layout, identifiable triggers or establishing meaning with their own unique backgrounds and exposures. The study explores some of the viewing aspects to provide an understanding of trends of visual attention through information processing and visual strategy as affected by style and genre of abstract paintings.

2 Experiment Design

Objective of the experiment is to explore viewer's visual attention and visual exploration strategies while viewing abstract paintings. Selection of the paintings was carefully done as a combination that included Abstract expressionistic paintings by Jackson Pollock and Willem Dekooning, which are spatially spread abstract expressionist compositions. Mary Abbot and W. Kandinsky's directional and vigorous-movement stroke and line oriented paintings, and Piet Mondrian's neo-plasticism geometrical painting (Fig. 1).

2.1 Equipment and Participants

Seventeen subjects took part in the study (12 m, 5 F, mean age 28). The subjects were post graduate students who volunteered for the experiment. All had normal or

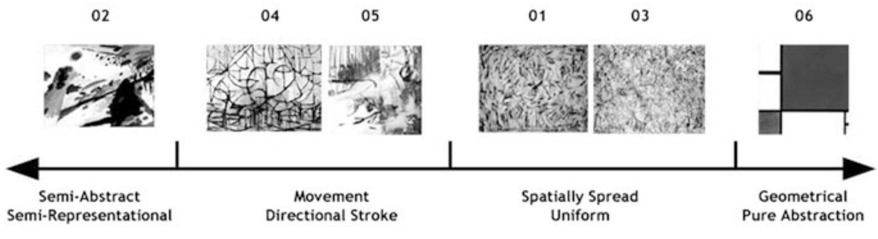


Fig. 1 Paintings grouped based on their treatment and morphology in style in a range from semi-abstract to pure abstract geometrical paintings

corrected to normal vision. An iView X system with RED III camera was used for eye-tracking, which is a dark pupil tracking system that uses infrared illumination and computer-based image processing. A pentium V, PC computer at 60 Hz speed, 96 dpi 17″ LCD monitor with a 1024 × 768 screen was used to display abstract painting images. The subject- screen distance was 720 mm and a chin rest was used to minimize head movements.

2.2 Stimulus Design and Procedure

The six select paintings were used in this study and participants were asked to view paintings at their own timing. The paintings were set in black border. A five point calibration was performed at the beginning of each viewing.

No two similar styles were put in order of viewing as shown in Fig. 2, to avoid the eye getting accustomed to a particular style. A gap of blank neutral gray slide was inserted between each stimulus to prevent any visual biases and to provide a visual break.

3 Rationale for Analysis

The Eye movement data was recorded and analyzed in Bgaze software. Recorded scan path of subjects visually appeared in data as shown in Fig. 3, where circles denote fixations. A Fixation is the moment when the eye is relatively still and focused on a target, indicative of attention, information processing and visual comprehension on that point of gaze. Radius corresponds to the duration of a fixation. Connecting lines to the circles represent saccades; these are rapid directive movements of the eye that help locating the target of attention [11, 12].

The EMR analysis considering the Fixation time and duration signifies the preference with respect to attention [12, 13], also indicating that a form that evokes maximum attention may have more interest areas [14]. Total viewing time, fixation-saccade ratio and Average Fixation Duration (AFD) were compared to assess information processing and search trends on each painting. The total fixation duration is divided by the number of individual fixations to reveal the average

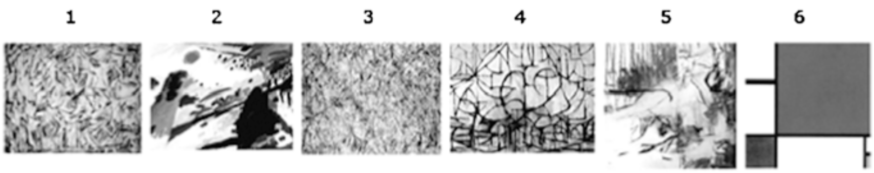


Fig. 2 Viewing order of the stimulus paintings

Fig. 3 A scan path of the eye movement consisting of fixations and saccades

duration (AFD in milliseconds). A fixation average length can be between 200–300 ms, an increase is indicative of higher attention, higher information processing and visual comprehension.

Visual exploration trend was sought by comparing long and short clusters of fixations. Short gazes reflect global surveying of compositional design related to diverse exploration and long gazes reflect focal scrutinizing of local pictorial features related to specific exploration [15]. Comparative analysis of these measures could indicate if higher information processing is congruent to the exploratory behavior. Further to the analysis, zonal preferences shall be observed on maximum attention areas to analyze attention density patterns.

4 Results and Analysis

4.1 Attention on Each Painting

Average fixation as shown in Figs. 4 and 5; indicate that paintings 1 and 3 evoked high attention (Fig. 5). Both are the uniformly-spatially spread paintings that evoked high information processing providing maximum number of information components. The AFD also recorded an increased score (2.6 and 2.61 s respectively).

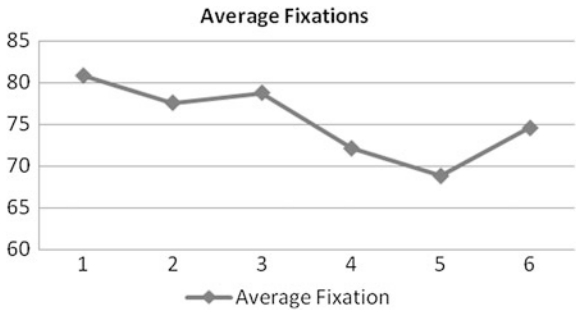


Fig. 4 Average fixation scores indicating attention on each painting

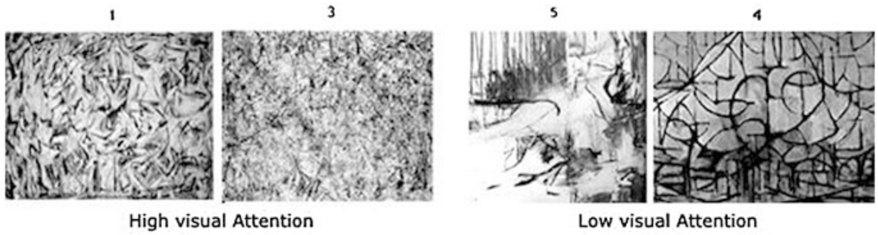


Fig. 5 Spatially spread paintings that received high attention 1 and 3. Stroke and line oriented paintings that received minimum attention 5 and 4

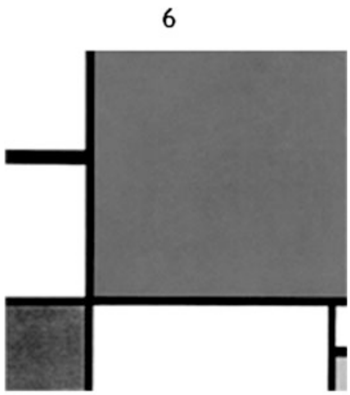


Fig. 6 Geometrical pure abstraction painting evoked maximum search

Painting 5 evoked minimum attention followed by painting 4, Figs. 4 and 5. (AFD also recorded a decreased score 2.1 and 2.2 s respectively.) These are both stroke and strong line oriented paintings that recorded low information processing.

Painting 6, (Fig. 6), evoked more saccades than other paintings showing that search activity was more on this pure abstraction geometrical style (Average Fixations 74.59 and saccades 15.20).

4.2 Visual Exploration

Short gazes reflect diverse and global viewing strategy on compositional aspects and long gaze reflect focal viewing strategy indicating specific exploration. These are the two visual exploration strategies analyzed.

Painting 1 (spatially spread, abstract expressionist) offers maximum components of information for the viewer to process. It also shows maximum diverse exploratory trend. However painting 6 (pure geometrical) is observed to be having less diverse exploration trend compared to high information processing as shown in Fig. 7.

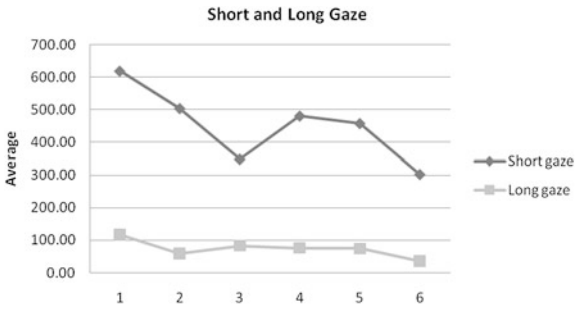


Fig. 7 Short and long gaze

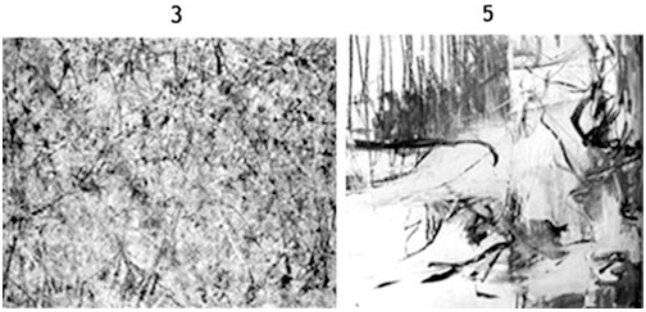


Fig. 8 Painting 3 (spatially spread) evokes high information processing but low at diverse exploratory behavior. Painting 5 (stroke and line oriented) evokes less information processing but shows high diverse exploration trend

Comparing the information processing trend by analyzing attention, and viewing strategies for the paintings, we observed that Painting 3 and 6, offers high information processing and comparatively less diverse exploration; but for 4 and 5 inversely, high diverse exploration is evoked with a decreased information processing trend (Fig. 8). Therefore, indicating that existence of higher information processing may not necessitate a high diverse exploratory behavior.

No significant difference is observed in focal scrutiny, while 1 is marginally high, 6 recorded lowest (Fig. 7). The average Fixation-Saccade ratio overall is 86 and 14 %; the higher ratio indicates more processing and less search activity overall for viewing paintings.

4.3 Attention Density on Zones

Regarding zonal attention, the maximum density of fixations is observed at the center of the painting 1, with a unique rigorous open stroke combination of red and

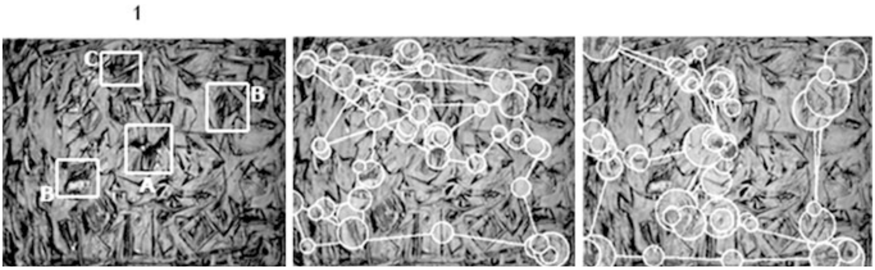


Fig. 9 Attention zones for the painting 1

blue (A); (Fig. 9). The second highest density is shared by two diagonally opposite strokes in red (B). Redundancy in pattern and stroke-style of the painting might have caused an attempt to fixate on a top red stroke clubbed with a star-shaped stroke in black (C). The viewer seems to be assembling these color codes and directional strokes in form, to establish a relationship between diversely located clues for visual mapping to develop their understanding.

For painting 2, the maximum density area is the center. The horse shapes overlapping (A) (Fig. 10). The second highest density area is shared by the foliage on right and the sun (B and C). Though the sun is less detailed than other areas, it appears as a point of reference and reconfirmation junction for visual perception.

For 3, the high point is positioned a little above the center (A). There are very few long gazes observed in this painting. Primarily the surface has been covered with very short and medium gazes implying a discursive route by overall composition to establish visual perception.

For painting 4, the maximum attention is on the off-centered left area with a significantly visible and prominent black stroke and the form in shape of an arc (A) (Fig. 11). It is observed that second highest attention area at the bottom left where there is a play of color glazes in ocher and blue (B). The curvature form is echoed at various places but most predominantly on right in a more perfect circle-stroke which is given the third highest attention (C). It is noticeable that though there is a deliberate effort to delegate interest toward right with continual inclined strokes and geometry, on the contrary the bottom left area evokes visual attention as there are seemingly complex, asymmetric stroke combinations. There are sweeping lines that are ignored at the right side. Organic and surprising form and spatial contrast takes most of viewer's attention in this painting than more geometrical and symmetric elements.

To sum up the results, the spatially spread abstract expressionist paintings evoked high information processing also providing maximum number of information components, while stroke and strong line oriented paintings offered lesser information processing. The pure abstract geometrical painting by Piet Mondrian evoked more search activity (Fig. 12).

While both spatially spread paintings evoke high visual processing, they are explored differently when it comes to diverse visual exploration. Similarly the

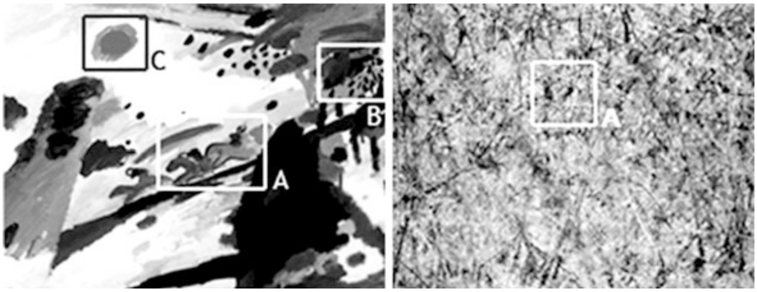


Fig. 10 Attention zones for the painting 2, 3

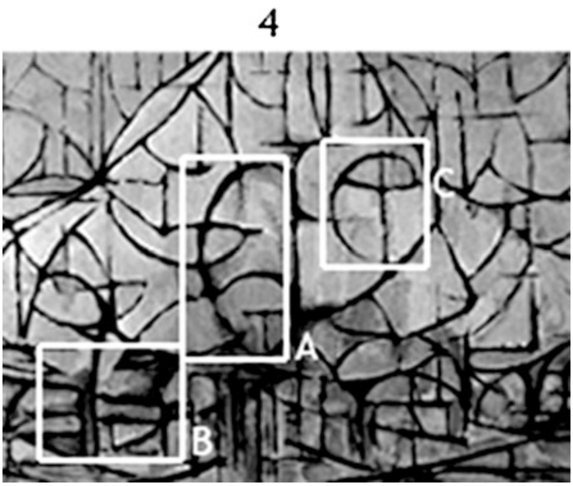


Fig. 11 Attention zones for the painting 4

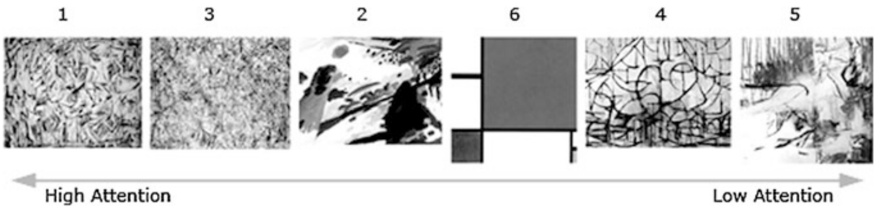


Fig. 12 Attention (information processing) trend for the paintings

stroke and line oriented paintings receive less information processing, but comparatively high diverse exploratory behavior (Fig. 13). The comparison of Information processing on components with the visual exploration trend shows that the two are distinct traits of visual response. Indicating that existence of higher information processing may not necessitate a high diverse exploratory behavior.

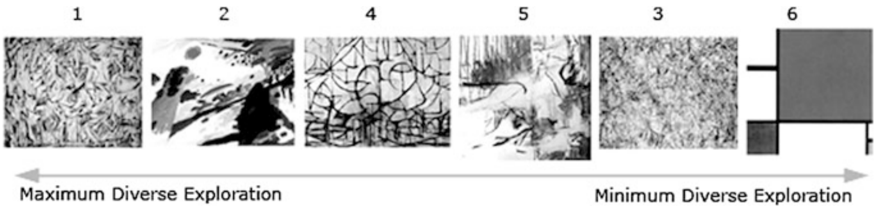


Fig. 13 Diverse visual exploration (short gaze) trend for the paintings

5 Conclusion

Viewer attention and visual exploration are probed specifically in the eye movement study, to understand viewer information processing through visual attention and viewer perception aims through diverse and focal visual strategies. We found that style of the painting affects the viewing response, which is in line with previous studies [9]. Further we form an understanding that, existence of higher information processing may not necessitate a high diverse exploratory behavior. These could be considered as two distinct traits of visual strategies which need to be explored further in various genres, to further the understanding.

This account of visual response as an area to study visual perception is an effective means of exploring the formal and in-built composition of art and design objects with visual perception [11]. A study of viewing strategies not only facilitates understanding of esthetical appreciation, but helps develop a rationale for understanding role of spatio-compositional use of elemental features within the morphology of a form. These features facilitate the visual communication and trigger the visual dialog with objects while abstracting through visual attention [16].

The number of participants, their age, and the limited number of stimuli are the limitations of the study. A large number of paintings of different genres with diversely variated subject groups may offer deeper insights and substantiate current learning.

References

1. Yarbus AL (1967) Eye movements and vision. Plenum Press, New York
2. Berlyne DE (1975) Studies in the new experimental aesthetics. Am J Psychol 88(3):520–523
3. Mial RC, Tchalenko J (2001) Eye movement in portrait drawing. Leonardo 34(1):35–40
4. Stark CM (2005) Algorithms for defining visual regions of interest: comparison with eye movement. IEEE
5. Zeki S (2001) Artistic creativity and the brain. Science 293:51–52
6. Privitera CM, Stark LW, Zangemeister WH (2007) Bonnard's representation of the perception of substance. J Eye Mov Res 1(3):1–6
7. Purcell AT (1993) Relations between preference and typicality in the experience of paintings. Leonardo 26(3):235–241

8. Hristova E, Grinberg M (2011) Time course of eye movements during painting perception. European perspectives on cognitive science
9. Leder H, Carbon CC (2006) Entitling art: influence of title information on understanding and appreciation of paintings. Acta Psychol 121:176–198
10. Leder H, Belke B (2004) A model of aesthetic appreciation and aesthetic judgments. Br J Psychol 95:489–508
11. Sharma SY, Chakravarthy BK (2011) Perception of form: a peep on the eye (ICoRD'11). In: International conference on research into design, Bangalore, pp 818–825
12. Duchowski AT (2002) A Breadth: first survey of eye tracking applications. Behavior and Research Methods instruments and Computers BRMIC
13. D Salvucci, Goldberg J (2000) Identifying fixations and saccades in eye tracking protocols. In: Proceedings of the eye tracking research and applications ETRA symposium, pp 71–78
14. Goldberg JH, Kotval XP (1999) Computer interface evaluation using eye movements: methods and constructs. Int J Ind Ergon 24:631–645
15. Nodine CF, Locher PJ (1993) The role of formal art training on perception and aesthetic judgment of art compositions. Leonardo 26(3):219–227
16. Sharma SY, Chakravarthy BK (2009) Abstraction: investigating the phenomena to facilitate form creation in design. In: International association of societies of design research (IASDR'09), - COEX, Seoul

Stimuli painting details

Painting title and style	Artist and year	Other information
1. Excavation	Willem De Kooning	Medium: oil on canvas. Size: 6 ft 8 in × 8 ft 4 in.
2. Paisaje romantico	Wassily Kandinsky	Medium: oil on canvas Size not known
3. Lavender mist	Jackson Pollock	Medium: oil and other media Size: 7 ft 2 1/2 in × 9 ft 11 in.
4. Alberi in fiore	Piet Mondrian	Medium: Oil on canvas Size: 86 × 66 cm.
5. Antioch (part of the painting)	Mary Abbot	Medium: oil and oil crayon on canvas. Size: 49 × 85 in.
6. Composition with red ,blue and yellow	Piet Mondrian	Medium: oil on canvas Size: 37 × 27 7/8 in.

Web source for paintings
1. http://www.artic.edu/aic/collections/artwork/76244
2. http://www.royal-painting.com/htmllarge/large-22917.html
3. http://www.ibiblio.org/wm/paint/auth/pollock/lavender-mist/
4. http://oseculoprodigioso.blogspot.in/2007/03/mondrian-piet-neo-plasticismo.html
5. http://raggedclothcafe.com/2007/04/22/mary-abbott-abstract-expressionist-by-clairan-ferrono/
6. http://www.wikipaintings.org/en/piet-mondrian/composition-with-red-blue-and-yellow-1930#close

Part V
Eco-Design, Sustainable Manufacturing, Design for Sustainability

Sustainability and Research into Interactions

Suman Devadula and Amaresh Chakrabarti

Abstract Sustainability is an ambitious interdisciplinary research agenda. The required knowledge, tools, methods and competencies being spread across wide-ranging areas pose challenges for researchers in sustainability who often specialize in one discipline. The efforts of researchers to understand sustainability comprehensively and contribute will be benefited if research outcomes are presented against an integrating framework for sustainability knowledge. Though general systems theory has this agenda, it targets consilience and not sustainability in particular as in sustainable development. However, systems concepts provide for a structure to imbibe aspects of sustainability. We propose a nested structure for organizing relevant research across the various scales of concerns that characterize sustainability. As understanding sustainability fundamentally requires understanding the interactions between natural and human systems, we discuss this in the context of the proposed structure and research into interactions.

Keywords Sustainability research · Nestedness · Interactions · Systems coherence

1 Introduction

Sustainability science is an ambitious agenda comparable to the Copernican revolution [1] and aspiring to integrate theory, applied science and policy, making it relevant for development globally and generating a new interdisciplinary

S. Devadula (✉) · A. Chakrabarti
Centre for Product Design and Manufacturing, Indian Institute of Science,
Bangalore 560012, India
e-mail: devadula@cpdm.iisc.ernet.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_39, © Springer India 2013

synthesis across fields [2]. It emphasizes management of the human, social and ecological systems from an engineering and policy perspective at earth scale. A systemic conception of earth comprises four spheres i.e., atmosphere, biosphere, lithosphere, hydrosphere, and the interactions between them. To make a further distinction, researchers in climate change have added the *Anthroposphere* or *technosphere* as separate from biosphere in comprising anything anthropogenic i.e., the effects of human and social systems in terms of the emissions off the first-world industrial revolution [3], resource over-use [4], etc. On the other hand, skeptics opine that progress of any civilization, both cultural and economic, is afforded by the provisions of the environment, and that when environmental conditions are themselves dependent on other cycles, periods of rise and extinction of species human or otherwise, become a consequence of these cycles. The frequency, amplitude and the coupling of these cycles can lead to periods that afford life or prove detrimental to it [5], relegating questions of sustainability to happenstance.

The questioning of current development trajectories and the future that the burgeoning third-world should take, leaves little scope for chances to be taken. Hence, addressing unsustainability at the required scale and intensity requires a systemic understanding of interactions between human, social and ecological systems for making meaningful inferences and consequent action. While there are dangers of conclusive inferences out of trials to force simple reductionist models onto a diverse set of world situations [6], approaches that rely on a sub-set of potential variables of socio-environmental systems (SESs) and propose abstract cure-alls for solving complex SES problems prove detrimental too [7]. Sustainability of SESs requires us to build a coherent understanding of how systems are progressively linked to ever larger systems and how upward and downward causation linkages occur within an SES as well as across diverse sectors and scales. This is a prescription for sustainability research involving interactions across scales. The varied nature of reading material, knowledge of worthy disciplinary contributions to sustainability requires a framework for structuring disciplinary knowledge in the broader context of sustainability. In this paper, we propose a structure for supporting systemic understanding of interactions at various scales that can also be used for organizing literature on sustainability.

2 Interactions

For understanding complex systems, it is believed that a focus on interactions rather than the entities within a system opens up vistas. Interactions are ontologically equivalent to entities in *entitification*. The process of *entitification* (Fig. 1) identifies entities. The existence of a differential simultaneously provides an ontological basis for entities and interactions. Interactions are self-liquidating as the differential gradient deteriorates with interaction time. Interactions are inferred through changes in energy, material, information or entropy generically.

The dynamic of interacting entities, as real world systems, is provided by modern thermodynamics. The second law of thermodynamics gives a direction to progression of systems. Isolated systems progressively increase their disorderliness toward thermodynamic equilibrium. Contrarily, open systems, when exposed to a sufficient differential, tend to spontaneously decrease their disorderliness while increasing that of their environment. Behaving in this way, these systems evade thermodynamic equilibrium by self-organizing and increasing in complexity. Such systems are referred to as far from equilibrium self-organizing dissipative structures (FFESODS), and by nature of their behavior including information, there is much debate on such interactions to be characteristic of organisms and life. Contrasting these two types of systems, which together comprise parts and the whole of the universe, shows that while the whole tends towards disorganization and equality, parts further organization and distinction. Such systemic behavior, of the particulars as well as the whole, fundamentally describes interactions among them. This is illustrated as a juxtaposition of two cycles (Fig. 1): one, in bold arrows, represents natural cycles where sustainability is not a question as this 'is'; and two, in outlined arrows, is the anthropogenic cycle, in which, out of knowledge of natural laws, the impression of differentials onto existing entities changes the availability of opportunity (resources) to natural cycles and hence potentially, their course e.g. the construction of dams changing downstream natural cycles, accumulated GHG's changing the intensity of monsoons etc. As the services humans get out of natural systems are irreplaceable, the magnitude of change they initiate affecting natural cycles to their own detriment is the subject matter of sustainability. Note that both these cycles ever abide by natural laws, the difference being the magnitudes of action of the anthropogenic cycle resulting in magnitudes of reaction of the natural cycle. The management of consequences arising due to differences of these magnitudes is the interest of sustainability, as a praxeological prescription of what should be the case for the human use of earth. Note that the above systemic notions used to define interactions assume as entities characterized by their boundaries, when in reality it is a continuum of their properties (or attributes). This leads to the concept of boundary uncertainty influencing interactions at different scales. These scales are nested by nature. As sustainability requires a reconsideration of many prevailing ways of interaction, Fig. 2 is conceived to systemically consider interactions across nested scales of reality. Though the concept of nestedness exists in ecological, AI and social sciences, the consideration of the unifying force across scales provides a context for explicitly considering interactions. The annular areas represent scales of reality; the concentric circles demarcate scales, the crossing of which marks interactions relevant between scales from sub-atomic (part) reality to the universe (whole). The entities that comprise a scale are alone not sufficient to describe that which results in the next level. Figure 2 should be read as any annular area being a scale of reality comprising of the physicality at the scale lower to it along with the interactions relevant between these scales as indicated in the interaction column to the right, e.g. particles along with nuclear forces comprises the atom, atoms along with chemical forces comprise molecules, etc. Proceeding from the organism ring either

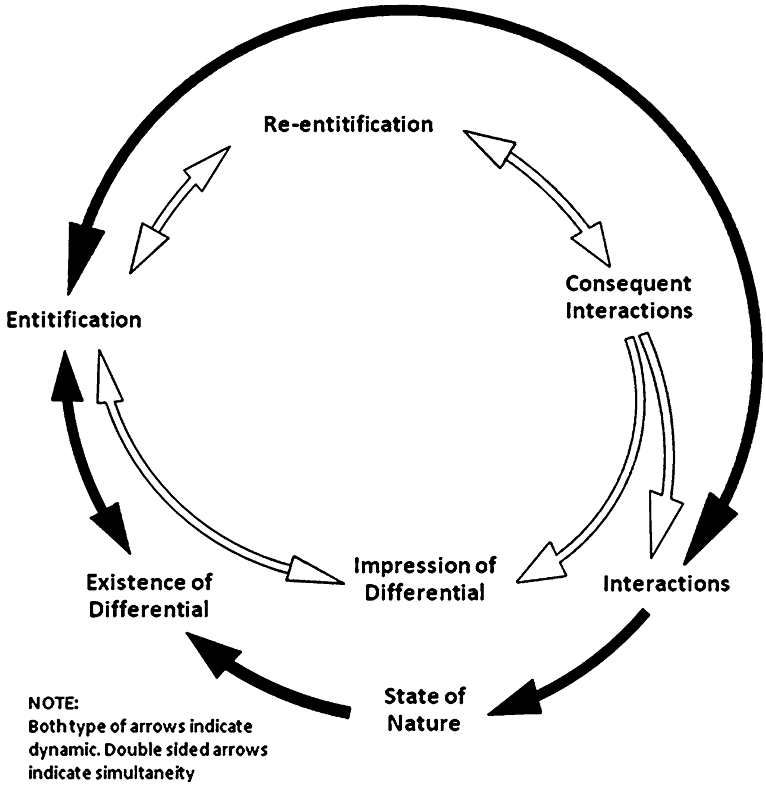


Fig. 1 Interactions in the cyclic nature of reality

ways, the dotted circles indicate the uncertainty in knowledge associated at the micro or macro scales. The organism ring is demarcated with full lines as the notion of certainty through identity, either in the form of cell wall for the cell or territory for the animal, is explicitly reinforced. However, proceeding either ways leads one to realize that identity, and in extension reality, is actually punctured. This realization of reality, the other inference of the dotted circle in Fig. 2, paradoxically leads to being nothing (represented by zero, at the centre) and everything (represented by infinity, at the outset). The implications of findings at the fundamental particle scale are applicable at the highest scale. Thus, at the scale of constituent atoms we are indisputably creatures derived from the cosmos [8]. However, the implications at the intermediary scales in terms of human-environment interactions are unclear, makes research inquiry challenging given the indeterministic, normative nature prevalent at these scales [9]. Given the fact that sustainability is characterized by requiring a transition from the self-obliterating state of affairs, the knowledge required for informing such a transition is felt at various scales culminating in a worldview which is an individual's or community's

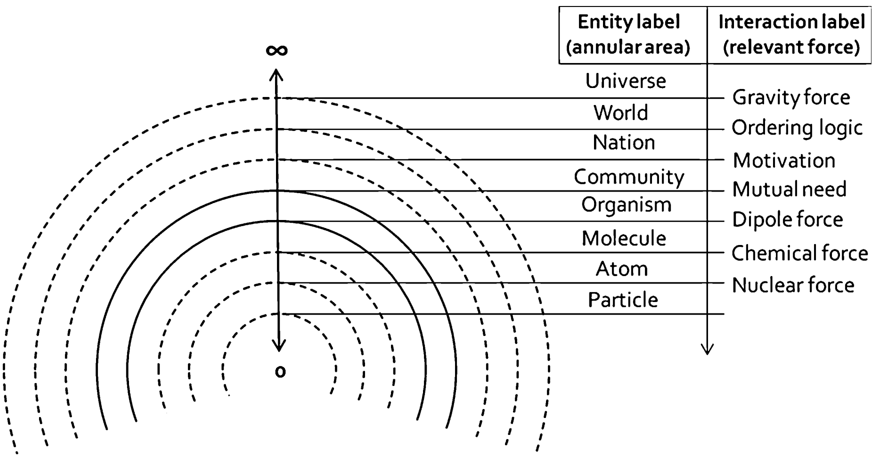


Fig. 2 A structure of reality for ordering knowledge of interactions for sustainability

conception of reality. We present issues and questions ordered according to the scales they address as relevant for a transition to making development sustainable.

2.1 Universe

The universe is so grand to our sense of time and space that we conceive it as one infinite i.e., 'uni'. Gravitational force, acting by virtue of the planetary mass and relative distance, is the unifying force of entities of the lesser scale. The grand scale of space, time and matter that the universe spans make it the bearer of evidence for answering questions of origin of matter and life within cosmic phenomena. The fact that certain life-sustaining physical constants have just come right in this earthly corner of the universe is attributed to chance [10]. We are yet to have a cosmic neighbor to share our mundane experiences of the planet and possibly learn from theirs. A view, provided by the universe beyond the earthly limits, that can establish any fact of planetary life elsewhere affords pan-earth notions of life and hence a provision for a cosmic-praxeological framework to hang our individual planetary behavior in comparison of our earthly responsibility. An example theorizing life's origin is *pan-spermia* which states that a great percentage of interstellar dust is microbial and that striking comets or meteors can be potential vehicles for these microbes to prime evolution [8] on habitable planets like earth. Another example is the notion of 'self-realization of the cosmos' [11], which, carrying forward Spinoza's idea of substance, states that the essence of universal substance is to seek plenitude. The metaphors linking this scale of reality to ours are *spaceship-earth, cosmic speck of dust, pale blue dot, cosmic sea, planetary stewardship* etc. What matters to our sustainability at this scale is the prompt knowledge of stellar events involving the earth and the ability to handle their effect e.g., a comet about to intersect the earth's revolutionary path, radiation from novae, the influence of the sun, etc. At the grandest scale the universe affords being considered as an isolated system. Consequently its ever increasing entropy makes chaos, irrespective of life's activity otherwise on earth, increasingly more probable. Though the time-scale of this fact is way beyond what can matter in a life-time, it provides an eventuality within which we may strive to achieve a goal that fits our human condition and is commonly agreed upon for its worth.

2.2 World

The world comprises nations and people in them. Nations, as protected sovereign territories by governments authorized through the consent of their people in a democratic election, come together out of common interest based on their respective foreign policy based on ordering logic [12]. The metaphors relevant at this scale of reality are mother earth, *Gaia, only home, earth democracy, earth system governance* etc. This scale and the two lower ones, nation and community, are partly or wholly human constructs, and are included as real scales in Fig. 1 as they are the sources of our highest institutions. As we have grown to be dependent upon our institutions, they serve as the instruments with which we organize effort in the economy, both for routine conduct of affairs of the state and for working out sustainable transitions required. The institutions at this scale are supranationalist e.g., the UN, ILO, IMF, WB etc. These were mostly products of first-world flagship and the necessity was/is felt particularly at times of challenges that span national borders e.g. League of Nations for stopping WW2, ILO for internationally protecting worker rights, UN for stopping WW3 and working for world peace and security, G5 nations comprising the superpowers having veto power in the UN etc. Consequently, interactions at this scale are determined by how states conduct in the international society of states based on the agreements they sign or ratify.

Sustainability is a problem irrespective of national divides and hence may be said to be situated at this scale of reality. One conception of the earth is as Gaia, indicating that the earth is a self-correcting system and that humans should consider consuming its resources within its spring-back. Though the climate crisis has proven that sustainability challenges need unqualified planetary scale efforts, nations continue to be divided on how to share responsibility for the causes of damage (CBDR argument of the Third-World), their repair, and the monetary and intellectual investment necessary for working out a global agenda. The failure of the recently held Rio+20 conference in relation to any of its preceding summits is testimonial to this fact. Leading environmentalists have observed that the call for sustainability is of earth scale, recommending 'earth democracy' from a preservation perspective. Others have called upon 'earth governance' in an effort to free individuals from the hold of their nationalist identities that offer no protection in times of natural calamity proving detrimental to humanity. Sustainability needs sincere, committed effort from the nations to invest in the required intellectual and technological capability towards helping all span the transition to a better world in which everyone realize their full potential.

2.3 Nation

The continental shelves along with geographic surface features provide for the political demarcations between countries that are otherwise explicitly erected and surveyed continuously. Beyond this the idea of a nation is constructed by two forces. One, the vesting of authority in the government by the will of the people participating in free and fair elections of representatives, and two, the patriotic feeling driven by the resourcefulness of the country necessary for sustaining its population. The metaphors in use e.g., *mother, homeland, motherland, fatherland* etc., are testimonial of the perspective of a provider of nourishment. The idea of lack of resources elsewhere accentuates the second feeling, more of which may seed fundamentalism [13]. Consequently, the matter of interest for sustainability at this scale is the preservation and distribution of national resources to its citizens through drafting effective policy [14–16] and appropriately realized and represented systems of governance and administration, the well-being indices by which national progress is measured, the human rights treaties to which nations are internationally signatory that serve to check its domestic policy against its own citizens as humans first, the transparency and independence of its judicial system to civilians, institutional provisions for recognition of civil societies etc.

2.4 Community

Environment provides necessary resources for the survival of plants and animals. Man is unique among these animals in having abilities to communicate using language [17, 18]. This enabled him to think, extend his cognition, gather groups, organize effort, enterprise and effect a change in the resources to produce tools and artifacts that in turn better equipped him for survival. Consequently his capabilities had multiplied beyond his rather frail abilities; however, this development has been non-uniform over the planet wherever people thrived into communities and civilizations. Each progressed at their own rate based on the limitations of locally available resources and their own physical and mental limitations in effecting change for their advantage. This may have led to exchange/trade across settlements and civilizations for mutual benefit driving a curiosity for and interest in exotic resources. Unlike the previous scales, the smaller size of this scale stands greater chance of suiting the physical and cognitive limitations of more of its members and hence results in more individuals knowing most about their communities. The first notions of community among simple bacteria that grow in local environs can be called ‘cultures’ while mutualism, commensalism, amensalism etc. are fitting labels for animals interacting within communities for satisfying shared needs. Ecologists, identifying the scales at which a phenomenon is applicable [19], have extensively researched establishing community structure within which they are now able to predict interactions with some certainty. Consequently, the scales at which such communities form, limited by available natural resources and mutual necessity of its members, seem to be closer to the natural cycle than higher scale constructs that are positively maintained to cater to the masses by the exploitation of resources elsewhere. This implies that communities at this scale are generally self-sustained within their knowledge-base of the surroundings and of collective action necessary for corrective measures to be taken in an event of disturbance [15]. Prevalent institutions here derive their authority either through democratically elected representatives in free and fair elections or are vested in members practicing traditional occupations that emerged in mutual necessity. Other communities that form are institutions e.g., welfare associations, manufacturing institutions, and virtual communities e.g., social networking, chat groups, etc. The role of these institutions for sustainability is commensurate with their resource use. One example is the corporate sustainability performance initiatives that have become important while emphasizing the role of the corporation in the affairs of the state and of people. Hence it is of interest to sustainability at this scale to understand how such institutions can be steered towards meeting goals of sustainability amidst tighter constraints. On another note, the community an individual is part of partly provides for the construction of his identity [20] and this is essential in framing his interactions with the other members and his contribution to the society as a whole.

2.5 Organism

From unicellular organisms to plants and humans, this level consists of all entities that are capable of self-maintenance and self-replication. This scale consists of all biota of the planet listed by the entities of the trophic levels in ecology. The fundamental unit of this scale is the ‘cell’ in its capability to maintain and replicate itself. Consequently of interest at this scale of reality are the capabilities of these organisms amidst changing contexts. The changing contexts are primarily of the environment requiring the organism to adapt to it or perish. However, contexts also change due to organismic activity, e.g., decreasing availability of resources as organismic populations increase. It is argued that the need, for formation of cell wall is necessitated by the competition for resources amidst increasing organismic populations in the *primordial soup*. This situates the problem for the organism’s sustainability amidst organisms similarly driven.

Homo Sapiens are the first to alter natural courses at planet scale and also be aware of this fact [6]. Though this generally occurs post facto, we only have instantial knowledge of doing otherwise under less severe situations like avoiding ozone depletion (Montreal Protocol). This gives rise to metaphors like *technological adolescence, earth-scale stupidity, geo-engineering, techno-fascination, earth-worthiness, megabuck science* etc. The capacity of humans residing in this scale to be aware of their bio-physical structure as well as their possible realization of entailing concepts of uncertainty and pervasiveness, make this a scale in which conceptions, however rudimentary or refined, of all the other scales become possible. One such concept is anthropocentrism that provides a basis for rights and hence sustainable development too. Objective validation of hypotheses, framed at various scales of reality through appropriate experiment and method may support the anthropocentric notion of sustainability. It is stated that to proceed "…from bacterium to people is less of a step than to go from a mixture of amino acids (molecules in Fig. 2) to that bacterium (organism in Fig. 2)" [21]. This scale of reality is also where notions of identification with oneself as an entity on the general basis of sustenance forms the pivot of all arguments in the process of evolution by natural selection. At the extremes, and exemplary in this context, are the creationist and naturalist [22] explanations to life. Consequently, the matters of concern at this scale are behavior, conduct, intentionality, responsibility, rights, duties, truth, purpose, agency etc. Correspondingly, the fields of interest are axiology and praxeology as ends, and ontology and epistemology [23] as means. In short, the worldview of humans is the fundamental concern as this [24] influences our conception of reality, including the earth and its use, in designing [25] to meet our requirements. Motivation for human action at various levels of satisfaction is otherwise provided by a hierarchy of human needs [26], though the influence of a worldview is beyond these motivations.

Worldview is a conceptual system by which we order reality, irrespective of its scale, and hence seem to find our way comfortably in it. Worldview orders interactions and the plurality of worldviews implicates sustainability of the whole. While ontological inquiry provides insight into what is and what being is, epistemological inquiry focuses on the process of acquiring this knowledge, particularly on tools and methods, and their limitations for such acquisition. Language of discourse, scientific method, deduction and inference are some examples of such tools and methods [27]. Axiology explores criteria for evaluation of reality, meaningful life worth living and what should one strive for. Sustainability, as a concept, with its notion of human centrality takes some answers for such axiological questions, granted. That human life is worth striving at the cost of anything else for by the individual himself and the community so that every individual realizes his full potential is one such answer. Even in phrases like 'environmental sustainability' or 'X sustainability', it is the human whose well-being has to be preserved, for which an environment's or x's contribution is required and hence to be ensured. However, if the epistemological basis for human centrality is ill-founded, the concept of sustainability needs to re-work its priorities as might be the case under a paradigm of 'life-centrism or ecological naturalism' [9]. Ontology and epistemology need provide the means for answering axiological and praxeological questions related to sustainability. The choices we make depend on the worldview we inherit or learn to adopt. Until we become conscious of our worldview and plan to override its influence, we may not be acting sustainably [28]. In this connection, leaders of religion and nations on different occasions have urged mankind to inculcate 'universal consciousness' that is fitting for world peace, security and sustainability.

2.6 The Lower Three Scales

These scales comprise of all a biota of the planet. Nomenclature is extensively developed in these fields, though development of integrative frameworks for organizing knowledge for interdisciplinary research has been an afterthought [29]. Implications of research findings at this level are fundamental to at all scales of reality, though within the assumed anthropocentrism, of relevance to sustainability is research that has direct implications to humans alone at whatever cost to the rest. Concepts like uncertainty encountered at these scales have far-reaching implications to our conception of reality as it could change our paradigms towards that necessary for sustainability.

3 Discussion

Sustainability science is a relatively new, inter-disciplinary, and fast developing field of inquiry, which lacks coherent reference material and textbooks [30]. Sustainability, as humanity's concern and at the scale at which it is required renders national, political and personal boundaries porous. Consequently, economies must invest in and drive the sustainability agenda domestically while co-operating to follow the sustainability roadmaps laid out by neutral, supranationalist organizations. In this regard, though the Rio Summit of 1992 was promising, the recent Rio+20 conference of the UN was a failure, described as the longest suicidal note by activist groups. Henceforth it is personal conviction in sustainability that should motivate people to commit time and effort towards influencing the short-term interests of their domestic governments towards making and leaving the planet a better place to lead life. Individuals value different scales of reality differently. These differences set up arenas for people to field opinion and discuss perspective comparatively. Sustainability, as a human ability, is predominantly a social argument, in requiring us to be able to mutually support successfully informing ourselves of realizing purposive action determined by the limits of the earth. Hence, within the natural tendency of systems to deteriorate, sustainability is a human ability to communicate action to come to grips with a deteriorating environment individually while limiting its voluntary deterioration in attending to needs alone [31]. With this basis to the argument, it is appropriate to refer to interventions as 'tackling unsustainability', in a Sisyphean sense [32], that is more real in involving more time and effort rather than a vainglorious phrase of 'achieving sustainability' which is only momentary.

The outlined inner cycle of Fig. 1 represents the design cycle of making, reflecting and modifying. From the perspective of interactions and the scales of reality across which they can occur, designers are implicated to control the amount of change that the product/process life-cycles have on the natural cycles. Philosophically this requires design to be negative rather than its conventional understanding of being positive. Negative design is about design being reactive, initiated only under circumstances where it is widely indicated that "…life has gone wrong" [33]. The stimulus for negative design is not an imagined future but a real problem in the form of a changed context similar to evolution fitting a new environmental context. Negative design intends only as much as necessary to bring the state of affairs back to being in accord with the new context. While positive design imagines a future and designs for it, negative design reacts to real world [34] problems and designs to resolve them. This contrast of design philosophy may be likened to the thermodynamic context of sustainability, i.e., as the contexts to which we need to self-organize as complex biological and social systems change naturally, personally furthering their magnitude and frequency of change is uncalled for as it may demand organization of a scale that we may not be able to match, in scale and in time. Though LCA assessments provide for point-estimates of environmental impacts, designers should be sensitive to the dynamic concern of sustainability, and assess the life-cycles of products and processes for their consequences on vital natural cycles, before going forth with product development locally or globally.

4 Conclusions

Understanding sustainability necessarily requires knowledge of aspects of multiple scales of reality and their interactions. The entailing requirements for data are so huge that sustainability research is limited to only few aspects of reality thereby falling short of making any holistic claims about sustainability. The integrative research agenda spanning scales of reality of sustainability science implicates science to coherently structure its disciplinary findings within a framework. Addressing this, a structure of reality is proposed to order knowledge of sustainability. Within the organism scale of this structure, the difficulty of addressing normative aspects within the methods of science and discussions on other approaches to conceive and understand reality is accommodated. Sustainability springs from a human rights and dignity core. As inviolable rights claiming their bearings in natural rights derived from natural law, the concept of sustainability needs to be founded naturally and thereby ground anthropocentrism, it relies on. The proposed description of interactions based on thermodynamics aids understanding the dynamics of interactions across all scales of real world systems. This, along with the description of the scales of reality proposed, indicate a probable theory of interaction that could order inquiry across disciplinary borders accommodating relevant normative aspects. Towards this, we have systemically structured exemplary sustainability literature, presenting aspects of it in context.

Acknowledgments The authors thank Ramani K for valuable comment on the draft and The Boeing Company for financial support under contract PC36018 at SID, IISc.

References

1. Schellnhuber H (1999) Earth system analysis and the second Copernican revolution. Nature 402(2):C19–C23
2. Wiek A, Withycombe L, Redman CL, Ferrer-Balas D (eds) (2011) Key competencies in sustainability: a reference framework for academic program development. 30 Mar 2011
3. Zalasiewicz J et al (2010) The new world of the anthropocene. Environ Sci Technol 44:2228–2231
4. Vitousek PM et al (1997) Human domination of earth's ecosystems. Science 277:494–499
5. Yu JF et al (2008) Recognition of Milankovitch cycles in the stratigraphic record: application of the CWT and the FFT to well-log data. J China Univ Min Technol 18(4):594–598
6. Mörner NA, Burdyuzha V (eds) (2006) The danger of ruling models in a world of natural changes and shifts: the future of life and the future of our civilization. Springer, Berlin, pp 105–114
7. Ostrom E, Janssen MA, Anderies JM (2007) Going beyond panaceas. Proc Natl Acad Sci 104(39):15176–15178
8. Wickramasinghe C, Burdyuzha V (2006) The spread of life throughout the cosmos: the future of life and the future of our civilization. Springer, Berlin, pp 3–21
9. Wang LS (2011) Causal efficacy and the normative notion of sustainability science, vol 7(2) Proquest Fall, NY. http://sspp.proquest.com
10. Sagan C (1961) On the origin and planetary distribution of life. Radiat Res 15:174–192
11. Mathews F (1999) The ecological self. Routledge, Great Britain. ISBN 0-203-00974-6
12. RP Claude, BH Weston (1992) Human rights in the world community: issues and action. In: Falk RA (ed) Theoretical foundations of human rights, pp 31–41
13. Ackoff RL (2001) Syst Pract Act Res 14(1):3–10
14. Hardin G (1968) The tragedy of the commons. Science 162:1243–1248
15. Ostrom E (1990) Governing the commons, ISBN 0 521 40599 8
16. Poteete AR, Ostrom E (2008) Fifteen years of empirical research on collective action in NRM: struggling to build large-N databases based on qualitative research. World Dev 36(1):176–195
17. Clark A (2004) Is language special? some remarks on control, coding and co-ordination. Lang Sci 26(6):717–726
18. Wheeler M (2004) Is language the ultimate artefact? Lang Sci 26(2004):693–715
19. Levin SA (1995) Scale and Sustainability: a population and community perspective. Munasinghe M, Shearer W (eds) Defining and measuring sustainability: the bio-geophysical foundations. The UN University, New York and The World Bank, USA, pp 103–114
20. Goffman E (1959) Presentation of self in everyday life. Doubleday Anchor Books, New York
21. Margulis L (1996) End of Science. Horgan J (ed) Addison Wesley, MA (Chapter 5)
22. Hume D (1994) Dialogues concerning natural religion: the english philosophers from bacon to mill. In: Burtt EA (ed) Random house modern library, New York. p 1779
23. Gallopin GC (2004) Sustainable development: epistemological challenges to science and technology. ECLAC. Chile
24. Galle P (2008) Candidate worldviews for a design theory. Des Stud 29(3):267–303
25. Galle P (1999) Design as intentional action: a conceptual analysis. Des Stud 20(1):57–81

26. Maslow AH (1943) A theory of human motivation. Psychol Rev 50:370–396
27. Aerts D et al (2007) Worldviews: From Fragmentation to Integration. In: Vidal C, Riegler A (eds) Internet edition, Originally published in 1994 by VUB Press
28. van Egmond ND, de Vries HJM (2011) Sustainability: the search for the integral worldview. Futures 43:853–867
29. Boulding KE (2004) General systems theory: the skeleton of science. E:CO vol 6 no 1/2, pp 127–139. First published in management science vol 2, no 3, Apr 1956
30. Chichilnisky G (1977) Economic development and efficiency criteria in the satisfaction of basic needs. Appl Math Model 1(6):290–297
31. Kates RW (ed) (2010) Readings in sustainability science and technology. CID working paper no. 213. Center for International Development, Harvard University. Cambridge, Dec 2010. http://www.hks.harvard.edu/centers/cid/publications/faculty-working-papers/cid-working-paperno.-213
32. Camus A (1955) The myth of sisyphus
33. Jones JC (1980) Thoughts about the context of designing: in the dimension of time. IPC Business Press, Design studies, pp 172–176
34. Papanek V (2005) Design for the real world: human ecology and social change. Academy Chicago Publishers, vol 2, p 394. First Published in (1972), ISBN13: 9780897331531

Residential Buildings Use-Phase Memory for Better Consumption Monitoring of Users and Design Improvement

Lucile Picon, Bernard Yannou and Stéphanie Minel

Abstract Residents' usages and behaviour are inadequately known and understood, as well as being highly variable. However, they play a determining role in the variability of both the energy consumption and environmental impact of residential buildings during their use-phase. This paper proposes a use-phase memory model for residential buildings, which stores energy and resource consumption, and usage patterns. Useful information is further extracted by data crossing and visual data representation. Building experts refer to it for two specific use-cases, namely designing a new sustainable building and renovating an existing one. This information helps them to understand energy and resource consumption and, real users' behaviour and activities. Building's users obtain different kinds of service in return for their collaboration and contribution. Our model is presently being deployed on a residential building, based on beneficial services for each building's stakeholder, thus introducing a sustainable relationship between designers, the residential building and its users.

Keywords Use-phase memory · Environmental impact · Use behaviour · Design tools

L. Picon · B. Yannou (✉)
Laboratoire Genie Industriel, Ecole Centrale Paris,
Grande Voie des Vignes, 92290 Chatenay-Malabry, France
e-mail: bernard.yannou@ecp.fr

L. Picon
Design Industriel, Ecole Nationale Superieure de Creation Industrielle,
48 Rue Saint-Sabin, 75011 Paris, France
e-mail: lucile.picon@gmail.com

S. Minel
Technopole Izarbel, Ecole Supérieure Des Technologies Industrielles Avancées,
64210 Bidart, France
e-mail: s.minel@estia.fr

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_40,

1 Introduction

Announced by the ADEME energy supervision agency [1] in 2011, the building sector consumes 43 % of total energy consumption and ejects more than 24 % of the national CO_2 emissions every year in France. This sector consumes and pollutes more than heavy industry and transport. That is why energy and environmental experts generate standards and regulations, such as the “Thermal Regulations 2012” in France. Molle et al. [2] explain that the “TR 2012” recommends the limitation of energy consumption and needs to five specific end-uses: heating, sanitary hot water, lighting, heat-ventilation-air-conditioning (HVAC) and auxiliaries using renewable energies, thermal insulation, building orientation, etc. However according to Yu et al. [3] total building energy and resource consumption is influenced by a building’s environment, building’s characteristics, as well as by residents’ behaviour and activities.

The issue is complex because resident usages and behaviour vary widely, are far from being completely known and understood, and different settings interact. The influence of appliances on building energy consumption and its environmental impacts is another factor to be considered because it varies according to their energy-efficiency, technology type, kind of usage and user’s behaviour. For instance, National Resources Defense Council [4] in 2007 has indicated that a new high-definition set-top box and its attached television consume more energy per year than a refrigerator. In addition, according to Yu et al. [3] “current simulation tools can only imitate human behaviour patterns in a rigid way” and Hoes et al. [5] explain that the algorithms used, most of the time and at best, focus on the manual opening of windows and lighting control. As a consequence, results of computer-aided design simulations are far from being representative of reality because of the number of influencing factors that are ignored and ignorance of residents’ needs, usages and behaviour. Building experts, for instance engineers and architects, need to know more about the way people transform, renew or degrade their equipments and appliances, which also in turn influence the resulting energy eco-efficiency, equipment life duration and environmental impacts. They would benefit from better knowing users needs. This knowledge would be useful in both situations of redesigning a sustainable construction and renovating an existing one. Concurrently, building users, such as residents, building administrator and employees, would benefit in getting feedbacks to improve their usages, tasks and quality of daily life. The establishment of links between building users, building experts and residential building’s lifetime is essential for more sustainable building designs and renovations.

That is why we propose in this paper a use-phase memory model for application to residential buildings, which can store during a building’s lifetime any information that can be useful for both construction companies and residential building’s stakeholders. In Sect. 1, we study the literature concerning impacts and understanding of usages, transmission of knowledge and relationship between companies and the end-users of their products or/and services. Then, in Sect. 2, we present our model of use-phase memory of residential building, its main aim and its beneficial services, which establish a sustainable relationship between building experts, the residential building and its users. We conclude by demonstrating the potential of use-phase memory for building experts. We illustrate by usage scenarios how useful information can be obtained in these two use-cases for the purpose of the design of a new sustainable building or the renovation of an existing one.

2 Background and Related Work

Although several studies have been carried out to analyse the influence of usages and behaviour on the variability of product or system's environmental impacts, and to understand their reasons, few of them have established sustainable link and dialog between users and designers.

Telenko et al. [6] underline that for many products "the environmental impacts during use can be more significant than manufacturing and end-of-life impacts". Studying the combination of usage and domestic lighting appliances on energy consumption, Zaraket et al. [7] conclude that energy consumption is influenced by three factors: the presence of the occupant at home, the domestic activities and corresponding usages, and the types of lighting appliances. And Borg et al. [8] demonstrate the effect of energy efficiency on domestic electric appliances and they underline stand-by consumption as an increasing problem. In 2002, Enertech [9] has also highlighted this problem in a report on the assessment of potential electricity savings in European households. Energy consumption and environmental impacts of products are deeply influenced by characteristics of product utilization and, beyond, by the purchasing choice people make more or less consciously. That is why, it is essential to understand usages and users' needs.

User Centered Research approach often assists understanding of usages. Lilley et al. [10] define this approach as "the process of gaining information about practices, habits or behaviours in order to inform the design of a product, service or system". Lofthouse et al. [11] present a range of techniques, based on UCR approach, which can help designers to better understand the end-users of their products or/and services, their misuses and ways in which they adapt products to better satisfy their needs. However a residential building is a very complex system, more complex than a mobile phone. In addition, it is unsuitable tool and method for gathering, storage and reuse data and information about usages on a long period.

As expressed by Escalfoni et al. [12], the knowledge of an organization and its sharing are important for developing innovation, which is a way to improve the quality of products and services, identifying new activities and business opportunities. Gibbert et al. [13] distinguish Customer Relationship Management from Customer Knowledge Management. Knowing customers needs and tastes is a good way to satisfy them. However understanding customers, their needs, their ways of using and transforming a product or/and service, is a strategic key to innovate.

The influence of usages and behaviour on the variability of product's environmental impacts is admitted and, organizations and designers are aware of users' experience worth. However, few sustainable relationships including at the same time, user satisfaction, problems encountered, and the ways people use, handle, and/or adapt a product or service, are established between these different stakeholders. Shen et al. [14] introduce a communication tool between building users and designers. Developing an interactive platform by means of a realistic 3D representation of the building, it allows building users to improve their understanding on the design, help them to specify their activities in the new building and increase their involvement in communication with designers. In that way, designers can realize pre-occupancy evaluation and collect building users feedback on the design.

3 Model of Use-Phase Memory of Residential Building for Future Sustainable Constructions and Renovations

We develop below a model of use-phase memory for residential buildings, illustrated in Fig. 1.

The system gathers and stores useful information during a residential building's lifetime, which are energy and resource consumption, recounted events and encountered problems and, noticed residents' usages and behaviour. Useful information is further extracted by data crossing and visual data representation. Building experts refer to it, automatically or at their request, to be assisted for two specific use-cases, namely designing a new sustainable building and renovating an existing one. This information helps them to understand energy and resource consumption and, real users' behaviour and activities. Building's users obtain different kinds of service in return for their collaboration and contribution. Firstly, residents monthly get an invoice giving detailed energy consumption, helping them to identify potential savings. Secondly, if they need and are interested, they can be backed by a customized diagnostic, allowing understanding their usage, needs, appliance consumption so as to inventory consumption savings. The building administrator can control the residential building's state, assisting him to identify recurrent and costly problems (technical, deterioration and damage). Our model is presently being deployed on a residential building, based on beneficial services for each building's stakeholder, thus introducing a sustainable relationship between designers, the residential building and its users.

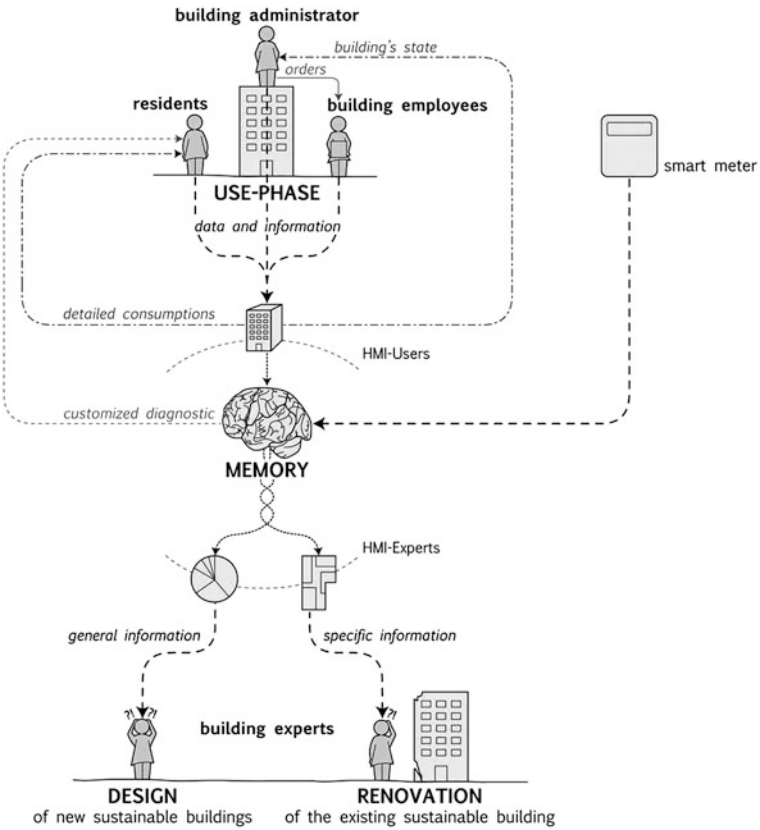


Fig. 1 Model of use-phase memory of residential building

3.1 Methodology

Dieng et al. [15] and Matta et al. [16] inspired our design of the use-phase memory and helped us to structure it. Of the three steps—gathering, storage and reuse—we focused on the input stage (gathering) and on the output stage (reuse). Several issues need to be dealt with: what data to collect, how to collect the data, what tools should be used for the input stage, how this information should be consulted, and how useful information should be extracted.

3.1.1 Data Gathering

The main issues are what data to collect, and how to collect these data.

On the one side automatically and quantitatively energy and resource consumption, which are consumed quantities of electricity, gas and wastewater, is measured thanks to automatic means. A principle of non-disclosure agreement with data providers is integrated into the agreements between the building administrator, residents and the use-phase memory of the residential building. For this study, we collaborate with a startup company that commercializes an electrical signal analysis box, further called *smart meter*. Used algorithm is able to assign each elementary signal to an electrical consuming category like: a washing machine, a toaster, lighting for a certain kind of electrical power and bulb technology. At the moment, existing installed gas and water meters being are used without detailed and automatic analysis. Consequently, residents or the building administrator (depending on the meters' location) must read the meters and transmit these data each month. And on the other side, usage patterns, noticed events and encountered problems are voluntarily and qualitatively gathered by building users.

3.1.2 Means of Obtaining Access to the Memory

Two aims and specific modes allowing access to the building memory are identified.

The feeding with gathered data and information by building users is done through an oriented Human Machine Interface user (HMI-User). Inspired by the platform described by Shen et al. [14] the HMI-User is connected to the use-phase memory of the residential building and allows the users to enter data and information directly on the 3D representation of the building. The feeding with electricity consumption is automatic thanks to the *smart meter*.

The consultation by building users is also done through the HMI-User. It displays the residential building's state through the 3D representation of building. The building experts use the HMI-Expert. Allowing them to display useful information for the two uses-cases. The next section details kinds of displayed information.

3.1.3 Useful Information and Knowledge Retrieval

The main aim of the use-phase memory for a residential building is to get building experts and building users useful information. Thanks to data crossing and different means of visualizing data, we extract from the collected data, information and knowledge for the building experts, as well as for the building administrator and residents in return for their collaboration.

First of all, the building experts need general information to design a new sustainable building, thus the HMI-Expert displays, by automatic analysis of the building's memory, statistical representations about energy and resource consumption. Renovating an existing building, they look for some specific information on the given building, therefore HMI-Expert firstly automatically displays the tagged building maps by most costly facts and problems. Then, for these two uses-cases, they can ask for specific information from the use-phase memory thanks to the request mode based on Structured Query Language.

The building administrator gets the building's state regarding energy and resource consumption, costly facts, and successes from the use-phase memory of the residential building through the HMI-User. Data gathered allow a first reference consumption resident to be defined on the scale of a building. The residents obtain the building's state and also their own consumption levels, which may be compared to the "reference consuming resident" previously evoked, this comparison being a source of energy saving questions and insights. This point is an important motivation for people to be challenged comparatively.

4 Demonstration of Useful Information Retrieval From Use-Phase Memory of Residential Building for Building Experts

In this section, we present the potential of our use-phase memory of residential building in terms of consultation of useful information and knowledge by building experts in the two use-cases of the design of a new sustainable building and renovation. We show one example of a possible scenario for each use-case.

4.1 Usage Scenario During the Design of a New Sustainable Building

Building experts quickly obtain global and useful information on energy and resource consumption. Then, they can browse and consult more detailed information on electricity consumption by end-uses and appliances such as shown by Figs. 2 and 3. Crossing data by automatic electrical consumption measurement and information passed on by residents, it is possible to identify which end-uses and appliances consume more energy, and their causes such as reduced energy-efficiency of an appliance or misuse.

They can get information on specific subjects from the use-phase memory through the request mode, which is detailed in the next section (Sect. 4.2) through the example of usage scenario by request mode during the renovation of an existing sustainable building.

4.2 Usage Scenario During the Renovation of an Existing Sustainable Building

Building experts automatically display specific information on most costly problems of the residential building. The ten most costly problems are located on the maps of the residential building, their financial importance being represented by the size of the bubble. Building experts can consult details of the problems thanks

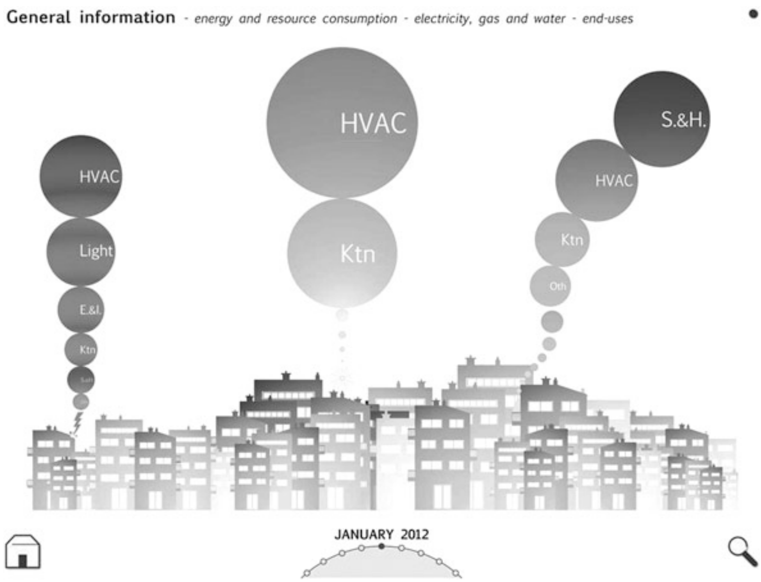


Fig. 2 Automatic display of electricity and gas consumption, and wastewater according to kind of end-uses

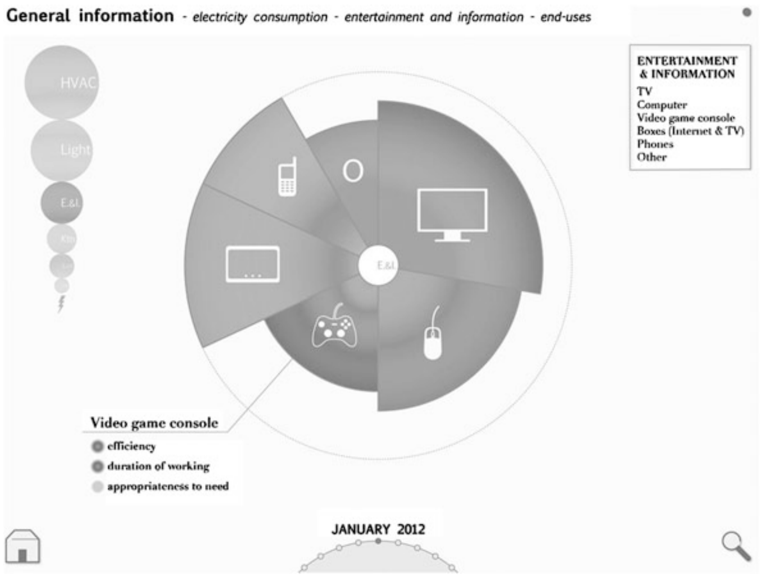


Fig. 3 Consultation of electricity consumption details according to kind of end-use and appliance

to reported information by the building administrator, residents and building employees. They can also browse in the different surface areas of the building. Information on costly problems is updated according to the scale of residential building such as block of flats, and accommodation and service spaces.

Using the request mode, building experts must specify the subject and the chosen setting(s). The request mode, based on Structured Query Language, is made up of two categories of information: subject and settings. The subject defines the type of information being researched. Two kinds of subject are proposed, namely “Consumption” and “Activities and needs”, and they are divided into several sub-categories. The settings allow building experts to specify their request. We selected 10 different settings, which are duration, frequency, period, cost, surface area, equivalent resident number, kind of household, level of satisfaction or dissatisfaction, kind of end-uses (Heating, Ventilation and Air-Conditioning: HVAC, kitchen, lighting, entertainment and information, housework and sanitary or other) and kind of appliances. Then, they display located and represented information on the maps of residential building. Figure 4 presents information for “problems: technical problems, damage, deterioration and other” according to “cost: costly” and “level of satisfaction/dissatisfaction: all expressed dissatisfaction”. For instance, it is possible to notice that for a costly problem the level of dissatisfaction is also very high and understand the reasons why. Of course, cost may not be the immediate problem for a resident: it could be problem’s duration, frequency or level of inconvenience. However, these details allow building experts to understand the problem, its reasons and also its consequences for residents.

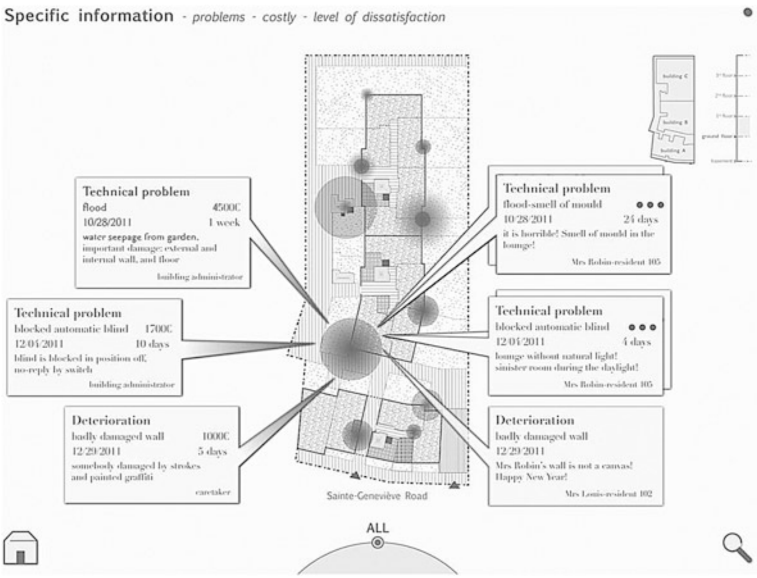


Fig. 4 Displayed result for “problems: technical problems, damage, deterioration and other, according to cost: costly, and level of satisfaction/dissatisfaction: all expressed dissatisfaction”

5 Conclusion

In this paper, we carry out a literature review on the impacts and understanding of usages, transmission of knowledge, existing concepts of memory and relationship between companies and the end-users of their products or/and services. Then, we detail the main aims of our proposed model for use-phase memory of residential buildings and explain which services and relationships are developed between residential building, building experts, building users. We end by demonstrating the potential of our proposition during the two use-cases, namely the design and the renovation processes of a new sustainable building.

Our proposition helps to better gather the usages and patterns of behaviour within a residential building thanks to gathered data and information on energy and resource consumptions, and also the events, successes and problems noticed and reported by building administrator, building employees and residents. For building experts, it is a means to obtain insights to develop or to improve solutions that will reduce the building's energy consumption and its environmental impacts. Use-phase memory also allows building experts to gain time during the two use-cases because much information and data are centralized internally. Our model is presently being deployed on a residential building. This stage of test and experimentation will allow us to develop, to improve and to validate the model of use-phase memory of residential buildings. Residents have just started to participate in the electricity/gas/water consumption bill feedback service. For electricity, data are automatically transferred to a central data treatment and warehouse; for gas and water, it requires a monthly personal declaration by Internet. We need at least two years to draw firm conclusions about how people behave both when they face their detailed consumption bill compared to others and for providing relevant and useful storytelling.

Some issues need to be studied and detailed. It is important to carry on HMI development, in terms of interface for users and experts, but also in defining technical aspects to feed, to share, to consult and to question the use-phase memory. And the development of data representation may be really useful to increase the creation of information and knowledge for building experts. Nowadays much research is being conducted on this question, such as David McCandless [17]. Other issues must be questioned, in particular the existing design and renovation processes, and the integration of use-phase memory into them. Building experts work with specific processes according to the project, its context and its aims. In our context of residential buildings, we notice many steps dividing up tasks, responsibilities and also building experts' dialogue. It may be necessary to change these approaches to designing and to renovating a sustainable building, or to invite other experts such as sociologists and lifecycle experts for instance. This study developing a model of use-phase memory of residential building places the focus on residents. They influence the variability of a building's energy consumptions and environmental impacts, but also they hold much useful knowledge allowing innovation and the development of more sustainable buildings. So one of the first tasks in carrying out this study is the detailed analysis of design and renovation processes and definition of changes needed to allow residents and their usages to be taken into account.

References

1. ADEME, www.ademe.fr
2. Molle D, Patry P-M (2011) RT 2012 et RT existant: réglementation thermique et efficacité énergétique pour construction et rénovation. Éditions Eyrolles 180. ISBN 978-2-2121-2979-3
3. Yu Z, Fung BCM, Haghighat F, Yoshino H, Morofsky E (2011) A systematic procedure to study the influence of occupant behaviour on building energy consumption. Energy Buildings 43(6):1409–1417
4. National Resources Defense Council (2007) Tuning into energy efficiency: prospects for energy savings in TV set-top boxes. p 4
5. Hoes P, Hensen JLM, Loomans MGLC et al (2009) User behaviour in whole building simulation. Energy Buildings 41(3):295–302
6. Telenko C, Seepersad C (2012) Probabilistic graphical models as tools for evaluating the impact of usage-context on the environmental performance. In: IDETC 2012: international design engineering technical conferences, Chicago, 12–15 Aug 2012
7. Zaraket T, Yannou B, Leroy Y, Minel S, Chapotot E (2012) An experimental approach to assess the disparities in the usage trends of domestic electric lighting. In: IDETC 2012: international design engineering technical conferences, Chicago, 12–15 August 2012
8. Borg SP, Kelly NJ (2011) The effect of appliance energy efficiency improvements on domestic electric loads in European households. Energy Buildings 43(9):2240–2250
9. ENERTECH (2002) End-use metering campaign in 400 households of the European community-assessment of the potential electricity savings. Commission of the European Communities, pp 321–339
10. Lilley D, Lofthouse V Bhamra T (2005) Investigating product driven sustainable use. Sustainable innovation ’05, 24–25 October, Farnham Castle Internal Briefing and Conference Centre, p 14
11. Lofthouse VA Lilley D (2006) What they really, want: user centered research methods for design. In: International design conference—design 2006, Dubrovnik, Croatia, May 15–18, p 9
12. Escalfoni R, Braganholo V, Borges MRS (2011) A method for capturing innovation features using group storytelling. Expert Syst Appl 38(2):1148–1159
13. Gibbert M, Leibold M, Probst G (2002) Five styles of customer knowledge management. And how smart companies put them into action. Research report, UG-HEC-CR—02-009, p 16
14. Shen W, Shen Q, Sun Q (2012) Building information modeling-based user activity simulation and evaluation method for improving designer–user communications. Autom Constr 21:148–160
15. Dieng R, Corby O, Giboin A et al. (1998) Methods and tools for corporate knowledge management. Research report, n°3485. INRIA, p 44
16. Matta N, Ribiere M Corby O (1999) Définition d’un modèle de mémoire de projet. Rapport de recherche, n°3720. INRIA, p 45
17. McCandless D (2011) Datavision. Robert Laffont. p 224. ISBN 978-2221126752

Developing Sustainable Products: An Interdisciplinary Challenge

Kai Lindow, Robert Woll and Rainer Stark

Abstract This paper presents an interdisciplinary method that allows engineers to map their view, that is usually focused on product parameters and characteristics, to the view of sustainability assessment experts, whose view is on a higher abstraction level and mainly focused on officially accepted sustainability indicators. The presented approach proposes to bridge the conceptual gap between the different views of both disciplines by focusing on a product's life-cycle processes such as manufacturing, distribution and end-of-life processes. Details about these processes need to be provided by respective experts that thus must be included into the interdisciplinary design process. The presented method builds on the House of Quality method and uses the existing Sustainability Dashboard software tool for a visual comparison of different design alternatives.

Keywords Sustainability · Interdisciplinary challenge · House of sustainability · Life cycle sustainability assessment · Sustainable engineering

K. Lindow (✉)
Department of Machine Tools and Factory Management, School of Mechanical Engineering and Transportation Systems, Technische Universität Berlin, Berlin, Germany
e-mail: kai.lindow@tu-berlin.de

R. Woll · R. Stark
Fraunhofer Institute Production Systems and Design Technology, Virtual Product Creation, Berlin, Germany
e-mail: robert.woll@ipk.fraunhofer.de

R. Stark
e-mail: rainer.stark@ipk.fraunhofer.de

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_41, © Springer India 2013

1 Introduction

The life cycle of a product/system roughly comprises design, manufacturing planning, manufacturing, use, maintenance, remanufacturing and the end of life situation respectively. Since design engineers basically do not have sufficient knowledge to evaluate the sustainability impacts of a product regarding the entire life cycle they have to rely on expertise from other disciplines, such as environmental and manufacturing engineering. Hence, evaluating and assessing a product/system's sustainability impact requires an interdisciplinary and cooperative approach, already during the design phase.

The paper presents on the one hand the results of the research project "Methodological sustainability assessment of machine components in the development process". The purpose of the project was to develop a method that allows a design engineer to estimate the impact of design decisions on the sustainability of a product/system already in the early design phase. To make this possible, design decisions have to be associated with the evaluation criteria for sustainability assessment. This in turn necessitates deep knowledge about the product/system's process, such as manufacturing, logistics, end-of-life treatment.

Apart from the new approach that was developed—a methodology that combines the House of Quality (HoQ) [1] approach with an integrated Life Cycle Sustainability Assessment (LCSA) covering (environmental) Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Social Life Cycle Assessment (SLCA)—the greater challenge occurred while developing and testing the new approach. The approach necessities the expertise and knowledge of different engineering disciplines. Due to that fact, design, manufacturing process and environmental engineers had to work jointly. During the research, several workshops among the different disciplines were carried out. It revealed that the most important challenge is to ensure a meaningful linking between the technical properties and characteristics (e.g. dimensions, fatigue behavior) of a product/system, the characteristics of manufacturing processes based on the manufacturing technology (e.g. cleaning technology) and indicators of LCSA (e.g. electrical energy consumption) [2].

The research has shown that it is very difficult to estimate in which context certain technical parameters and characteristics of the products/systems are directly associated with specific sustainability indicators (e.g. relation between diameter of a rotor and the consumption of electrical energy) [3]. It has shown that the relationship between technical parameters and sustainability indicators can only be conducted via its processes. For that reason, the design of a product/system has a significant influence on the processes in the following life cycle phases.

2 Objectives and Challenges of Sustainable Product Development

Nowadays, environmental pollution and shortage of natural resources are anchored in people's mind that also highlights the importance of the development of sustainable products. The term "sustainability" comprises—in addition to environmental challenges—economical and social challenges. Lately, the social aspect has been stressed making it even more difficult to overcome the challenges of a sustainable product development [4]. Due to that, questions arise like: How much workload and what kind of a working environment can be considered healthy for a human being or how is it possible to prepare employees for a dynamically changing labor market? It becomes obvious that the term sustainability alone raises versatile and important views.

It has not been answered yet which implications the unspecified demand for sustainable product development does have. Companies are trying to develop products that make the customer/the consumer feel that they are using a sustainable product during their utilization phase [5].

The question of how a product is developed, manufactured or recycled/remanufactured is usually not on the focus of the user. Nevertheless, a supposedly sustainable product can be expected to fulfill all the requirements of sustainability in its entire lifecycle [6]. For example, a fuel-efficient vehicle should also be manufactured in a healthy and harmless working environment by using as less resources as possible. Examining the sustainability along the entire product lifecycle makes the goal of having a sustainable product a rather complex and difficult mission.

Considering a product along its entire lifecycle is especially a challenge from the perspective of engineering and design. The reason for that is that the decisions made during the design phase significantly influence how a product is going to be manufactured, used, recycled or re-manufactured [7]. Important effects of decisions made during the early stages of design are mostly not well-known. Topics like manufacturing processes, environmental guidelines and recycling processes are important for the development of a sustainable product but it can hardly be expected of a design engineer to be an expert in all these fields. Considering this fact, the development of a sustainable product also becomes a challenge regarding the qualification of people who participate in this process. A team of experts with different qualifications is needed to be able to evaluate and determine the lifecycle of a product regarding sustainability.

Materials, supplies or auxiliary materials used along the product lifecycle should also be sustainable. A product which can only be re-used if it is remanufactured manually by using harmful chemicals cannot be considered sustainable since it may harm the health of the workers.

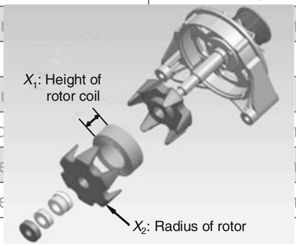
It can be summarized as follows: A product can only be considered to be sustainable if it fulfills social conditions along its lifecycle while its negative influence on the environment is as little as possible [7]. Engineering is only sustainable if it contributes to the creation of a socially acceptable (justifiable), eco-friendly and economically successful product. Considering the fact that the properties and characteristics of a product are determined during the early stages of design it is possible to argue that late stages of the lifecycle are predetermined. This implies that engineering has a decisive impact on the sustainability of a product along its entire life cycle.

3 Different Languages and Perspectives of Different Disciplines

Within the research project "Methodological sustainability assessment of machine components in the development process" a method was developed that allows a design engineer to estimate the impact of design decisions on the sustainability of a product already in the early design phase. In order to make this possible, design decisions have to be associated with evaluation criteria for sustainability. The central challenge is: While a design engineer makes specific choices in terms of technical parameters and characteristics (e.g. dimensions, applicable load) of the product, the sustainability of a product is measured at a different, much more abstract level (e.g. Global Warming, Child labor), cp. Figs. 1 and 2. For design engineers it is very difficult to estimate in which context certain technical parameters and characteristics of the product are linked/associated with specific indicators of sustainability. To fill this conceptual gap, a way must be found on how these different aspects can be accommodated in an understandable manner and in a correct context. Regarding the project a specific example of an alternator that has to be re-designed, in order to make it suited for sustainable remanufacturing, was chosen (cp. Fig. 1). To limit the complexity of the research case, the focus has been limited to the process of disassembly, cleaning and re-assembly (cp. Fig. 2). The different design alternatives were evaluated with respect to sustainability issues. The evaluation did not allow a reliable assessment of sustainability throughout the entire life cycle since only a fragment of the last life cycle phase was considered—though it provided evidence on how to proceed in order to establish a relationship between technical parameters and sustainability indicators.

The most important finding was: The relationship between technical parameters and sustainability indicators can be drawn via processes. The design of a product has a significant influence on the processes in the life cycle phases. Experts can assess quite accurately how the process at a particular stage of life will behave, depending on characteristics of the designed product. Thus, an expert can estimate different manufacturing processes and pathways which will be necessary in order to manufacture a product with certain characteristics. For the assessment of sustainability on the other hand, information on exactly these processes are needed in order to determine measurable results for sustainability indicators. In the selected

Part	Material	Reman - Scenario 1	Reman - Scenario 2
Stator	Steel	Material recycling	Reuse
Rotor coil	Copper C10100	Material recycling	Reuse
Rotor	Iron Cast G25	Disposal (landfill)	Reuse
Drive shaft	Steel	Material recycling	Material recycling
Belt fitting	Alumi	ig	
Fan	Steel		
Spacer	Alumi		
Bearing	Rollec	ig	
Slip ring N	Coppe	ig	
Slip ring S	Coppe	ig	



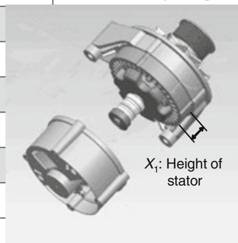


Fig. 1 Engineer's view on different remanufacturing scenarios of an alternator (product's properties and characteristics)

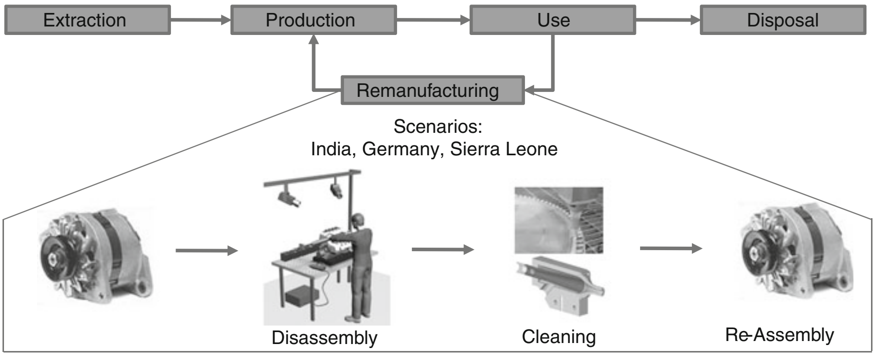


Fig. 2 Sustainability expert's view on different remanufacturing scenarios of an alternator (assessment of processes and location regarding Global Warming, child labor etc.)

research case, the disassembly and assembly process were examined using the method of Life Cycle Sustainability Assessment (LCSA) [8].

Figure 3 illustrates the link between the language of the design engineer and the language of the sustainability expert. To connect between technical product parameters, process characteristics and sustainability indicators, an expert on remanufacturing and an LCSA expert have been involved. The sustainability expert, together with a process expert, created a list of the process properties that are relevant for the determination of the values of sustainability indicators. Afterward design engineers and process experts identified together the influence of the relevant technical parameters for the design on the previously created elements in the list.

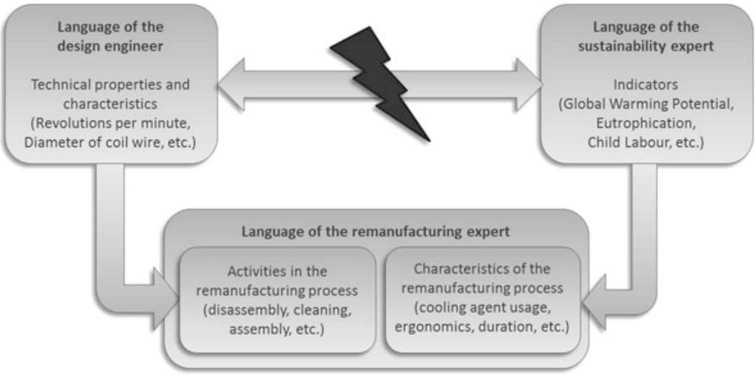


Fig. 3 Bridging the gap between design engineer's and sustainability expert's language

4 An Interdisciplinary Design Approach: The "House of Sustainability"

Based on the findings described in the previous sections the methodology "House of Sustainability" (HoS) was developed. It represents a combination of the "House of Quality" (HoQ) approach combined with the LCSA approach. The HoS approach consists of different steps that are partly supported by software. Initially, the relationships between the product parameters and manufacturing process characteristics (in this case those of the assembly and disassembly process for remanufacturing) are specified together by a team of design engineers, manufacturing process experts and sustainability experts. Subsequently, the design engineers determine design alternatives in the form of different configurations of properties and characteristics. At the same time, sustainability experts draw different remanufacturing scenarios based on the processes at different remanufacturing locations. Afterward, the different design alternatives are evaluated with respect to their remanufacturing scenario. Eventually, the interpretation of assessment results is done together by design engineers and sustainability experts.

The aim is to figure out which design alternative suits best to which remanufacturing scenario—and which scenario has the best performance on sustainability.

A detailed process flow chart was developed using the Business Process Modeling Notation (BPMN) (Fig. 4). The first half of the process ensures the creation of a data base for the different design alternatives. After that indicators for the sustainability assessment are identified. By using the HoQ the relationships between customer requirements and product parameters can be modeled. This allows for ranking the parameters depending on their importance for the fulfillment of customer requirements.

At the beginning of the HoS approach (shown in Fig. 5) a sustainability expert and a process expert jointly determine the quantifiable properties of a particular production process that are relevant to certain sustainability requirements.

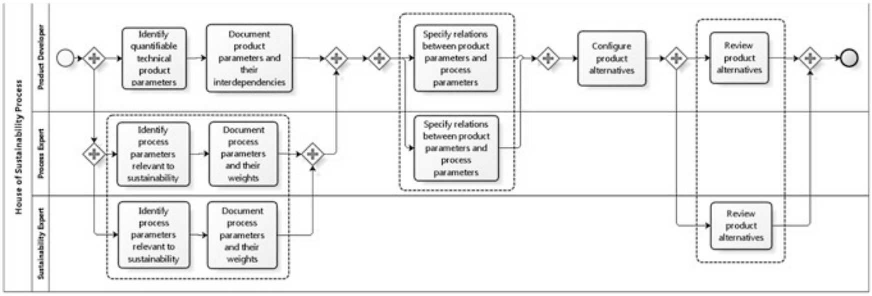


Fig. 4 Process chart for creating a "house of sustainability"

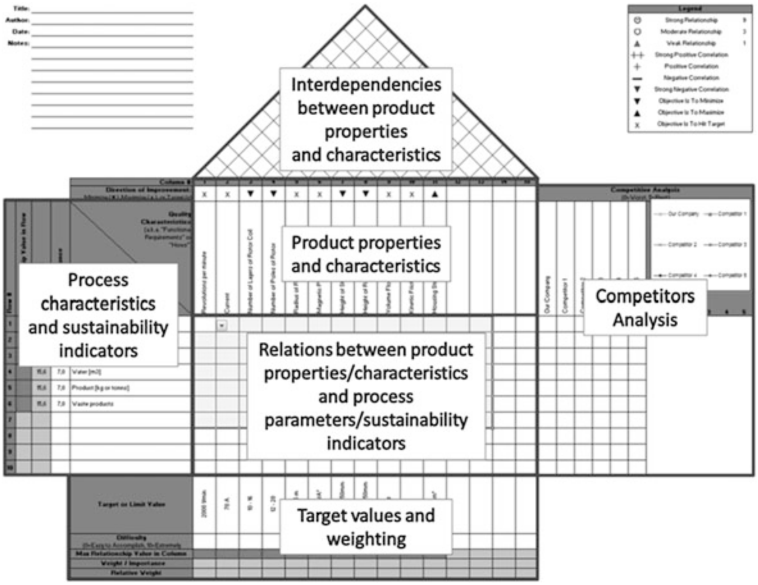


Fig. 5 House of sustainability as a modified "house of quality" editor

The properties identified in this process are listed in the left section of the HoS (Fig. 5). In parallel, the design engineer can already gather the product parameters in order to estimate the interactions between them and thus determines the top of the HoS. Subsequently, the process expert and the design engineer estimate together what relationships exist between the product parameters and characteristics and enter them in the middle of the HoS.

This approach differs from the typical use of a HoQ in such that process characteristics are listed in the left section (where usually customer requirements would be listed). Additionally, the design engineer usually estimates the dependencies between customer requirements and product parameters whereas in this case relations are specified between process characteristics and product parameters. Process characteristics are usually out of scope in the HoQ. The two previously mentioned sections of a typical HoQ, the competitor analysis (right in Fig. 5) and the weighting of the technical product parameters can optionally be filled.

Once the HoS is completed the design engineer configures three different design alternatives. The configuration of design alternatives is done by setting the technical parameters for each alternative. At this time only the technical parameters for which there exists no fixed target value can be varied (e.g. power output is fixed, diameter and length can vary). For parameters with a predetermined interval low (near the lower limit of target value), medium and high (near the upper limit of target value) levels can be set. The user interface only displays those parameters that do have at least one relationship with a process property. Additionally, the parameters of the product are sorted that the properties with the highest influence on the process are listed on the top. Since those parameters which have fixed target values are also shown, the design engineer consciously confines only those parameters that are relevant for a sustainable outcome.

When the configuration of design alternatives is completed the system performs an automatic assessment and evaluation based on the information provided by the HoS. This assessment is based on a simple computation that takes as input the degrees (and direction) in which the different product properties influence the process characteristics (this information is specified by the users in the central matrix of the HoS) and the settings of the technical parameters for the different design alternatives.

For example, if the technical parameter ‘diameter’ affects the energy consumption of the development process (and a larger diameter means more energy consumption) then the alternative with the largest diameter will have the most negative effect on energy consumption. And since energy consumption is an environmentally relevant sustainability indicator this alternative will have the worst relative score related to the environmental dimension. The degrees at which a technical parameter influences a process can have three different values: low (weight 1), medium (weight 3) and strong (weight 9). Hence, if multiple parameters influence the same process and one of them has a strong influence it has as much impact as 3 medium-scored parameters or 9 low-scored parameters. For simplicity it is assumed that different settings for a parameter (please note: this is not the ‘influence degree’ from the HoS but a specific value for a design parameter that is specified when the design alternatives are configured) have a linear proportional relation with the influence degree. That means that if the diameter has three alternative settings (small, medium, large) and the influence degree of it on energy consumption is medium (i.e. weight 3) then the small version has a negative effect of 0 (0 * 3), the medium version 3 (1 * 3) and the large version 6 (2 * 3).

For each design alternative the algorithm computes the negative effects of all parameters on all process characteristics and sums them up for each process characteristic. Once the results are computed they are visualized in the “Sustainability Dashboard”. The Sustainability Dashboard is used for rapid visual analysis of assessment results and uses an intuitive color coding (traffic lights) to compare the three coexisting product alternatives. For each alternative it is shown how they were individually evaluated in terms of their economic, environmental and social sustainability. For simplicity it is assumed that for each process characteristic one alternative can only perform either well, medium or bad, i.e. if the cumulated negative effect of all parameters of alternative A on energy consumption is 9, the one for alternative B is 10 and the one for alternative C is 40, then alternative a is considered good (green color code), alternative B mediocre (yellow color code), and alternative C (red color code) bad. The actual relative difference between their ratings is omitted.

This way every single aspect of sustainability can be considered in detail, in which case the specific sustainability indicators are displayed and how each alternative was evaluated. The sustainability expert can explain the exact meaning of these indicators to the design engineer.

Based on the sustainability assessment the design engineer can choose an alternative or configure new alternatives. In this context it is important to note that the reliability of the results is directly depending on how well the HoS was elaborated. A reliable assessment of sustainability is only possible if all relevant process characteristics have been identified, and if the correlations were estimated realistically between the product parameters and process characteristics.

5 Complexity, Reliability and Effort: Challenges for the Future

The paper shows the evidence on how to proceed in order to establish a relationship between design parameters and sustainability indicators against the background of measuring the sustainability impact of a product/system. Moreover, the paper discusses the complexity, reliability and effort about the presented approach. Eventually, future challenges of interdisciplinary sustainability assessment are discussed.

During the development of the House of Sustainability approach and during the final evaluation with expert teams of three different research departments of the Technische Universität Berlin a number of basic challenges regarding the sustainability evaluation of products were identified. The first challenge has been mentioned in the previous section implicitly: The information that forms the basis of assessment results is estimated and it is usually not verifiable on the basis of detailed measurements. Poorly specified correlations between product properties and process characteristics can lead to assessment results that do not reflect reality sufficiently well. In order to avoid—or at least to minimize—disputable design decisions, a more detailed analysis of the processes has to be approached. The effect of a detailed analysis on the reliability of the evaluation should be investigated further. Likewise the costs for analysis are increasing with the degree of detail. An investigation of different business cases should be subject of further research.

A key challenge in carrying out a combined LCSA is allocating the large amount of information that must be procured to perform a full assessment. In the presented research project solely the process of assembly and disassembly in remanufacturing was investigated. The workshop in which three different experts provide the necessary product, process and sustainability information took more than a week already. Since sustainability is assessed along the entire life cycle with all its processes therein, it can be concluded that similar workshops have to be conducted. The creation of a comprehensive data base for a complete assessment of sustainability using the House of Sustainability approach is a task that could thus take several persons months until completion. Hence, the question of the cost-benefit ratio arises. However, there is already a multitude of companies that carry out similar efforts for performing LCAs on their products—at a point of time in the project when no design changes are realistically possible. Though, the overall aim should be to develop a sustainable product from the early phases of design instead of checking retrospectively if the product is sustainable. Therefore, another research question would be whether the efforts in the acquisition of information during product design can lead to a reduction of expenses for future LCSA.

Another important finding is the difficulty of involving social aspects in product design. Generally, design relations with social aspects of ergonomics and workplace safety can be identified even though a number of important other social sustainability indicators exists, such as working hours or wages. Social aspects that have no relation to other life cycle processes cannot directly be affected by product design. Nonetheless, they can be influenced by the choice of (re-) manufacturing locations, manufacturing equipment and business partners.

The research has identified a very practical problem that has already been indicated: Technical properties and characteristics of a product have no range of target values but a fixed target value at the time a LCSA is carried out. Such parameters cannot be changed in design alternatives and their impact on sustainability may thus not be optimized. The effects of design decisions on the sustainability of the product have to be examined already in the early stages of the design process.

Future research has to focus on approaches that deal with supporting the engineer's work in setting-up the foundation for sustainable products. Therefore, life cycle knowledge, expert know-how and experiences from other disciplines are needed and have to be merged in early phases of product development. In particular, solutions have to be developed for modeling the relationships between design decisions and the sustainability impact on the entire life cycle. Finally, all these information must be presented in a way that a design engineer is able to make sustainable decisions.

Acknowledgments We thank Kilian Müller and the sustainability team involving Erwin Schau, Marzia Traverso and Matthias Finkbeiner at the Department of Environmental Technology, Technische Universität Berlin. This research project is funded by the German Research Foundation DFG as part of the university wide research project (DFG PAK 475/1) "Sustainable value creation exemplified on mini-factories for remanufacturing".

References

1. Akao Y (2009) Development history of quality function deployment. The customer driven approach to quality planning and deployment. Asian Productivity Organization, Minato, Tokyo 107 Japan, p 339
2. Schau EM, Traverso M, Lehmann A, Finkbeiner M (2011) Life cycle costing in sustainability assessment—a case study of remanufactured alternators. Sustainability 3(11):2268–2288
3. Birkhofer H, Wäldele M (2008) Properties and characteristics and attributes and… —an approach on structuring the description of technical systems, AEDS 2008 Workshop, Pilsen—Czech Republic
4. Hanusch D, Birkhofer H (2010) Creating socially sustainable products—examinating influence and responsibility of engineering designers. In: Marjanović H, Štorga D, Pavković M, Bojčetić N (eds) Proceedings of the 11th international design conference DESIGN 2010, Dubrovnik, Croatia, pp 771–778
5. Kerga E, Taisch M, Terzi S (2011) Integration of sustainability in NPD process: Italian experiences. In: Proceedings of the international conference on product lifecycle management (PLM2011), Eindhoven
6. Niemann J, Tichkiewitch S, Westkämper E (2009) Design of sustainable product life cycles. Springer, Berlin
7. Devanathan S, Ramanujan D, Bernstein WZ, Zhao F, Ramani K (2010) Integration of sustainability into early design through the function impact matrix. J Mech Design 132
8. ISO 14040 (2006) Environmental management—life cycle assessment—principles and framework. International Organisation for Standardisation (ISO), Geneva

Life Cycle Assessment of Sustainable Products Leveraging Low Carbon, Energy Efficiency and Renewable Energy Options

S. S. Krishnan, P. Shyam Sunder, V. Venkatesh and N. Balasubramanian

Abstract Design of sustainable products is a critical process with enormous implications on the energy consumption and Green House Gas (GHG) emissions. The impact on energy and emissions can be measured by an analysis of specific performance indicators at each stage of the product lifecycle. The analysis can provide useful insights to the design process. In this paper, Life Cycle Costs (LCC), Life Cycle Energy (LCE) and GHG emissions over the use phase of common appliances such as refrigerators, air conditioners, distribution transformers, street lights and irrigation pumps are examined. This study presents the current energy ratings and analyses the impact of energy efficiency, renewable energy, and low carbon material options on the overall energy and emissions at the individual unit and national aggregate levels.

Keywords Life cycle costs · Appliances · Energy efficiency · Product design · Sustainable manufacturing

S. S. Krishnan (✉) · P. Shyam Sunder · V. Venkatesh · N. Balasubramanian
Center for Study of Science, Technology and Policy, Bangalore, India
e-mail: ssk@cstep.in

P. Shyam Sunder
e-mail: shyam@cstep.in

V. Venkatesh
e-mail: venkat@cstep.in

N. Balasubramanian
e-mail: nbalu23@cstep.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_42,

1 Introduction

The deployment of sustainable products is gaining importance and has huge demand across the globe. Designing such products needs technological update and management of life cycle energy and associated emissions. Managing energy for products over their life cycle phases starts from materials extraction, manufacturing and end use. The associated emissions are directly or indirectly involved with the environment. India is witnessing a huge demand for energy to manage all the sectors and particularly has huge challenge for delivering reliable energy to residential, commercial and agricultural sectors. These sectors are considered to be unorganized and volume of appliances is outnumbered. The sector wise energy consumption is as shown in Fig. 1. According to IEA the residential sector consumed around 168 Mtoe (37 %) out of India's total energy consumption of 449 Mtoe in 2009 [1] and GHG emissions from residential sector have contributed to about 138 Mt CO2 in 2007 [2].

Several policy measures have been undertaken across the world to address energy related aspects within the product life cycle.

The energy star programme by the U.S. Department of Energy (DoE) first introduced the energy efficiency concept amongst consumer durables to help consumers save money and to protect the environment through energy efficient products and practices [3]. In India, the Bureau of Energy Efficiency (BEE) is implementing the star labelling system for appliances under the National Mission for Enhanced Energy Efficiency (NMEEE) [4].

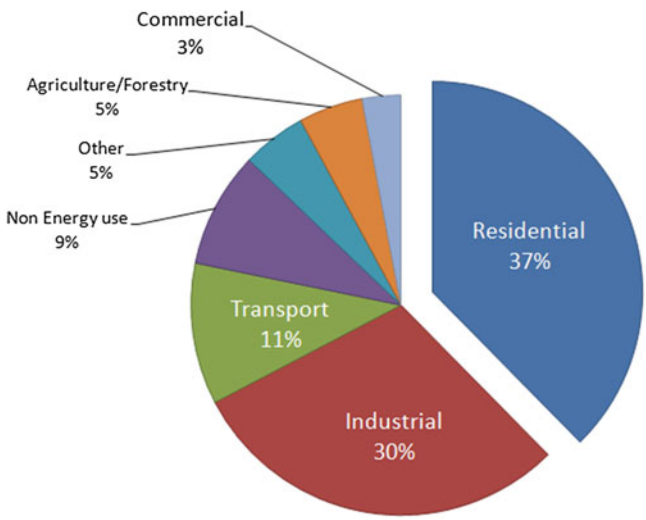


Fig. 1 Sector-wise energy consumption in 2009 (includes non-energy use—the petrochemical feed stocks)

2 Sustainable Design and Manufacture

Typically a manufacturing system considers materials, energy consumed and released accompanied by the corresponding wastes released. The life cycle system is broadly classified into various stages such as, raw material extraction, manufacturing, the use phase of the product and finally end-of-life phase. This is a far broader view of manufacturing than simply looking at consumption, wastes and pollutants occurring at the factory. It has become clear that integrating manufacturing into a sustainable society requires the broader systems view [5]. A unique Sustainable Manufacturing (SM) process model detailing the sequence of processes that occur in the life cycle of manufacturing was developed by researchers at the Centre for Study of Science and Technology (CSTEP) [6]. This model shown in Fig. 2 illustrates the major activities in the product life cycle and their interaction with the environment directly and indirectly.

Activities such as raw material mining, energy production, manufacturing, use phase, recycling and others have a direct interaction with the environment. The interactions are in the form of accessing raw materials, energy to waste disposal and emissions. Other activities such as the design process, maintenance and end-of-life analysis have indirect interactions, and also have the potential to alter the activities direct impact to the environment. For example design stage is more theoretical and involves technical brainstorming activities. An efficient or

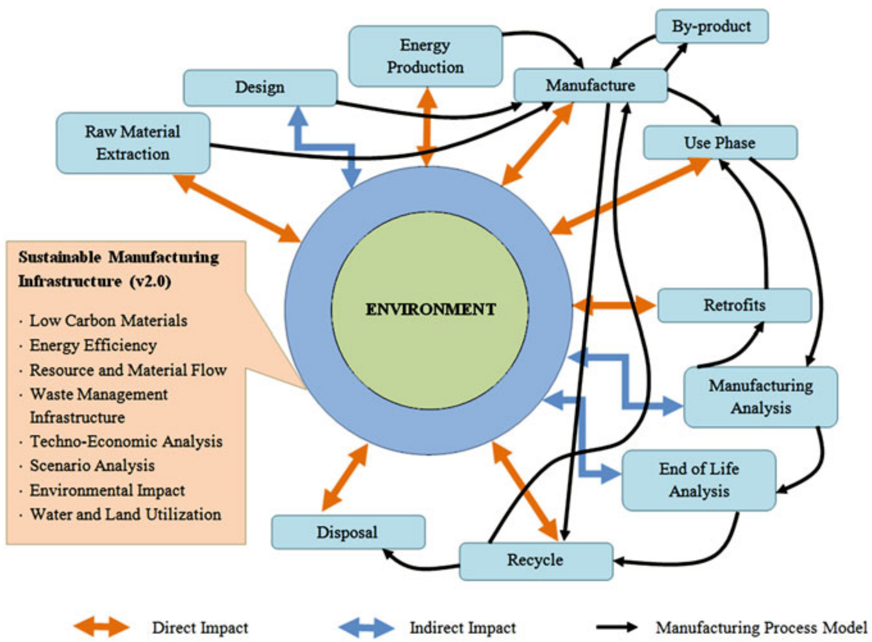


Fig. 2 Sustainable manufacturing process model

outstanding design can foresee the best and economical way to manufacture sustainable products provided several manufacturing intricacies, best manufacturing process, selection of materials, reduction of emissions and many others are assessed in this stage, This may reduce the actual material consumption, lead to energy efficient manufacturing, and also improve sustainable life of the product. Figure 2 describes the sustainable manufacturing process model. One can observe the different components and the inter component interactions as depicted by black arrows. These show that processes not only have direct and indirect interaction but must also follow the path to disposal after passing the efficient use phase, recycle, reuse of parts, and retrofits. The model also highlights that all the processes must interact with the environment through the sustainable infrastructure layer.

The component view of sustainable manufacturing infrastructure shows the involvement of various stake holders. Each stakeholder in SM infrastructure forms an aggregate relationship in unified modelling language (UML) terminology. The report states that sustainability has to be integrated in all the activities that comprise the current economic processes of human endeavour. Thus, sustainability analysis has to be incorporated in different components shown in the SM infrastructure model. Figure 3 shows the component view in the sustainable manufacturing infrastructure.

Fig. 3 Sustainable manufacturing infrastructure: component view

Each activity of the SM process model has to perform its entire repertoire of sub-activities whilst treating sustainability consideration as an additional factor. This may be treated in various formulations by different components as an optimisation function, a hard constraint, a soft constraint, a policy option, a policy mechanism guideline, a compliance target parameter or in other ways a modification of societal preferences, value systems and demands. However, the fact remains that in a systems view of the SM process, sustainability needs to be integrated into the current set of activities.

3 Life Cycle Energy Efficiency

Table 1 shows life cycle energy consumption and savings over 5, 10 years for a typical refrigerator, and air conditioners Each appliance is assessed based on efficiency level class 'A, B and C', where 'A' being the most efficient and C being least efficient.

For example, if an average rated refrigerator with annual energy consumption of 663.05 kWh, is replaced by an efficient unit with annual energy consumption of 397.50 kWh, it could lead to life cycle energy savings of 315.19 GWh over 5 years and 895.91 GWh over 10 years for the population of units rated under each efficiency levels. The estimated volume of units under each efficiency levels is based on number of units rated by BEE in the energy labelling system in 2010 [7]. A 13 % growth rate is taken in estimating the energy consumption over 5 and 10 years respectively. The volume of appliances used in the calculation under each category of appliances is derived from BEE.

In the case of irrigation pumps, most of the units sold were with most efficient rating. About 67,518 units were rated under 5 star, 252 units of 3 star and only 4 units of least efficient were sold in 2010.

The savings are estimated based on actual energy efficiency rated under 5-star to 1-star. In the agricultural sector, a submersible pump of 10 stages, 90 m pump head which is widely used in irrigation with 3 efficiency levels also shows potential savings of 0.12 and 2.25 GWh from least and average rated units respectively if the corresponding units are replaced with efficient units. Alternatively, if a portion of energy itself is supported from renewable energy resources, there are even greater potential of energy conservation in the domestic sector. Figure 4 shows the comparative conventional energy consumption and with renewable energy mix (75 % Conventional, 25 % Solar).

The study also examined distributional transformer (DT). DTs are widely used to step-up or step-down the electrical voltage. The assessment of its efficiency is based on losses at 100 and 50 % load over the years. BEE has rated a variety of DT models ranging from 16–200 kVA in a similar format.

The Losses from a 63 kVA distribution transformer at 50 and 100 % load are 490 and 1,404 W respectively. These losses are from least efficient type transformers. The estimated avoidable losses at 50 % load if a least efficient DT was

Table 1 Life cycle energy consumption (use phase only) of appliances and savings

Appliances		Annual per unit energy consumption (kWh)	Life cycle energy consumption		Life cycle energy savings	
			in 5 years (GWh)	in 10 years (GWh)	in 5 years (GWh)	in 10 years (GWh)
Refrigerators	B	663.05	786.98	2,236.95	315.19	895.91
	A	397.50	1,666.73	4,737.56		
Air conditioners	C	7,777.39	18,229.69	51,816.71	7,032.23	19,988.67
	B	5,627.43	25,252.91	71,779.75	3,815.33	10,844.83
	A	4,777.21	7,325.62	20,822.60		

Calculation is based on data available from Bureau of energy efficiency (BEE)

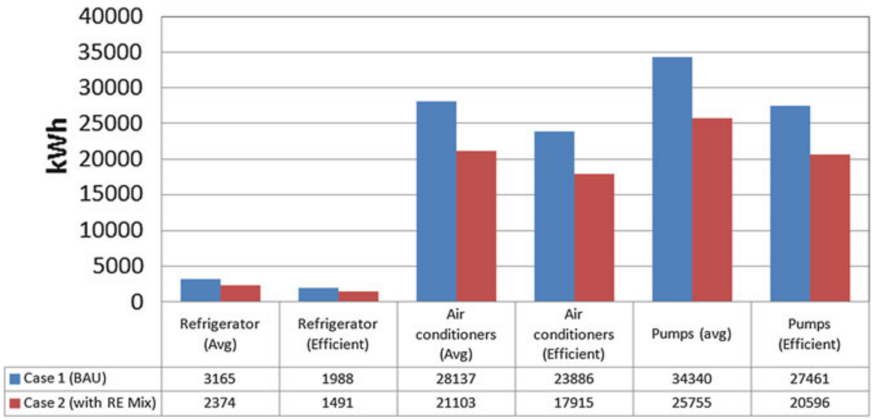


Fig. 4 Per unit energy consumption scenarios with and without renewable energy options

replaced by the most efficient one for 5 and 10 years were 8,322 and 16,644 kWh respectively (Table 2).

Lastly, street lighting is considered to be the more by numbers and energy intensive in the appliances sector. According to USAID and BEE, lighting alone accounts for 10–38 % of total energy bills in typical cities worldwide [8]. Energy efficient technologies and designs can cut street lighting costs dramatically (often by 25–60 %); these savings can eliminate or reduce the need for new generating plants and provide the capital for alternative energy solutions for population in remote areas. The BEE, based on Central Electricity Authority (CEA) statistics, has estimated gross energy consumption for public lighting to be 6,131 million kWh in India for the years 2007–2008 [8], Table 3 shows the typical lamp technology and life of units.

Table 2 Life cycle energy losses in the use phase of 63 kVA distribution transformers

Appliance	Class	Losses at 50 % load (W)	Life cycle energy losses (kWh)		Avoidable energy losses (kWh)	
Distribution transformers			5 years	10 years	5 years	10 years
(63 kVA)	C	490	21,462	42,924	8,322	16,644
	B	368.8	16,153	32,306	3,013	6,026
	A	300	13,140	26,280		

Calculation is based on data available from Bureau of energy efficiency (BEE), ‘A’ most efficient, and ‘B’, average efficient and ‘C’ least efficient

Table 3 Street lights technology and efficiency (data from USAID-BEE) [8]

Type of lamp	Luminous efficacy (lm/W)	Lamp life hours
High pressure mercury vapour (MV)	35–65	5,000
Metal halide (MH)	70–130	8,000
High pressure sodium vapour (HPSV)	50–150	15,000
Low pressure sodium vapour (LPSV)	100–190	15,000
Low pressure mercury fluorescent tubular lamp (T12 and T8)	30–90	5,000
Energy-efficient fluorescent tubular lamp (T5)	100–120	5,000
Light emitting diode (LED)	70–160	50,000

4 Life Cycle Cost Assessment

This section discusses the life cycle assessment of appliances over 5–10 years. The life cycle cost is calculated with a discount rate of 12 % and also assumes the electricity tariff of Rs 5/kWh for residential appliances and Rs 3/kWh for irrigation pumps. Table 4 provides the life cycle cost and payback period for the investment incurred on shifting to efficient refrigerators, air conditioners and irrigation pumps. In the case of refrigerators, most units were rated average or above average, as per BEE star labelling scheme. The estimation of cost is for BEE rated units in operation during 2010.

4.1 Distribution Transformers

The life cycle cost assessment of DTs has been computed for least efficient and most efficient units at 50 and 100 % load. From Table 5, we observe that the life

Table 4 Life cycle cost of appliances over 5, 10 years of life of product

Appliances	Category Class	Life cycle cost (use phase, million Rs)		Additional investment (Rs)	Pay back period for additional investments (years)
		5 years	10 years		
Refrigerators	B	2,188.9	3,430.9	13,000	9.79
	A	4,635.7	7,266.2		
Air conditioners	C	50,703.1	79,473.4	10,000	0.67
	B	70,237.1	110,091.5	5,000	1.18
	A	20,375.1	31,936.5		
Irrigation pumps	C	0.7	1.1	25,000	1.08
	B	31.0	48.6	10,000	1.46
	A	6,648.4	10,420.9		

*Estimation corresponds to the existing products

Table 5 Life cycle energy and operating cost of 63kVA DT

Annual energy costs	(@ 50 %)	(@ 100 %)
Annual operating cost (63 kVA) 1 star (Rs)	21,497	61,608
Annual operating cost (63 kVA) 4 star (Rs)	14,916	48,807
Savings (Rs)	6,580	12,800
Savings (kWh)	1,314	2,555
Life cycle operating cost over years	**5 years**	**10 years**
Least efficient at 50 % load (Rs)	107,486	214,972
Most efficient at 50 % load (Rs)	74,582	149,164
Least efficient at 100 % load (Rs)	3,080,426	616,085
Most efficient at 100 % load (Rs)	2,440,380	>488,076
Total life cycle savings 50 % load (Rs)	32,904	65,808
Total life cycle savings 100 % load (Rs)	74,582	149,164
Payback		**Years**
Pay back on incremental cost (@ 50 % load)		4.56
Pay back on incremental cost (@ 100 % load)		2.34

cycle operating cost increases with higher load and further, the payback period by switching to efficient units is less at 100 % load operation,

4.2 Street Lights

In street lights, the total annual energy cost is less for high pressure sodium vapour lamps. By replacing all high pressure mercury vapour lamp with high pressure sodium vapour lamps with slightly lower wattage, our analysis finds that savings of 20–25 % can be achieved [8] (Table 6).

Table 6 Annual costs of street lighting (data from USAID-BEE) [8]

Type of lamp	Installed cost (only lamp + luminaries supply) (Rs)	Annual energy cost (Rs)	Annual operating cost (Rs)	Total annualized cost (energy cost + operating cost) (Rs)
(MV)	465,800	805,920	43,625	849,545
(MH)	2,449,615	464,954	77,703	542,657
(HPSV)	1,750,286	345,394	10,512	355,906
(LPSV)	1,370,400	394,200	119,837	514,037
(T12 and T8)	390,857	550,629	36,041	586,670
(T5)	510,000	474,500	105,120	579,620
(LED)	6,000,000	372,300	–	372,300

Assuming 7.5 m wide, dual carriageway type, 1 km long road

5 Integration of Low Carbon Material Assessment

We have developed a scenario based analysis on estimating the impact of substitution of low carbon materials in place of energy intensive materials. This indicative analysis gives an insight during materials selection in the design stage of product life cycle. In this section we examined low carbon based design scenario for refrigerator, air conditioners and distribution transformers which are the most widely used appliances. The proportion and kinds of material used in this model are arrived by using the Gabi software model. Moreover the selection of materials was based on the functionalities of the replaced material i.e. Strength, durability albeit with less carbon content. Figure 5, shows the raw materials composition of a 2.1 kW single duct room air conditioner with a cooling capacity of 0.68 ton. The total weight of the unit is 28.96 kg, with metals 67.05 % (includes the steel, copper, iron and aluminium) and 30 % plastic materials (including rubber). The estimated emissions from single Air conditioners are 88.258 kg CO_2. Steel is extensively used material (about 10.15 kg) which involves energy intensive process. If 25 % (2.539 kg) of steel is replaced with low carbon materials with close approximate properties imitating similar strength and durability, the per unit emissions from the manufacturing stage alone can reduce by 6.24 % (Table 7).

The selected DT [11] for our analysis is a 315 kVA—Primary 11 kV and Secondary 433 V. An estimated 533 kg of steel and 200 kg of aluminium are used in manufacturing this DT; respective per unit embodied emissions are 1,321.73 and 1,955 kg CO_2 (combined Al sheets and wire). Table 8 provided similar analysis, showing LC materials inclusion in distribution transformers manufacturing. Case 1 depicts the sample conventional transformers materials analysis, Case 2, an LC based design replacing 25 % of Steel.

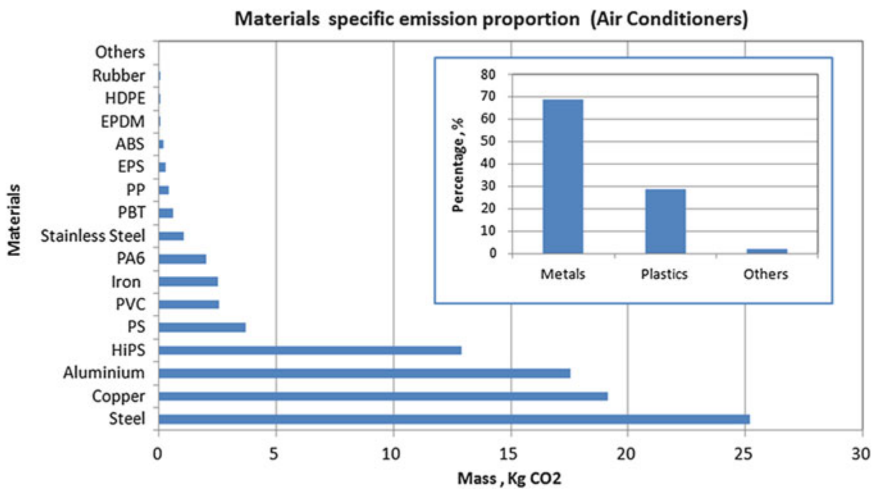


Fig. 5 CO_2 emissions from sample air conditioners

Table 7 Low carbon assessment of 2.1 kW air conditioner

Materials [9]	kg	%	CO_2 emission from each materials (kg-CO_2)	kg	CO_2 from each materials (kg-CO_2) [10]
	Case 1			Case 2	
Aluminium	1.795	6.22	17.567	1.795	17.567
Copper	4.918	17.04	19.134	4.918	19.134
Iron	2.062	7.14	2.526	2.062	2.526
Stainless steel	0.424	1.47	1.051	0.424	1.051
Steel	10.155	35.19	25.182	7.616	18.887
HDPE	0.021	0.07	0.033	0.021	0.033
PP	0.237	0.82	0.417	0.237	0.417
PS	1.894	6.56	3.702	1.894	3.702
EPS	0.114	0.39	0.294	0.114	0.294
Hi-PS	4.678	16.21	12.903	4.678	12.903
PVC	1.17	4.05	2.554	1.170	2.554
PA6	0.366	1.27	1.999	0.366	1.999
PBT	0.174	0.60	0.606	0.174	0.606
ABS	0.062	0.21	0.189	0.062	0.189
Rubber	0.006	0.02	0.019	0.006	0.019
EPDM	0.043	0.15	0.082	0.043	0.082
Others	0.742	2.57		0.742	
Low carbon materials	–	–	–	2.539	4.722
Total	28.861	100	88.258	28.861	86.684

25 % of steel is only replaced with LC material; percentage of rest of the material is same as existing product

Table 8 CO_2 emissions for sample transformer

Materials [11]	kg	%	CO_2 emission from each material (kg-CO_2)	kg	CO_2 emission from ach material (kg-CO_2)
	Case 1			Case 2	
Core steel	533	36.09	1,321.73	399.75	991.30
Transformer oil	340	23.02	1,14.92	340	114.92
Steel tank	324	21.94	803.46	324	803.46
Al wire	113.51	7.69	1,110.90	113.51	1,110.90
Al sheet	86.3	5.84	844.60	86.3	844.60
Insulation	59.9	4.06	194.82	59.9	194.82
Porcelain	11	0.74	3.36	11	3.36
LC material	–	–	–	133.25	247.83
Other	9	0.61		9	
Total	1,476.71	100	4,393.78	1,476.7	4,311.18

25 % of steel is only replaced with LC material with the same functionalities; percentage of rest of the material is same as existing product

Table 9 Impact on emissions for low carbon designed refrigerator

Refrigerator materials [12]	Case 1 Mass (kg)	Case 2	Case 1 Emissions (kg-CO_2)	Case 2
Aluminium	2.321	2.321	22.715	22.715
Polystyrene expandable granulate (EPS)	6.875	6.875	17.711	17.711
Acrylonitrile–butadiene–styrene granulate (ABS)	5.577	5.577	17.020	17.020
Copper	2.97	2.97	11.555	11.555
Glass	3.256	3.256	7.254	7.254
Cast iron	5.016	5.016	6.144	6.144
Brass	0.781	0.781	3.539	3.539
PVC	1.111	1.111	2.481	2.481
Styrene–butadiene rubber mix (SBR)	0.187	0.187	0.580	0.580
Steel	52.305	39.22	56.68	42.51
Low carbon materials	–	13.07	–	10.62

The results show that metals such as steel and aluminium emit high quantity of CO_2, 56.68 and 22.71 kg CO_2 per unit respectively and plastics materials like ABS and EPS together were estimated to emit 34 kg CO_2 as shown in Table 9 illustrate similar analysis, showing LC materials inclusion in refrigerator manufacturing. Case 1 depicts the materials analysis of a sample refrigerator, Case 2, an LC based design replacing 25 % of Steel. Additionally, from the Gabi software analysis also estimate the particulate matter (SPM) in the atmosphere from typical refrigerator units were contributed by aluminium, glass and other metals. Collectively from metals, about 100–110 g of SPM is displaced into the atmosphere and overall, from all the selected materials, approximately 170 g of SPM is displaced in the air from a single refrigerator unit.

6 Conclusion

This work depicts some of the valuable indicators in the life cycle of sustainable product design. Managing energy for a populous country like India in near future is a challenging task. Though current policy by BEE assists in the penetration of energy efficient appliances in the market, but, considering the population growth rate coupled with increase in income levels of the population, the demand for energy and appliances are increasing at an alarming rate. The study identifies several factors including replacement of conventional materials by their low carbon counterparts which can be integrated in products at the design stage itself and this can result in large energy and emissions savings over the entire product life cycle. These factors need to be integrated into the framework for sustainable product design for a low carbon economy. Further, the proposed methods need to become standard practices for increasing the competitiveness of products given the societal and political aspersion for sustainable practices and stricter environmental norms. We are pursuing the above work with the development of specific design options in the context of Indian manufacturing.

References

1. IEA (Online) (2010) Energy balance for India. http://www.iea.org. Accessed on 30 June 2012
2. Ministry of Environment and Forest (2010) India: Greenhouse Gas Emissions 2007
3. Environment Protection Agency (EPA) (2012) Energy Star. ENERGY STAR Qualified Products (Online). http://www.energystar.gov. Visited on 30 June 2012
4. Bureau of Energy Efficiency (BEE) (2012) Standard and labeling program. BEE (Online). http://www.beeindia.in/. Visited on 15 June 2012
5. Gutowski TG (Panel Chair), Murphy CF (Panel Co-chair) et al (2001) WTEC panel report on Environmentally Benign Manufacturing. International Technology Research Institute, 1 April 2001
6. Krishnan SS, Balasubramanian N, Subrahmanian E, Arun Kumar V, Ramakrishna G, Murali Ramakrishnan A, Krishnamurthy A (2009) Machine level energy efficiency analysis in discrete manufacturing for a sustainable energy infrastructure. Second annual international conference on infrastructure systems and services, Chennai, India, December 2009
7. Bureau of Energy Efficiency (BEE) (2010) Verified energy saving activities of Bureau of Energy Efficiency (BEE) for the year 2009–10. National Productivity Council (NPC), September 2010
8. USAID-BEE (2010) Guidelines—energy efficient street lighting. Bureau of Energy Efficiency, New Delhi
9. Boustani A, Sahni S, Gutowski TG, Graves SC (2010) Appliances remanufacturing and energy savings. Environmentally Benign Manufacturing Laboratory, January 2010
10. PE international GmBH (2009) GaBi sustainable assessment tool and database
11. ABB, Environmental product declaration. Distribution Transformers' Darra, QLD 4076
12. Yuhta Alan H (2004) Life cycle optimization of household refrigerator and freezer replacement. Center for Sustainable Systems, University of Michigan

Inverse Reliability Analysis for Possibility Distribution of Design Variables

A. S. Balu and B. N. Rao

Abstract Reliability analysis is one of the major concerns at the design stage since the occurrence of failures in engineering systems may lead to catastrophic consequences. Therefore, the expectation of higher reliability and lower environmental impact has become imperative. Hence the inverse reliability problem arises when one is seeking to determine the unknown design parameters such that prescribed reliability indices are attained. The inverse reliability problems with implicit response functions require the evaluation of the derivatives of the response functions with respect to the random variables. When these functions are implicit functions of the random variables, derivatives of these response functions are not readily available. Moreover in many engineering systems, due to unavailability of sufficient statistical information, some uncertain variables cannot be modelled as random variables. This paper presents a computationally efficient method to estimate the design parameters in the presence of mixed uncertain variables.

Keywords Fuzzy variables · High dimensional model representation · Inverse reliability analysis · Random variables

A. S. Balu (✉) · B. N. Rao
Structural Engineering Division, Department of Civil Engineering,
Indian Institute of Technology Madras, Chennai 600036, India
e-mail: arunsbalu@gmail.com

B. N. Rao
e-mail: bnrao@iitm.ac.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_43, © Springer India 2013

1 Introduction

The solution procedure for inverse reliability problems is required to determine the unknown design parameters such that prescribed reliability indices are attained. One way to solve the inverse reliability problem is through trial and error procedure, using a forward reliability method like first-order reliability method (FORM) and varying the design parameters until the achieved reliability index matches the required target [1]. However, the trial and error procedures are inefficient and involve difficulties resulting from repetitive forward reliability analysis. As a result there is considerable interest in developing an efficient and more direct approach to determine the design parameters for a specified target reliability level. An inverse first-order reliability method (inverse FORM) was developed for the estimation of design loads associated with specified target reliability levels in offshore structures, later it was extended to general limit state functions [2]. The inverse reliability methods were extended to design the wind turbines against ultimate limit states [3]. To overcome the drawbacks of the inverse FORM, artificial neural network (ANN)-based inverse FORM [4] as well as polynomial-based response surface method [5] were developed. The traditional performance measure approach (PMA) was modified to improve the efficiency and accuracy [6]. The various inverse measures and their usage for Reliability-Based Design Optimization (RBDO) were described to establish the relationship between Probabilistic Performance Measure (PPM) and Probabilistic Sufficiency Factor (PSF) [7]. The most probable point (MPP) based dimension reduction method was developed for RBDO of nonlinear and multi-dimensional systems [8].

Traditionally, inverse reliability methods require complete statistical information of uncertainties. These uncertainties are treated stochastically and assumed to follow certain probability distributions. However, in many practical engineering applications, the distributions of some random variables may not be precisely known or uncertainties may not be appropriately represented with probability distributions. In the design problem with both statistical random variables and fuzzy variables, if the random variables are converted into fuzzy variables by generating membership functions, the method may yield a design that is too conservative because treating the random variables as fuzzy variables loses accuracy of the uncertainties. On the other hand, treating fuzzy variables as random variables by adopting approximate probability distributions may lead to an unreliable optimum design. Therefore, in this paper a novel solution procedure for inverse reliability problems with implicit response functions without requiring the derivatives of the response functions with respect to the uncertain variables is proposed to determine the unknown design parameters such that prescribed reliability indices are attained in the presence of mixed uncertain variables.

2 High Dimensional Model Representation

High Dimensional Model Representation (HDMR) [9, 10] is a general set of quantitative model assessment and analysis tools for capturing the high-dimensional relationships between sets of input and output model variables. It is a very efficient formulation of the system response, if higher order variable correlations are weak, allowing the physical model to be captured by the first few lower order terms. Practically for most well-defined physical systems, only relatively low order correlations of the input variables are expected to have a significant effect on the overall response. HDMR expansion utilizes this property to present an accurate hierarchical representation of the physical system. Let the N-dimensional vector $\mathbf{x} = \{x_1, x_2, \ldots, x_N\}$ represent the input variables of the model under consideration, and the response function as $g(\mathbf{x})$. Since the influence of the input variables on the response function can be independent and/or cooperative, HDMR expresses the response $g(\mathbf{x})$ as a hierarchical correlated function expansion in terms of the input variables as

$$\begin{aligned} g(\mathbf{x}) = g_0 + \sum_{i=1}^{N} g_i(x_i) + \sum_{1 \le i_1 < i_2 \le N} g_{i_1 i_2}(x_{i_1}, x_{i_2}) + \cdots \\ + \sum_{1 \le i_1 < \ldots < i_l \le N} g_{i_1 i_2 \ldots i_l}(x_{i_1}, x_{i_2}, \ldots, x_{i_l}) \quad + \cdots + g_{12\ldots N}(x_1, x_2, \ldots, x_N) \end{aligned} \tag{1}$$

where g_0 is a constant term representing the zeroth-order component function or the mean response of $g(\mathbf{x})$. The function $g_i(x_i)$ is a first-order term expressing the effect of variable x_i acting alone, although generally nonlinearly, upon the output $g(\mathbf{x})$. The function $g_{i_1 i_2}(x_{i_1}, x_{i_2})$ is a second-order term which describes the cooperative effects of the variables x_{i_1} and x_{i_2} upon the output $g(\mathbf{x})$. The higher order terms give the cooperative effects of increasing numbers of input variables acting together to influence the output $g(\mathbf{x})$. The last term $g_{12,\cdots,N}(x_1, x_2, \cdots, x_N)$ contains any residual dependence of all the input variables locked together in a cooperative way to influence the output $g(\mathbf{x})$. Once all the relevant component functions in Eq. 1 are determined and suitably represented, then the component functions constitute HDMR, thereby replacing the original computationally expensive method of calculating $g(\mathbf{x})$ by the computationally efficient model. The expansion functions are determined by evaluating the input–output responses of the system relative to the defined reference point $\mathbf{c}$ along associated lines, surfaces, subvolumes, etc. in the input variable space. This process reduces to the following relationship for the component functions in Eq. 1.

$$g_0 = g(\mathbf{c}) \tag{2}$$

$$g_i(x_i) = g\left(x_i, \mathbf{c}^i\right) - g_0 \tag{3}$$

$$g_{i_1 i_2}(x_{i_1}, x_{i_2}) = g\left(x_{i_1}, x_{i_2}, \mathbf{c}^{i_1 i_2}\right) - g_{i_1}(x_{i_1}) - g_{i_2}(x_{i_2}) - g_0 \tag{4}$$

where the notation $g(x_i, \mathbf{c}^i) = g(c_1, c_2, \ldots, c_{i-1}, x_i, c_{i+1}, \ldots, c_N)$ denotes that all the input variables are at their reference point values except x_i. The g_0 term is the output response of the system evaluated at the reference point $\mathbf{c}$. The higher order terms are evaluated as cuts in the input variable space through the reference point. Therefore, each first-order term $g_i(x_i)$ is evaluated along its variable axis through the reference point. Each second-order term $g_{i_1 i_2}(x_{i_1}, x_{i_2})$ is evaluated in a plane defined by the binary set of input variables x_{i_1} and x_{i_2} through the reference point, etc. Considering terms up to first-order in Eq. 1 yields

$$g(\mathbf{x}) = g_0 + \sum_{i=1}^{N} g_i(x_i) + \mathcal{R}_2 \tag{5}$$

Substituting Eqs. 2 and 3 into Eq. 5 leads to

$$g(\mathbf{x}) = \sum_{i=1}^{N} g(c_1, \ldots, c_{i-1}, x_i, c_{i+1}, \ldots, c_N) - (N-1)g(\mathbf{c}) + \mathcal{R}_2 \tag{6}$$

Now consider first-order approximation of $g(\mathbf{x})$, denoted by

$$\tilde{g}(\mathbf{x}) \equiv g(x_1, x_2, \ldots, x_N) = \sum_{i=1}^{N} g(c_1, \ldots, c_{i-1}, x_i, c_{i+1}, \ldots, c_N) - (N-1)g(\mathbf{c}) \tag{7}$$

Comparison of Eqs. 6 and 7 indicates that the first-order approximation leads to the residual error $g(\mathbf{x}) - \tilde{g}(\mathbf{x}) = \mathcal{R}_2$, which includes contributions from terms of two and higher order component functions. The notion of 0th, 1st, etc. in HDMR expansion should not be confused with the terminology used either in the Taylor series or in the conventional least-squares based regression model. It can be shown that, the first order component function $g_i(x_i)$ is the sum of all the Taylor series terms which contain and only contain variable x_i. Hence first-order HDMR approximations should not be viewed as first-order Taylor series expansions nor do they limit the nonlinearity of $g(\mathbf{x})$. Furthermore, the approximations contain contributions from all input variables. Thus, the infinite number of terms in the Taylor series is partitioned into finite different groups and each group corresponds to one cut-HDMR component function. Therefore, any truncated cut-HDMR expansion provides a better approximation and convergent solution of $g(\mathbf{x})$ than any truncated Taylor series because the latter only contains a finite number of terms of Taylor series. Furthermore, the coefficients associated with higher dimensional terms are usually much smaller than that with one-dimensional terms. As such, the impact of higher dimensional terms on the function is less, and therefore, can be neglected. Compared with the FORM and SORM which retain only linear and quadratic terms, respectively, first-order HDMR approximation $\tilde{g}(\mathbf{x})$ provides more accurate representation of the original implicit limit state function $g(\mathbf{x})$.

3 Inverse Structural Reliability Analysis Using HDMR and FFT

The objective of the inverse reliability analysis using HDMR and FFT [11, 12] is to find a new MPP, denoted by $\mathbf{x}^*_{\text{HDMR}}$, which will be then used in the subsequent iteration of analysis. The proposed computational procedure involves the following three steps: estimation of failure probability in presence of mixed uncertain variables, reliability index update, and MPP update.

3.1 Estimation of Failure Probability in Presence of Mixed Uncertain Variables

Let the N-dimensional input variables vector $\mathbf{x} = \{x_1, x_2, \ldots, x_N\}$, which comprises of r number of random variables and f number of fuzzy variables be divided as, $\mathbf{x} = \{x_1, x_2, \ldots, x_r, x_{r+1}, x_{r+2}, \ldots, x_{r+f}\}$ where the subvectors $\{x_1, x_2, \ldots, x_r\}$ and $\{x_{r+1}, x_{r+2}, \ldots, x_{r+f}\}$ respectively group the random variables and the fuzzy variables, with $N = r + f$. Then the first-order approximation of $\tilde{g}(\mathbf{x})$ in Eq. 7 can be divided into three parts, the first part with only the random variables, the second part with only the fuzzy variables and the third part is a constant which is the output response of the system evaluated at the reference point $\mathbf{c}$, as follows

$$\tilde{g}(\mathbf{x}) = \sum_{i=1}^{r} g\left(x_i, \mathbf{c}^i\right) + \sum_{i=r+1}^{N} g\left(x_i, \mathbf{c}^i\right) - (N-1)g(\mathbf{c}) \tag{8}$$

The joint membership function of the fuzzy variables part is obtained using suitable transformation of the variables $\{x_{r+1}, x_{r+2}, \ldots, x_N\}$ and interval arithmetic algorithm. Using this approach, the minimum and maximum values of the fuzzy variables part are obtained at each α-cut. Using the bounds of the fuzzy variables part at each α-cut along with the constant part and the random variables part in Eq. 8, the joint density functions are obtained by performing the convolution using FFT in the rotated Gaussian space at the MPP, which upon integration yields the bounds of the failure probability.

3.2 Transformation of Interval Variables

Optimization techniques are required to obtain the minimum and maximum values of a nonlinear response within the bounds of the interval variables. This procedure is computationally expensive for problems with implicit limit state functions, as optimization requires the function value and gradient information at several points in the iterative process. But, if the function is expressed as a linear combination of interval variables, then the bounds of the response can be expressed as the summation of the bounds of the individual variables. Therefore, fuzzy variables part of the nonlinear limit state function in Eq. 8 is expressed as a linear combination of intervening variables by the use of first-order HDMR approximation in order to apply an interval arithmetic algorithm, as follows

$$\sum_{i=r+1}^{N} g\left(x_i, \mathbf{c}^i\right) = z_1 + z_2 + \ldots + z_f \tag{9}$$

where $z_i = \left(\beta_i x_i + \gamma_i\right)^{\kappa}$ is the relation between the intervening and the original variables with κ being order of approximation taking values $\kappa = 1$ for linear approximation, $\kappa = 2$ for quadratic approximation, $\kappa = 3$ for cubic approximation, and so on. The bounds of the intervening variables can be determined using transformations [13]. If the membership functions of the intervening variables are available, then at each α-cut, interval arithmetic techniques can be used to estimate the response bounds at that level.

3.3 Estimation of Failure Probability using FFT

Concept of FFT can be applied to the problem if the limit state function is in the form of a linear combination of independent variables and when either the marginal density or the characteristic function of each basic random variable is known. In the present study HDMR concepts are used to express the random variables part along with the values of the constant part and the fuzzy variables part at each α-cut as a linear combination of lower order component functions. The steps involved in the proposed method for failure probability estimation as follows:

1. If $\mathbf{u} = \{u_1, u_2, \ldots, u_r\}^T \in \Re^r$ is the standard Gaussian variable, let $\mathbf{u}^* = \{u_1^*, u_2^*, \ldots, u_r^*\}^T$ be the MPP or design point, determined by a standard nonlinear constrained optimization. The MPP has a distance β_{HL}, which is commonly referred to as the Hasofer–Lind reliability index. Construct an orthogonal matrix $\mathbf{R} \in \Re^{r \times r}$ whose rth column is $\boldsymbol{\alpha}^* = \mathbf{u}^*/\beta_{HL}$, i.e., $\mathbf{R} = [\mathbf{R}_1 | \boldsymbol{\alpha}^*]$ where $\mathbf{R}_1 \in \Re^{r \times r-1}$ satisfies $\boldsymbol{\alpha}^{*T}\mathbf{R}_1 = 0 \in \Re^{1 \times r-1}$. The matrix R can be obtained, for example, by Gram–Schmidt orthogonalization. For an orthogonal transformation $\mathbf{u} = \mathbf{R}\,\mathbf{v}$. Let $\mathbf{v} = \{v_1, v_2, \ldots, v_r\}^T \in \Re^r$ be the rotated Gaussian space with the associated MPP $\mathbf{v}^* = \{v_1^*, v_2^*, \ldots, v_r^*\}^T$. The transformed limit state function $g(\mathbf{v})$ therefore maps the variables into rotated Gaussian space $\mathbf{v}$. First-order HDMR approximation of $g(\mathbf{v})$ in rotated Gaussian space $\mathbf{v}$ with $\mathbf{v}^* = \{v_1^*, v_2^*, \ldots, v_r^*\}^T$ as reference point can be represented as follows:

$$\tilde{g}(\mathbf{v}) \equiv g(v_1, v_2, \ldots, v_r) = \sum_{i=1}^{r} g\left(v_1^*, \ldots, v_{i-1}^*, v_i, v_{i+1}^*, \ldots, v_r^*\right) - (r-1) g(\mathbf{v}^*) \tag{10}$$

2. In addition to the MPP as the chosen reference point, the accuracy of first-order HDMR approximation in Eq. 10 may depend on the orientation of the first $r-1$ axes. In the present work, the orientation is defined by the matrix $\mathbf{R}$. In Eq. 10, the terms $g(v_1^*, \ldots, v_{i-1}^*, v_i, v_{i+1}^*, \ldots, v_r^*)$ are the individual component functions and are independent of each other. Equation 10 can be rewritten as

$$\tilde{g}(\mathbf{v}) = a + \sum_{i=1}^{r} g\left(v_i, \mathbf{v}^{*i}\right) \tag{11}$$

where $a = -(r-1)g(\mathbf{v}^*)$.

3. New intermediate variables are defined as

$$y_i = g\left(v_i, \mathbf{v}^{*i}\right) \tag{12}$$

The purpose of these new variables is to transform the approximate function into the following form

$$\tilde{g}(\mathbf{v}) = a + y_1 + y_2 + \cdots + y_r \tag{13}$$

4. Due to rotational transformation in $\boldsymbol{v}$-space, component functions y_i in Eq. 13 are expected to be linear or weakly nonlinear function of random variables v_i. In this work both linear and quadratic approximations of y_i are considered. Let $y_i = b_i + c_i v_i$ and $y_i = b_i + c_i v_i + e_i v_i^2$ be the linear and quadratic approximations, where coefficients $b_i \in \Re$, $c_i \in \Re$ and $e_i \in \Re$ (non-zero) are obtained by least-squares approximation from exact or numerically simulated conditional responses $\left\{g(v_i^1, \mathbf{v}^{*i}), g(v_i^2, \mathbf{v}^{*i}), \ldots, g(v_i^n, \mathbf{v}^{*i})\right\}^T$ at n sample points along the variable axis v_i. Then Eq. (13) results in

$$\tilde{g}(\mathbf{v}) \equiv a + y_1 + y_2 + \cdots + y_r = a + \sum_{i=1}^{r} (b_i + c_i v_i) \tag{14}$$

$$\tilde{g}(\mathbf{v}) \equiv a + y_1 + y_2 + \cdots + y_r = a + \sum_{i=1}^{r} \left(b_i + c_i v_i + e_i v_i^2\right) \tag{15}$$

The least-squares approximation is chosen over interpolation, because the former minimizes the error when $n > 2$ for linear and $n > 3$ for quadratic approximations.

5. Since v_i follows standard Gaussian distribution, marginal density of the intermediate variables y_i can be easily obtained by simple transformation.

$$p_{Y_i}(y_i) = p_{V_i}(v_i)\left|\frac{1}{dy_i/dv_i}\right| \tag{16}$$

6. Now the approximation is a linear combination of the intermediate variables y_i. Therefore, the joint density of $\tilde{g}(\mathbf{v})$, which is the convolution of the individual marginal density of the intervening variables y_i, can be expressed as follows:

$$p_{\tilde{G}}(\tilde{g}) = p_{Y_1}(y_1) * p_{Y_2}(y_2) * \ldots * p_{Y_r}(y_r) \tag{17}$$

   where $p_{\tilde{G}}(\tilde{g})$ represents joint density of the transformed limit state function.

7. Applying FFT on both sides of Equation 17, leads to

$$FFT\left[p_{\tilde{G}}(\tilde{g})\right] = FFT[p_{Y_1}(y_1)]FFT[p_{Y_2}(y_2)]\ldots FFT[p_{Y_r}(y_r)] \tag{18}$$

8. By applying inverse FFT on both side of Eq. 18, joint density of the limit state function $\tilde{g}(\mathbf{v})$ is obtained.
9. The probability of failure is given by the following equation

$$P_F^{\mathrm{HDMR}} = \int_{-\infty}^{0} P_{\tilde{G}}(\tilde{g})d\tilde{g} \tag{19}$$

After computing the probability of failure P_F^{HDMR} using coupled HDMR-FFT technique, the corresponding reliability index β_{HDMR} can be obtained by

$$\beta_{\mathrm{HDMR}} = -\Phi^{-1}\left(P_F^{\mathrm{HDMR}}\right) \tag{20}$$

where $\Phi(\bullet)$ is the cumulative distribution function of a standard Gaussian random variable.

3.4 Reliability Index and MPP Update Procedure

As expected it is very likely that the β_{HDMR} (computed using Eq. 20) is not the same as the target reliability index $\beta_t = -\Phi^{-1}(P_F^{\mathrm{Tar}})$, and hence, using the difference between these two reliability indices, a recursive formula is obtained as

$$\beta^{(k+1)} \cong \beta^{(k)} - (\beta_{\mathrm{HDMR}} - \beta_t) \tag{21}$$

where $\beta^{(k)}$ is the reliability index at the current step, with $\beta^{(0)} = \beta_t$ at the initial step.

The updated MPP is approximated as

$$\mathbf{u}_{k+1}^* \cong \frac{\beta^{(k+1)}}{\beta^{(k)}}\mathbf{u}_k^* \quad \text{or} \quad \mathbf{v}_{k+1}^* \cong \frac{\beta^{(k+1)}}{\beta^{(k)}}\mathbf{v}_k^* \tag{22}$$

The updated MPP obtained through Eq. 22 is called the coupled HDMR-FFT based MPP, denoted by $\mathbf{u}_{\text{HDMR}}^*$ in $\mathbf{U}$-space or $\mathbf{x}_{\text{HDMR}}^*$ in $\mathbf{X}$-space.

4 Numerical Examples

To obtain the approximation of the HDMR component functions of the nonlinear limit state function in Eq. 12, n sample points $\mu_i - (n-1)\sigma_i/2$, $\mu_i - (n-3)\sigma_i/2$, …, μ_i, …, $\mu_i + (n-3)\sigma_i/2$, $\mu_i + (n-1)\sigma_i/2$ are deployed along axis of each of variable x_i. If N and n respectively denote the number of uncertain variables, the number of sample points taken along each of the variable axis, then using first-order HDMR approximation the total cost of original function evaluation entails a maximum of $N \times (n-1) + 1$ by the proposed method. The efficiency and robustness of the proposed method is expected to increase with increase in the complexity of the structure, number of uncertain variables.

4.1 Hypothetical Limit State Function

This example considers a four dimensional quadratic function of the following form:

$$g(\mathbf{x}) = -x_1^2 - x_2^2 - x_3^2 - x_4^2 + 9x_1 + 11x_2 + 11x_3 + 11x_4 - 95.5 \tag{23}$$

where $x_1 - x_3$ are assumed to be independent normal variables with $N(5, 0.4)$. The variable x_4 is assumed as fuzzy represented by the triplet [4.6, 5.0, 5.4]. The objective is to find the membership functions of $x_1^* - x_3^*$ values, such that the target reliability index $\beta_t = 1.645$ (which corresponds to a failure probability $P_F = 0.05$) is achieved. The presence of mixed uncertain (both random and fuzzy) variables, leads to the membership function of MPP ($x_1^* - x_3^*$) instead of having a unique value at the target reliability index. Figure 1a–c respectively show the membership functions of $x_1^* - x_3^*$ values at the target reliability index estimated by the proposed method using linear and quadratic approximations. The effect of number of sample points is studied by varying n from 3 to 9. In Fig. 1a–c it can be observed that the

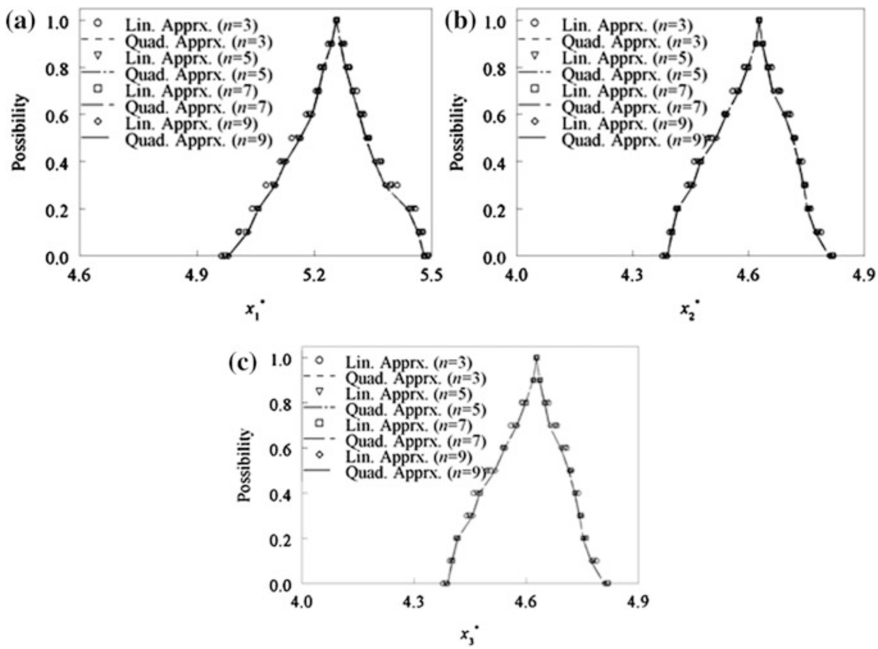


Fig. 1 Membership function of design variables **a** x_1^*, **b** x_2^*, and **c** x_3^*

membership functions of $x_1^* - x_3^*$ values estimated by the proposed method using $n = 7$ and 9 are overlapping each other.

4.2 Single Story Linear Frame Structure

In this example a linear frame structure of one story and one bay as shown in Fig. 2a is considered. The cross sectional areas A_1 and A_2 are assumed to be log-normally distributed random variables with mean values of 0.36 and 0.18, and standard deviation values of 0.036 and 0.018 respectively. The horizontal load P is treated as fuzzy with a triplet of [15, 20, 25]. The sectional moments of inertia are expressed as $I_i = \alpha_i A_i^2$ $(i = 1, 2;\ \alpha_1 = 0.08333,\ \alpha_2 = 0.16670)$. The Young's modulus E is treated as deterministic. $E = 2.0 \times 10^6$ kN/m^2. In this study, the functional relationship to define the horizontal displacement at the top of the frame is:

$$g(A_1, A_2, P) = \Delta_{\text{lim}} - u_h \tag{24}$$

where Δ_{lim} is taken as 10 mm. Our interest is to find A_1^* and A_2^*, such that the target reliability index $\beta_t = 2.831$ (which corresponds to a failure probability $P_F = 2.32 \times 10^{-3}$) is achieved.

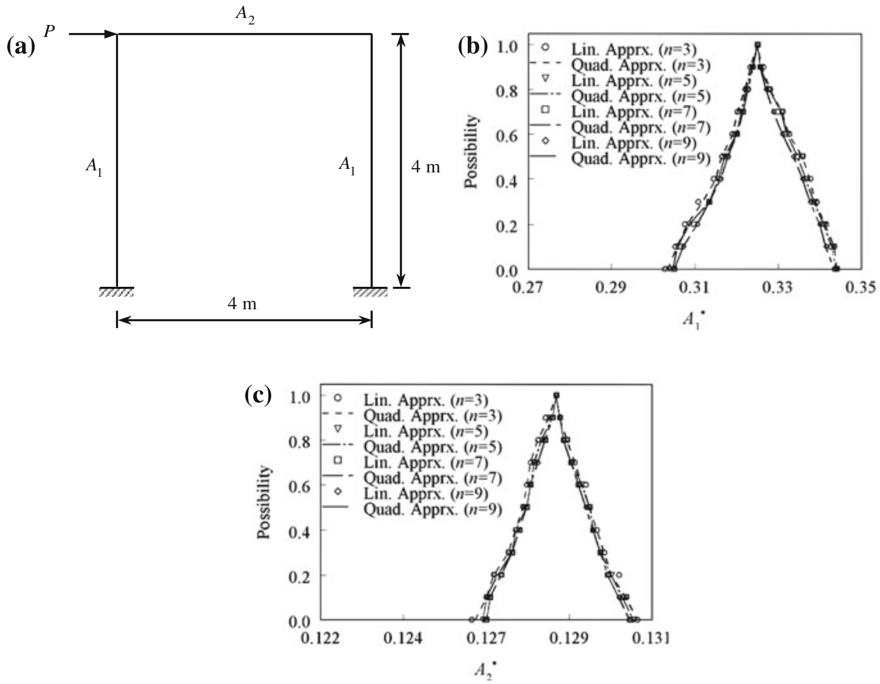


Fig. 2 **a** Single story linear frame, **b** A_1^*, and **c** A_2^*

The implicit limit state function given in Eq. 24 is approximated using first-order HDMR by deploying n sample points along each of the variable axis. The approximated limit state function is divided into two parts, one with only the random variables along with the value of the constant part, and the other with the fuzzy variables. The joint membership function of the fuzzy part of approximated limit state function is obtained using suitable transformation of the fuzzy variables. Using the proposed inverse reliability method in conjunction with linear and quadratic approximations, the membership functions of A_1^* and A_2^* values at the target reliability index are obtained, and shown in Fig. 2b and c. The effect of number of sample points is studied by varying n from 3 to 9 and observed that the membership functions of A_1^* and A_2^* values estimated by the proposed method using $n = 7$ and 9 are overlapping each other.

5 Summary and Conclusions

An efficient, accurate, robust solution procedure alternative to existing inverse reliability methods is proposed for nonlinear problems with implicit response functions, that can be used to determine multiple unknown design parameters such that prescribed reliability indices are attained in the presence of mixed uncertain (both random and fuzzy) variables. The proposed method avoids the requirement of the derivatives of the response functions with respect to the uncertain variables. The proposed computational procedure involves three steps: (1) probability of failure calculation using High Dimensional Model Representation (HDMR) for the limit state function approximation, transformation technique to obtain the contribution of the fuzzy variables to the convolution integral, and fast Fourier transform for solving the convolution integral, (2) reliability index update, and (3) most probable point (MPP) update. The limit state function approximation is obtained by linear and quadratic approximations of the first-order HDMR component functions at MPP. The methodology developed is versatile, hence can be applied to highly nonlinear or multi-parameter problems applicable involving any number of fuzzy variables and random variables with any kind of distribution. The accuracy and efficiency of the proposed method is demonstrated through six numerical examples.

In addition, a parametric study is conducted with respect to the number of sample points used in approximation of HDMR component functions and its effect on the estimated solution is investigated. An optimum number of sample points must be chosen in approximating HDMR component functions. Very small number of sample points should be avoided as approximation may not capture the nonlinearity outside the domain of sample points and thereby affecting the estimated solution.

References

1. Li H, Foschi RO (1998) An inverse reliability method and its application. Struct Saf 20:257–270
2. Der Kiureghian A, Zhang Y, Li CC (1994) Inverse reliability problem. ASCE J Eng Mech 120:1154–1159
3. Saranyasoontorn K, Manuel L (2004) Efficient models for wind turbine extreme loads using inverse reliability. J Wind Eng Ind Aerodyn 92:789–804
4. Cheng J, Zhang J, Cai CS, Xiao RC (2007) A new approach for solving inverse reliability problems with implicit response functions. Eng Struct 29:71–79
5. Cheng J, Li QS (2009) Application of the response surface methods to solve inverse reliability problems with implicit response functions. Comput Mech 43:451–459
6. Du X, Sudijianto A, Chen W (2004) An integrated framework for optimization under uncertainty using inverse reliability strategy. ASME J Mech Des 126(4):561–764
7. Ramu P, Qu X, Youn BD, Choi KK (2006) Inverse reliability measures and reliability-based design optimization. Int J Reliab Saf 1(1, 2):187–205
8. Lee I, Choi KK, Du L, Gorsich D (2008) Inverse analysis method using MPP-based dimension reduction for reliability-based design optimization of nonlinear and multi-dimensional systems. Comput Methods Appl Mech Eng 198:14–27
9. Rabitz H, Alis OF (1999) General foundations of high dimensional model representations. J Math Chem 25:197–233
10. Sobol IM (2003) Theorems and examples on high dimensional model representations. Reliab Eng Syst Saf 79(2):187–193

11. Rao BN, Chowdhury R (2008) Probabilistic analysis using high dimensional model representation and fast Fourier transform. Int J Comput Methods Eng Sci Mech 9:342–357
12. Sakamoto J, Mori Y, Sekioka T (1997) Probability analysis method using fast Fourier transform and its application. Struct Saf 19(1):21–36
13. Adduri PR, Penmetsa RC (2008) Confidence bounds on component reliability in the presence of mixed uncertain variables. Int J Mech Sci 50:481–489

Analyzing Conflicts Between Product Assembly and Disassembly for Achieving Sustainability

S. Harivardhini and Amaresh Chakrabarti

Abstract Environmental performance of a product could be increased throughout its life cycle by incorporating design requirements which consider Design for Disassembly (DfD) from a life cycle perspective by aiding ease of disassembly of the product across its life cycle. These design requirements, including DfD for different life cycle phases, should be made compatible with Design for Assembly (DfA) requirements within an integrated framework. Using such an integrated framework should reduce various layers of complexity introduced into design and should help designers to develop products that are easy to both assemble and disassemble, without compromising the product's functionality. Prerequisites to developing the integrated framework are to: understand the requirements for DfD and DfA, identify if they are in conflict with one another, understand the underlying causes, and develop means to resolve these. To determine whether DfD and DfA requirements conflict one another, various existing products are analyzed, for conflicts among their assembly and disassembly processes. Various conflicts are found to be present among these processes. These conflicts are outlined, and possible causes for these are identified.

Keyword: Disassembly · DfD · DfA · Conflicts

S. Harivardhini (✉) · A. Chakrabarti
IDeaS Lab, CPDM, Indian Institute of Science, Bengaluru 560012, India
e-mail: vardhini@cpdm.iisc.ernet.in

A. Chakrabarti
e-mail: ac123@cpdm.iisc.ernet.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_44, © Springer India 2013

1 Introduction

Sustainability is a growing concern among all countries. This is due to various factors, such as the following: manufacturers continue to introduce huge quantities of products without considering future reuse during their development, and customers often get dissatisfied with their products even through these are in good working condition. Factors such as these lead to a wide variety of products being disposed rather than being recovered and reused.

Society has started realizing the likely environmental threats that might result from disposal; for instance, governments are enacting strict legislations for disposal of products in an environmental friendly manner. One impact of these regulations is increased responsibility on the part of manufacturers in the End-of-Life (EoL) phase of their products. This scenario makes manufacturers rethink about the decisions taken during their product design and manufacturing stages. Decisions taken during the design stage are critical because it is during this stage that most product attributes are decided [1] and most of the considerations that have the potential to resolve environmental issues are incorporated. Designing products with reduced impact on environment in their EoL phase is a far better option than products that are not designed for this purpose, and hence destined to end in disposal. However, in order to achieve environmental sustainability, it is not enough to focus only on the EoL phase of the product. Impacts caused by the product in its other life cycle phases also add to its environmental consequences. Therefore, it is crucial to improve the environmental performance of a product throughout its life cycle [2]. The product should be developed in such a way that its likely impact on the environment is minimized in each of its life cycle phases.

One way to improve the environmental performance of a product throughout its life cycle is to design the product such that it aids ease of disassembly in all its life cycle phases. Design for (ease of) Disassembly (DfD) is one of the strategies to improve disassemblability of the product. It is an approach in which disassembly considerations are incorporated into the product at the design stage itself [3], thereby increasing the product's ease of disassembly. While doing this, DfD should be balanced against other design considerations [4] such as DfA in order to avoid new problems being introduced into the design; evidence for this can be found [5], who observed that introducing Design for X guidelines for one aspect (e.g. assembly) without considering other often led to new problems.

This paper emphasizes the need for developing an integrated framework for DfD. Prerequisites to this are: to understand the requirements for DfD and DfA, to identify whether or not they are conflicting, identify the reasons behind the conflicts, if any, and develop means to resolve the conflicts. Existing products were analyzed for conflicts in their assembly and disassembly processes to understand DfD and DfA compatibility. We found that various conflicts exist among assembly and disassembly processes of these products. In this paper, these conflicts are outlined, and possible causes are discussed.

Section 2 elaborates the importance of carrying out disassembly in each life cycle phase; Sect. 3 explains what DfD is and how DfD needs to be different for each life cycle phase; Sect. 4 reviews existing literature on the relationship between DfD and DfA, and establishes the need for an integrated framework for DfD; Sect. 5 reports on a pilot study carried out to determine whether conflicts exist among ease of assembly and disassembly processes of existing products and what cause these conflicts; conclusions and future work are presented in Sect. 6.

2 Disassembly

Brennan et al. [6] defined disassembly as ‘‘the processes of systematic removal of desirable constitute parts from an assembly while ensuring that there is no impairment of the parts due to the process”

“Ease of disassembly” is one of the requirements for achieving easy transportation, easy service and maintenance [7], easy recovery of parts at EoL [7, 8]. We argue, therefore, that disassembly has the potential to improve environmental performance of a product throughout its life cycle by improving efficiencies of the operations carried out during all the life cycle phases of the product. Henceforth, we refer to this objective as “disassembly for all life cycle phases”.

2.1 Disassembly for Various Life Cycle Phases

2.1.1 Disassembly for Production

During assembly, the possibility of parts ending up in a wrong fitting is high when parts have similar geometric structure and multiple possible ways of being fitted. In such cases, disassembly would be necessary for removal of those parts for reassembly in the same product, thus preventing the use of new parts. Another reason is that testing may reveal issues with functioning of the product; to resolve these, product must be disassembled.

2.1.2 Disassembly for Distribution

Some complex products are difficult to distribute, because their product architecture will not allow their components to get separated during transportation and later reassembled for use. Disassembly of such products could improve the distribution efficiency by making products occupy less storage space during transportation.

2.1.3 Disassembly for Use

Disassembly enables maintenance and enhances serviceability [7]. Thus it increases the life of a product [1].

2.1.4 Disassembly for EoL

The recovery processes are often economically unviable if the products are originally designed with no consideration to their future reuse. So, very often, disposal is the only option for such products. To resolve this issue, products should be variously remanufactured, reused or recycled, so as to maximally recover its sub-assemblies, components or materials, from used products, in order to make these available for new products. Disassembly is necessary in carrying out these recovery processes.

3 Design for Disassembly

According to Giudice et al. [23], DfD is a design approach with the objective of optimizing the architecture and all other constructional characteristics of a product in relation to the following main requirements: limiting the time and costs of disassembly; simple and rapid separability of parts to be serviced or recovered. DfD can also be defined as "the consideration of the ease of disassembly during the design process" [3].

3.1 DfD for various life cycle phases

Production phase

The objective of DfD for production is to design such that the parts having similar geometric structure and ambiguous fitting possibilities are easily accessed, disassembled and assembled in order to rectify the assembly, if applicable.

Distribution Phase

The objective of DfD for distribution is to design the product with high modularity, i.e., easy access, disassembly and reassembly of all modules, with all functional requirements satisfied after reassembly.

Use phase

The objective of DfD for service and maintenance is to make design choices that most efficiently ease accessibility, disassembly and reassembly of certain predetermined components that require servicing intervention.

EoL phase

The objective of DfD for EoL is to design a product such that its subassemblies, parts and materials, at the end of its useful life, are easily accessible and separable (and in some cases re-assemblable) from their adjacent subassemblies, parts and materials, so as to make them amenable to appropriate EoL treatments e.g. remanufacturing, reuse, or recycling.

4 Compatibility Between DfD and DfA

4.1 Literature on Relationships Between DfD and DfA

Boothroyd and Alting [9], Jovane et al. [10], Penev and De Ron [11] and Gupta and McLean [12] have studied DfA methods and discussed research opportunities in DfD. Shu and Flowers [13] showed that joints designed for ease of assembly and recycling may not facilitate remanufacturing. One problem with disassembly of existing products, reported by Alting and Legarth [2], is that it requires a large number of steps to take products apart as joining techniques are directed towards assembly and not disassembly.

Harjula et al. [14] identified that though DfA redesigns could be beneficial in simplifying disassembly, additional design changes have to be incorporated for simplifying removal of critical items. Several differences between assembly and disassembly have been identified, such as (1) irreversible operations like welding, riveting or breakage of components [15], (2) selective disassembly [16]. Based on the implications of these differences, Srinivasan et al. [17] concluded that the most economical assembly sequence need not be the most economical disassembly sequence. Kroll et al. [8] pointed out that DfD and Design for Manufacture and Assembly (DfMA) may seem similar in intent, but are often quite different in practice. They reported that many products designed for assembly are very hard to disassemble, e.g., those with certain types of snap-fit joints.

Westkamper et al. [18] have compared assembly and disassembly for different EoL options (including repair), based on following criteria: productivity, quality, lead time, time to delivery, process time, and flexibility. Their study highlights how to integrate assembly and disassembly given that logistics, systems, technical installations, flexible automation, management of product life cycle data were to be made common for both assembly and disassembly. While this work focuses on integrating assembly and disassembly systems for existing products, the focus of our work lies in integrating assembly and disassembly requirements at the design stage.

Nof and Chen [19] argued that Design for assembly and disassembly (DFAD) involves integrating the specific domain knowledge of manufacturing, design, and decision-making. They have developed an approach called Cooperation Requirement Planning (CRP), the output of which is analyzed for conflicts among task assignments and assembly planning in CRP. The focus of our work is distinct from this work by resolving conflicts among DfA and DfD requirements to achieve sustainability rather than resolving conflicts among task assignments and assembly planning in CRP to achieve optimum utilization of cooperation among robots.

Also our definition of DfAD is to design products such that it enables easy assembly and easy disassembly. But Nof and Chen considers disassembly as reverse of assembly. DfAD is approximately equal to DfA in their work.

Motevallian et al. [1] have modified the DfMA process, and incorporated DfD into a framework; however, this integrates DFMA and DfD in a serial manner, allowing possibility for conflicts among these to remain in the final product. Gkeleri and Tourassis [4] pointed out that disassembly concerns must be balanced against other design considerations. They also mentioned that industrial firms complained about the increasing layers of complexity imposed upon the product design process. Integrating various DfX concepts into a single framework is required [5].

4.2 Need for an Integrated Framework for DfD

As discussed in Sect. 2, a major means for improving environmental performance should be to support "disassembly for all life cycle phases". From literature (Sect. 4.1), it can be argued that substantial differences can exist between requirements for DfD and DfA; design requirements that enable easy assembly can be different from those that enable easy disassembly. There is a need to balance disassembly concerns with other design considerations, and a need to integrate various DfX concepts into a single framework. The overall objective is therefore to develop an integrated framework that supports consideration of design requirements for ease of disassembly for all phases of product life cycle while being compatible with requirements for ease of assembly in these life cycle phases.

To achieve this, the following steps are necessary:

1. Understand the requirements for DfD and DfA,
2. Identify whether they conflict one another,
3. Understand the underlying causes for conflicts or their absence, and
4. Develop means to resolve or learn from these.

To carry out Steps 1–3, a series of existing products are taken, and their assembly and disassembly processes are analyzed to answer the following research question: Are there any conflicts among the assembly & disassembly processes for the same product, if yes, what are the conflicts, and why do they occur?

5 Conflicts Among Assembly & Disassembly Processes

As a preliminary investigation to answer the research question in Sect. 4.2, two studies were undertaken. The first was a literature based study, where existing cases in literature that report conflicts among assembly and disassembly processes of a product are analyzed to identify the underlying causes. The second is a pilot

Table 1 Results of literature based study—conflicts in assembly and disassembly processes

Products (Mechanical assemblies)	Assembly process	Disassembly process	Conflicts	Causes of conflicts
Rivet in Aircraft structure (from literature [20])	Rivet is passed through the holes in the parts and then forming (upsetting) a second head in the pin on the opposite side The deforming operation can be performed hot or cold and by hammering or steady pressing	Support the structure to prevent distortion and permanent damage to the remainder of the structure Undercut rivet heads by drilling Drilling must be exactly centered and to the base of the head only After drilling, break off the head with a pin punch and carefully drive out the shank Inspect rivet joints adjacent to damaged structure for partial failure	More effort and longer time to disassemble than to assemble	Use of many disassembly tools (bucking bar, drill, pin punch) Fastener design did not consider disassembly. (deforming the second head)
Retaining ring in Gear assembly (from literature Ref 21)	Installation is manually carried out using hammer	These rings with no lug holes are impossible to remove without either destroying the ring or warping it out of specified tolerances Once installed, the rings become tamper proof and make it difficult to be removed.	More effort to the extent of destruction is required in disassembly unlike in assembly.	Fastener design did not consider disassembly (e.g. without lug holes). Becomes tamper proof
Shrink fit in Shaft hub assembly (from literature Ref 22)	The external part is heated to enlarge by thermal expansion, and the internal part either remains at room temperature or is cooled to contract its size The parts are then assembled and brought back to room temp so that external part shrinks and internal part expands to form a strong interference fit	If evenly distributed heat is used to remove parts from shafts. This will increase the time cycle and create heat buildup in the shaft that can result in both parts expanding thus causing difficulty in removal. In this case, it is often best to shock that particular component with a rapid heat. This should be done carefully to prevent expansion of both the parts	More effort to disassemble than to assemble	Evenly distributed heat leading to expansion of both parts Accessibility and visibility influence the shock given since shock needs to be given only for a particular component

Table 2 Results of questionnaire based study—conflicts in assembly and disassembly processes

Products	Assembly process	Disassembly process	Conflicts	Causes of conflicts
Welding in Levers (from questionnaire)	Connection between parts to be welded is established using an agent that together with the material of the parts undergoes phase transition	Usually destructive disassembly is used to separate welded joints	More effort and longer time to disassemble than to assemble	Difficult to access the parts Low clearance for tooling
Cotter and nut in Bicycle pedal crank (from questionnaire)	Slide in pedal crank into axle	The process of removal of the cotter from the pedal crank requires reversal of the tight fit between them	More effort and longer time to disassemble than to assemble	Corrosion
	Align cotter into the pedal and hammer it for tight fit	Since they had rusted and joined up with each other, power drill was used to drill out		
	Screw in the nut on to the cotter from other end of the cotter head	Cotter and pedal got damaged while trying to separate them		
Snap fit in Laptop Key (from questionnaire)	Used fingers to carefully engage the projection in one part to other	Used nail to force open the snap fit. However, it was difficult to take apart	More effort to disassemble than to assemble.	Parts were hidden. Joints were invisible Structure was delicate to handle
Snap fit in Wrist watch (from questionnaire)	A small hammer was used to establish snap fit between back cover and dial of the watch	A strong blade was to disassemble	More effort to disassemble than to assemble	Low clearance for tooling Fit design has little. consideration to disassembly (back cover and dial are almost jammed)

study that was conducted with data collected using a semi-structured questionnaire (with both open and close-ended questions) among Masters and PhD students with formal engineering training at Indian Institute of Science and in some cases with industrial experience; the students were asked about products known to them that have conflicts among assembly and disassembly processes, and according to the subjects, what the causes might have been. Three products (each of them a mechanical assembly) from literature and associated information about their assembly and disassembly processes, were selected for analysis. A further four products from participants in the questionnaire survey, feedback on these from 12 participants on 12 questions (answered over a period of 15 days) are also analyzed. The results from these seven products are shown in Tables 1 and 2, respectively.

5.1 Results and Discussion

The above studies showed the existence of conflicts among assembly and disassembly processes of existing products. In all cases, conflicts seemed to occur in the amount of effort and/or the time required to carry out assembly and disassembly processes. Causes behind the effort and/or time to disassemble are interpreted to be among the following:

Design Issues

1. **Fasteners** The fastener or fit design did not consider (or considered little) the disassembly requirements. Additional conflicting requirements (e.g. tamper proof) forced the design to be difficult to disassemble.
2. **Product architecture** Accessibility and visibility of parts and joints were low, or structure of parts was delicate to handle during disassembly.
3. **Materials** Rust formed due to corrosion and made disassembly difficult.

Other Issues

1. **Tooling** Use of many tools, and/or low clearance for tooling made disassembly difficult.

6 Conclusions and Future Work

Existing products were analyzed for conflicts among assembly and disassembly processes using two studies. It seemed that conflicts occurred in the amounts of effort and/or time required to carry out the assembly and disassembly processes. Various causes for these conflicts were identified: these came either from the product (parts, interfaces and their materials), or from joining elements or associated tools. The study indicates that conflicts exist among assembly and disassembly processes, and all of the causes identified could be addressed during the design process. However, this is only a pilot study, with relatively few subjects and products, and with subjects who are not assembly/disassembly professionals. The goal is to expand this study into a comprehensive study involving professional engineers and assemblers from industry.

Acknowledgments I would like to acknowledge the research students of IDeaS Lab and Masters students of VDS Lab, CPDM, IISc for participating in the study conducted using the questionnaire.

References

1. Motevallian B, Abhary K, Luong L, Marian RM (2007) Integration and optimisation of product design for ease of disassembly. In: Dudas L (ed) Engineering the future, Sciyo, pp 317–340. ISBN 978-953-307-210-4. doi:10.5772/291
2. Alting L, Legarth JB (1995) Life cycle engineering and design. Annals ClRP 44(2):569–580
3. Veerakamolmal P, Gupta SM (2000) Design for disassembly, reuse and recycling. Environmentally responsible engineering. Butterworth-Heinemann, Oxford, pp 69–82
4. Gkeleri VP, Tourassis VD (2008) A concise framework for disassemblability metrics. In: IEEE, 2008
5. Chiu MC, Kremer GEO (2011) Investigation of the applicability of design for X tools during design concept evolution: a literature review. Int J Prod Develop 13(2):132–167
6. Brennan L, Gupta SM, Taleb KN (1994) Operations planning issues in an assembly/ disassembly environment. Int J Oper Prod Manage 14(9):57–67
7. Desai A, Mital A (2003) Evaluation of disassemblability to enable design for disassembly in mass production. Int J Ind Ergon 32:265–281
8. Kroll E, Hanft TA (1998) Quantitative evaluation of product disassembly for recycling. Res Eng Des 10:1–14
9. Boothroyd G, Alting L (1992) Design for assembly and disassembly. Annals of CIRP 41:625–636
10. Jovane F, Alting L, Eversheim W, Feldmann K, Seliger G, Roth N (1993) A key issue in product life cycle: disassembly. Annals ClRP 42(2):651–658
11. Penev kD, De Ron AJ (1996) Determination of a disassembly strategy. Int J Prod Res 34(2):495–506
12. Gupta SM, McLean CR (1996) Disassembly of products. Comput Ind Eng 31:225–228
13. Shu LH, Flowers WC (1995) Considering remanufacture and other end-of-life options in selection of fastening and joining methods. In: IEEE, 1995
14. Harjula T, Rapoza B, Knight WA, Boothroyd G (1996) Design for disassembly and the environment. Annals ClRP 45(7):109
15. Lee K, Gadh R (1996) Destructive disassembly to support virtual prototyping. IIE J Des Manuf 30:359–72
16. Srinivasan H, Gadh R (1997) Virtual selective disassembly: a geometric tool to achieve net positive environmental value. In: 30th ISATA, Florida, Italy
17. Srinivasan H, Shyamsundar N, Gadh R (1997) A Virtual Disassembly Tool to support environmentally conscious product design. In: IEEE, 0-7803-808-1
18. Westkamper E, Feldmann K, Reinhart G, Seliger G (1999) Integrated development of assembly and disassembly. Annals ClRP 48(2):557–585
19. Nof SY, Chen J (2003) Assembly and disassembly: an overview and framework for cooperation requirement planning with conflict resolution. J Intell Rob Syst 37:307–320

20. AFS-640 (1998) Acceptable methods, techniques, and practices aircraft inspection and repair, Title 14 of the code of federal regulations (14 CFR) guidance material : Advisory Circular 43.13-1B /U S Department of Transportation; Federal Aviation Administration. pp 4–12
21. Ref 1: Retaining ring from Wiki - http://en.wikipedia.org/wiki/Retaining_ring
22. Ref 2: Induction shrink fitting from Wiki - http://en.wikipedia.org/wiki/Induction_shrink_fitting
23. Giudice F, La Rosa G, Risitano A (2006) Product design for the environment: a life cycle approach. CRC/Taylor & Francis, Boca Raton, p 348

A Conceptual Platform to View Environmental Performance of a Product and Its Usage in Co-Design

Srinivas Kota, Daniel Brissaud and Peggy Zwolinski

Abstract All the stakeholders in product life cycle needs to work together to achieve best possible sustainable solution. User perspectives need to be considered in design, for products to be sustainable in use. Literature review and empirical studies helped in identifying requirements to include user perspectives in design. An activity model is developed after thoroughly studying the usage of electric kettle. In this paper we propose a computer aided conceptual platform to visualize and interact with the product in virtual environment by the user for performing basic activities in use of that product. The platform also supports designer to create product and its usage scenarios based on requirements' from users. It also captures and stores the data generated while user performs the activities virtually for assessment. This is achieved with the help of 3D stereo display, motion capture devices and visualization tool kits. A questionnaire is planned to obtain designer and user feedback on the platform to evaluate the support.

Keywords Eco-design · Co-design · User centered design · 3D visualization · Use · Activity

S. Kota (✉) · D. Brissaud · P. Zwolinski
Grenoble-INP/UJF-Grenoble 1/CNRS, UMR5272 G-SCOP Laboratory,
Grenoble 38031, France
e-mail: srinivas.kota@g-scop.inpg.fr

D. Brissaud
e-mail: Daniel.Brissaud@g-scop.inpg.fr

P. Zwolinski
e-mail: Peggy.Zwolinski@g-scop.inpg.fr

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_45, © Springer India 2013

1 Introduction

Eco-friendly characteristics of the product and the stake holders throughout the life cycle need to be considered from the requirements through detail design to develop eco-friendly products. This calls for different stakeholders with different perceptions work simultaneously. Pre-use and post-use phases in product lifecycle are influenced by use phase via user and usage; hence this research focuses on those. Designer has to take into account user and usage in design, as products are designed for use. User has to provide usage requirement scenarios and subsequently help in test and feedback for improvement. Designer and user needs to work together to achieve best possible solution, this needs new methods to support different perspectives of different stakeholders in design.

Life Cycle Assessment (LCA) [1] is a proven approach for determining the environmental impact and needs experts for interpretation of assessment results. It needs detailed information about processes due to which impact is generated. As usage determines the information about the processes in use it needs to be observed. Required information can be captured based on this observation. Virtual Reality especially 3D visualization and interaction can help in this regard. When the environmental impact results are shown to users and designers, these impacts need to be filtered as the users and designers have varied interests and skills. For example, if environmental impact is conveyed in points, which is the measurement in Eco-indicator'99 which is one of the methodologies used in LCA for calculating environmental impact to user it won't make any sense as the user is not aware of the methodology.

Designers develop products based on user requirements. Users perform activities using products that results in environmental impact during use phase. Actual usage environmental impact varies a lot from designed usage as the products are designed for ideal use and in reality it is not so. It will be good to see the impact based on actual usage in design so that impact can be minimized by changing design.

The following sections report the research carried out on understanding the requirements of stakeholders in use phase and proposing a conceptual support to fulfill the requirements. Literature review (Sect. 2) helped in general understanding and establishing the need for a support in use, empirical studies on electric kettle helped in understanding the multiple stakeholders' requirements in use phase (Sect. 3). Based on these requirements, a platform is proposed in Sect. 4 and discussion about evaluation is detailed in (Sect. 5).

2 State of the Art

Lifecycle thinking helps in thinking holistically about the whole product lifecycle and its stakeholders. The use phase of energy consuming products is very important towards reducing environmental impact, as 80 % of the environmental impact occurs in that phase [2]. Studies highlight the importance of the reporting of valid alternative usage phase scenarios; the lack of rigor and justification for this step can indeed be significantly detrimental to the validity of LCA results [3]. Most of the authors and practitioners point to the need for methods to define usage scenarios; which are scarcely found in LCA studies. This is an obstacle to the truth of results of some LCA.

In practice, users have their own way of using products and it results in varied impacts [4, 5]. The data used in assessment were often extremely simplified and defined arbitrarily due to complexity and diversity involved in use phase. The data is generalized and solutions are generated for generic requirements which have wide scope in determining impact in usage. Normally requirements are considered while developing solutions, but the solutions depend on many factors including context, actual actions etc. The impact is going to change based on variety of factors which needs to be considered while developing solutions [6]. It is important to instrument designers with tools that model the user characteristics and use phase scenarios of the product.

Research towards studying and influencing user behaviour through design measures is reported in literature [7]. Studies done to see how some strategies like on product information (OPI) and explicit ecological instruction affect the usage [8]. But to conduct these kinds of studies, we need multiple physical prototypes with respective strategies. In actual practice these studies are limited as they are costly, time consuming and require lots of effort. The situation can be improved by providing the product and strategies in virtual environment so that a number of concepts and use scenarios can be explored with little effort, time and money to achieve those. Various representations of users with highlighted behavioral characteristics that influence the environmental performance of products in use phase need to be identified by different exercises using users. This will help in producing, consuming and disposing products in a sustainable way.

Virtual reality [9] gives experience to several senses without the presence of real object. The environment can be non-immersive (3D display) or semi-immersive (HMD) or fully immersive (CAVE) with visual [10], tactile and audio technologies. The capabilities of the systems depend on resolution, interference, and lag. The decision to opt for any of these systems should consider set up time, ease of use, and cost.

Virtual reality is being used successfully in different domains: manufacturing [11], architecture, automobile, aerospace, and retail [12] for different purposes. Virtual reality is also successfully used in making 3D annotations in collaborative environments [13] for design. Methodologies like VRID [14] and [15] developed to guide the creation of virtual reality interfaces. Work is also reported on successfully combining conventional CAD and Virtual reality [16].

Co-design can help development of environmentally friendly use by supporting generation and evaluation of concepts, user preferences, and use scenarios with user inputs. This requires supporting multiple views, interactions of product and user in usage at the same time. Virtual reality can support co-design efficiently by showing multiple views of different aspects of real world complex situations [17]

Fig. 1 Generic kettle parts *Source* http://karisimby.wordpress.com/2009/08/09/parts-of-a-kettle/

to different stakeholders for analysis at the same time. Computerized tools ease design and assessment by helping in capture, manipulation and communication of the required data iteratively. Advanced visualization and interactive equipment are needed to achieve these objectives. Successful use of Kinect, an advanced skeletal motion capture device is reported in [18] for querying and visualization of complex datasets. Next section details the empirical studies done for identifying requirements that need to be supported.

3 Empirical Studies

Empirical studies were performed to understand better, the use phase in terms of its constituents, characteristics of its constituents, and interactions [19] among its constituents. A device which has impact in use is studied for requirements to be satisfied, functions which fulfill the requirements, behaviour of different constituents and required structure to achieve those.

Generic electrical kettle for producing hot water for making tea is used in this study. The kettle and its use are studied thoroughly. Figure 1 shows the individual components of the structure of the kettle. The kettle consists of power cable (1), base (2), water container (3), handle with lid top and on/off switch (4), heating element (5), removable filter (6), bottom of base (7), lid bottom (8), lid release button (9), lid release spring (10), rubber seal (11), kettle control, switch and thermal fuse (12), LED (13), and bi-metallic disk (14). Apart from these shown in figure kettle also comes with cardboard packing box and usage manual.

Different stakeholders were involved in the use phase of the kettle; Retailer (who sells), Buyer (who buys), User (who uses), Maintainer (who maintains can be

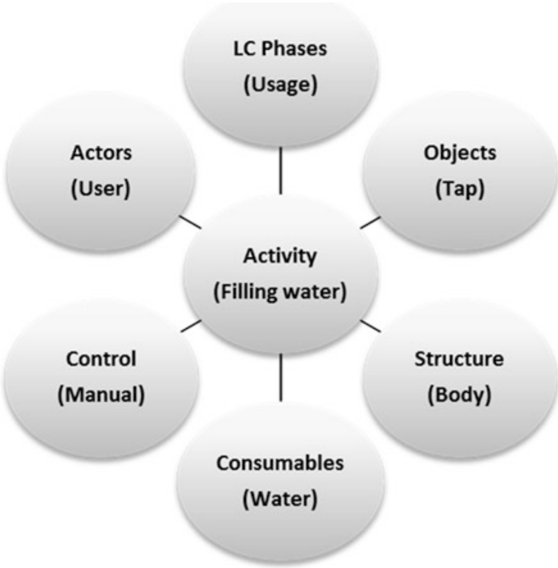


Fig. 2 Factors influencing *filling water activity* in use

user or a different person), Repairer (who repairs), Collector (who collects after use), which are all *actors* performing actions.

The use of the kettle need to be supported by other products (*objects*) like surface on which kettle is placed (table), place where kettle is cleaned (sink), (sponge) with which kettle is cleaned, (tap) from which water is filled, (cup) to which water is poured, (coffee machine) alongside which kettle is placed. Other elements which are consumed (*consumables*) in the process are water, energy, detergent, vinegar, tea which influence the usage.

The *activities* involved in use phase are: making place for kettle, removing packing, reading manual, unwinding the cable, placing the base, connecting the plug, removing any stickers/packing items (till here the activities corresponds to *installation*), opening lid, filling water, rinsing kettle, closing the lid, keeping kettle on base, pressing on/off switch, taking cup, taking tea packet, placing tea packet in the cup, pouring hot water from kettle after boiling, keep kettle on base, adding sugar, disposing tea packet, drinking tea, cleaning cup (these activities are in *usage*), rinsing, wiping, removing scales (corresponds to *maintenance*), fixing chord, replacing parts (*repair* subphase), taking back, donating, reselling (*dispose*). Some of the activities in use are dependent on the *control* (manual/programmable/ automatic) determined by the product's design.

Figure 2 shows an instance at which an activity is influenced by different elements; In usage sub phase, user is performing an activity of filling water into the body from tap and the activity is manually performed. The same activity can be

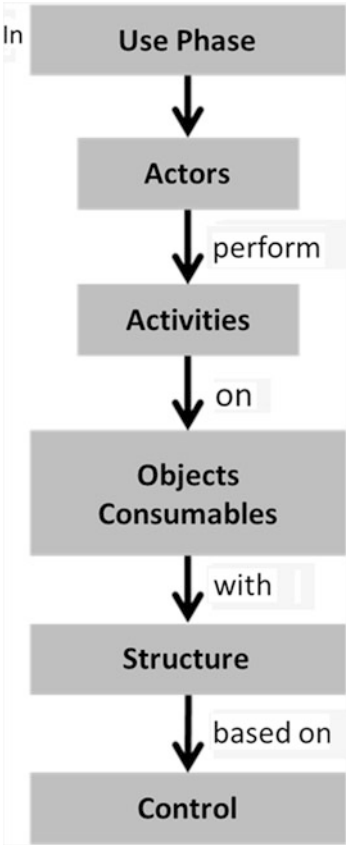


Fig. 3 Activity based model in use phase

differently performed based on the control and will be influenced by objects, structure and consumables. Figure 3 shows the activity based model in use phase; in *use phase*, *actors* perform *activities* on *objects*, and *consumables* with *structure*, based on *control* provided. These are defined as follows:

Life Cycle Phase: A distinctive phase of product life from raw material extraction through after use of the product under consideration.
Actors: Stakeholders involved in each phase of the product life cycle.
Activities: Actions performed by the actors throughout the life cycle of a product. Object: A non-consumable physical entity other than the product used in an activity.
Consumable: a consumable entity other than the product used in an activity.
Structure: Physical construction of the product throughout the life cycle.
Control: Way in which product can be operated.

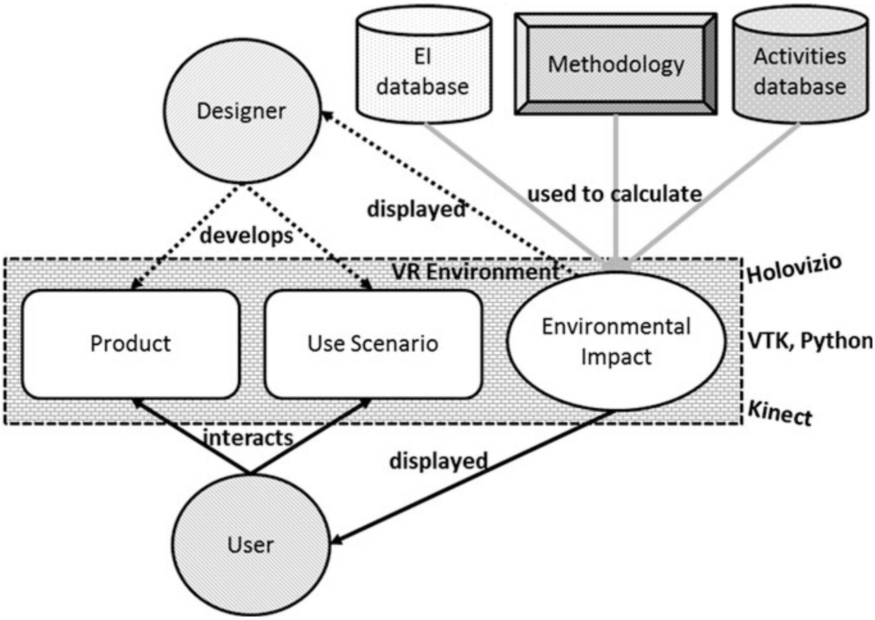


Fig. 4 Proposed platform architecture

4 Platform

The proposed platform will support designer to create and manipulate multiple concepts and scenarios for evaluation by users. It will also support users to use the product virtually for performing basic activities. Information regarding the status of objects, consumables and structure will be collected from the activities performed by user based on the control provided on the product. The support will also help in showing the impacts based on the above information to user and designer so that they can interpret and understand the consequences effectively. Illustrative 3D visualization and interaction of product, activities and the associated environmental impact by users and designers should help in better understanding of the product, users, and strategies during use phase.

The platform uses Holovizio 3D display [20] to show the product in virtual environment to the user and designer via user mode and designer mode. The interactive capability will be achieved by Kinect (a motion capture device) for performing basic activities by users. These two modes will have relevant characteristics based on requirements from users and designers. In Use phase the impact will be calculated based on activities performed and the severity of the results will be shown and explained per activity via intensity of the colour and depth in 3D.

The support can also provide facility to capture requirements, evaluate and select requirements, link between requirement & functions, help in performing activities, record the activities and their characteristics, calculate impact based on data from activities, life cycle databases and impact categories, and shows impact visually. Figure 4 shows the modules in the intended platform. The modules, people (designer and user), product, use, environmental impact visualization will be front-end of VR environment and other modules, like environmental impact database, methodology for assessment and database of activities which will be used in calculating environmental impact before showing to designer and user will be back-end. This platform is going to be implemented using visualization tool kit (VTK) in python programming language with Holovizio display unit and a motion capture setup.

5 Discussion

The platform will be evaluated by asking users to do set of tasks depending on different designs using the support and see how the designs and users contributing to the environmental impact based on different design characteristics and user activities. User feedback on interaction with the product using the proposed support will be collected by a questionnaire to evaluate the usability and effectiveness of the support.

The following will be evaluated using a questionnaire: Given a support to see how the different eco-design strategies actually (virtually) work instead of making prototype. See if providing the product and performing actions virtually help in determining the associated environmental impact (EI) effectively.

- Develop CAD model
  - Without temperature control (auto-off after boiling)
  - With temperature control (stepped/exact)
- Develop use environment
  - With interaction/Without interaction
- Capture details like
  - How many times device is used (allow user creation)
  - How long (show actual time in sec/min on kettle)
  - What capacity each time (Exact/Premeasured (1cup/2cups…etc.))
  - What temperature (Boil/Exact/Switched-off at will)
- Observe and measure
  - User satisfaction level

Can all the relevant actions be performed

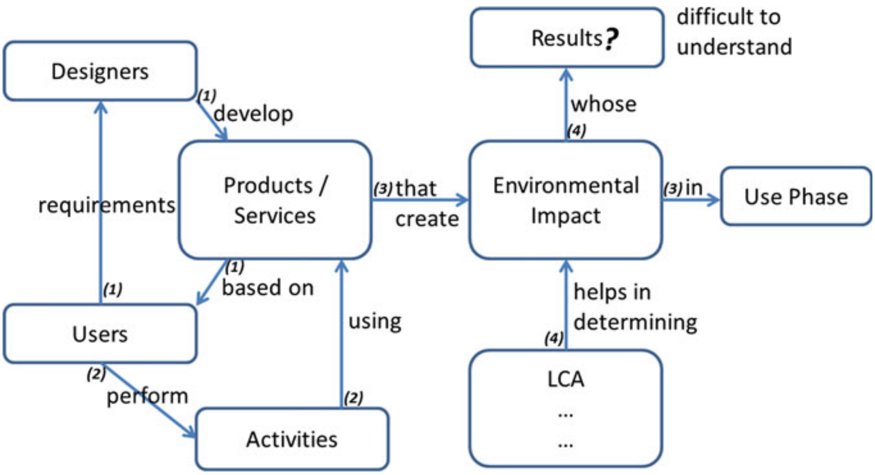


Fig. 5 Current situation

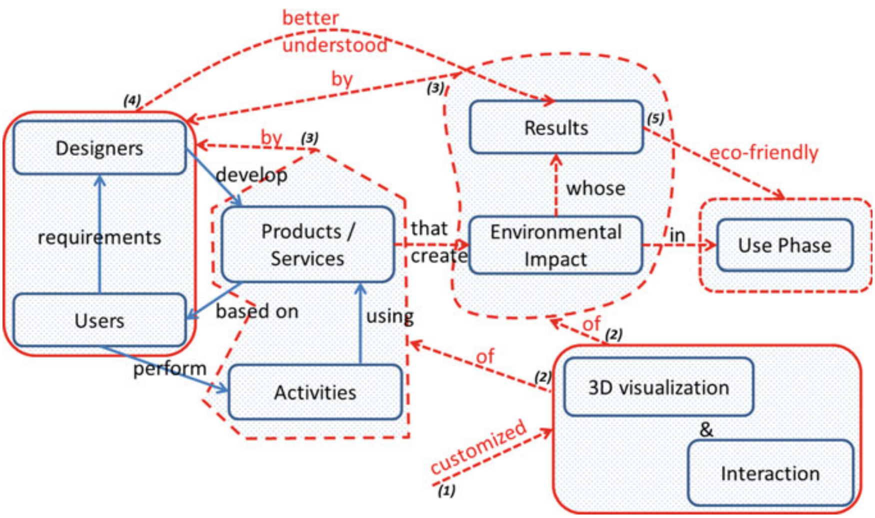


Fig. 6 Future situation

How satisfactorily each action can be performed

– What is the outcome

Planned (Full/Partial)/Un Planed (Good/Bad)

– Cleaning

After each use (water (hot water/normal water)/detergent)
After number of uses/After number of days

– On product information/display control labels/control positioning

What to display/How to display/where to display
What to give for control/How much control/When to give control/How to give control

– Control

Time
Materials/Energy
Desired output
Conditioned input or any input
Temperature control/sensor/Auto-cutoff temperature

– Use (hot water for (drinking / making (tea / coffee)))

Open tap
Fill the kettle with water (how much)
Press on/off switch (wait for water to boil (how much)
Take cup (clean/unclean)
Dispose tea packet (reuse/dispose)
Clean cup (detergent/no detergent/hot water/cold water)

– Maintain

Rinse with (water/detergent/vinegar) (daily/weekly/per number of uses)
Wipe with (damp cloth/dry cloth) (inner body/outer body) (after each use/daily/weekly)
Remove scales (weekly/bi monthly/monthly)

– Repair

Personal (broken cord etc.)
Service centre (parts broken/not working)

– Dispose

Take back/sell/donate/garbage
Reuse/recycle/incinerate/landfill

- Analyse to see the effect on environment

  Reduction in time / reduction in energy
  Exact temperature / exact amount of water
  User satisfaction in terms of reach / view / strategy

- Calculate impact based on "agreed" categories
- Show impact with and without strategy to user so that he can perceive the importance of the way activities done and steer towards eco-friendly usage

Figures 5 and 6 show the current situation and intended future situation using the platform. Designers develop products/services based on user requirements (1). Users perform activities using products/services (2) that create environmental impact in use phase (3). Life cycle assessment helps in determining the environmental impact whose results difficult to understand (4) that can be detrimental to producing eco-friendly products and their use. We want to better the understanding of the results by introducing customized 3D visualization and interaction of products, activities and associated environmental impacts and thus help in eco-friendly use phase.

The proposed support will lead to future situation in Figure 6 as customized 3D visualization and interaction (1) of products/services, activities and environmental impacts, results (2) by designers and users (3) will lead to better understanding of results (4) which helps in eco-friendly use phase (5)

6 Conclusions and Future work

It is important to bring together designer and user in design and assessment for creating environmentally friendly product usage. There are challenges associated with bringing different stakeholders together and need new methods and technologies to be adapted while developing support. 3D visualization and interaction can help in better understanding of the product and its use and will reduce the ambiguity in environmental impact results by presenting the relevant information effectively. The empirical study helped in identifying the elements and requirements in use phase that lead to development of the activity model. In use, impact is based on activity and it is influenced by actors, structure, objects, consumables and the control provided on the product. The knowledge generated will be used for implementing the conceptual support outlined here. The support will be evaluated using the proposed plan outlined in the discussion section in future work.

Acknowledgments This work is supported by Agence Nationale de la Recherche (ANR, The French National Research Agency) funding (project number: 1081C0212/ANR-10-ECOT-006-01).

References

1. Consoli F (ed) (1993) Guidelines for life-cycle assessment: a 'code of practice. Society of Environmental Toxicology and Chemistry (SETAC), Brussels
2. Wenzel H, Hauschild M, Alting L (1997) Environmental assessment of products, vol 1. Chapman and Hall, London

3. Reap J, Roman F, Duncan S, Bras B (2008) A survey of unresolved problems in life cycle assessment. Int J Life Cycle Assess 13:374–388
4. Cara DB, Rodney AS, Kelly F (2011) A novel mixed method smart metering approach to reconciling differences between perceived an actual residential end use water consumption. J Cleaner Prod doi:10.1016/j.jclepro.2011.09.007
5. Geppert J, Stamminger R (2010) Do consumers act in a sustainable way using their refrigerator? The influence of consumer real life behaviour on the energy consumption of cooling appliances. Int J Consum Stud 34(2):219–227
6. Zhou F, Xu Q, Jiao RJ (2011) Fundamentals of product ecosystem design for user experience. Res Eng Design 22:43–61
7. Sauer J, Wiese BS, Ruttinger B (2002) Improving ecological performance of electrical consumer products: the role of design-based measures and user variables. Appl Ergon 33(4):297–307
8. Sauer J, Wiese BS, Ruttinger B (2003) Designing low-complexity electrical consumer products for ecological use. Appl Ergon 34(6):521–531
9. Lu SCY, Shpitalni M, Gadh R (1999) Virtual and augumented reality technologies for product realization. Annals CIRP 48(2):471–494
10. Ronchi AM (2009) Date visualization and display technologies in ECulture: cultural content in the digital age. Springer, Berlin, pp 113–137
11. Sadeghi S, Masclet C, Noel F (2012) Gathering alternative solutions for new requirements in manufacturing company: collaborative process with data visualization and interaction support. In: 45th CIRP conference on manufacturing systems, 16–18 May 2012, Athens, Greece
12. Guidi G, Micoli LL (2011) A semi-automatic modeling system for quick generation of large virtual reality models. In: Proceedings of the ASME world conference on innovative virtual reality WINVR2011, 27–29 June, 2011, Milan, Italy
13. Lenne D, Thouvenin I, Aubry S (2009) Supporting design with 3D-annotations in a collaborative virtual environment. Res Eng Design 20:149–155
14. Tanriverdi V, Jacob RJK (2001) VRID: a design model and methodology for developing virtual reality interfaces. In: VRST'01, 15–17 Nov 2001, Banff, Alberta, pp 175–182
15. Weidlich D (2007) Virtual reality approaches for immersive design. Annals CIRP 56(1):139–142
16. Stark R, Israel JH, Wöhler T (2010) Towards hybrid modeling envrionments-merging desktop-cad and virtual reality technologies. CIRP Annals—Manuf Technol 59:179–182
17. Cabral M, et. al. (2007) An experience using X3D for virtual cultural heritage. In: Web3D, 15–18 April 2007, Perugia, Italy, pp 161–164
18. Hirte S. et. al. (2012) Data3—a kinect interface for olap using complex event processing. In: IEEE 28th international conference on data engineering, 1–5, April, 2012, DC, USA, pp.1297–1300
19. Chen LH, Lee CF (2008) Perceptual information for user-product interaction: using vacuum cleaner as example. Int J Des 2(1):45–53
20. http://www.holografika.com/Products/HoloVizio-128WLD.html

Design of Product Service Systems at the Base of The Pyramid

Santosh Jagtap and Andreas Larsson

Abstract The Base of the Pyramid (BoP) consists of about two-fifths of the world population. This population can be categorized as poor with income of less than 2 dollars per day. It is important to alleviate poverty. One of the promising approaches to tackle the wicked problem of poverty is business development combined with poverty alleviation. In this approach, integrated solutions are necessary in order to address the diverse issues in the BoP. These integrated solutions are in the form of product service systems (PSS) rather than the conventional product-oriented or service-oriented solutions. In this paper, we explore different issues that need to be addressed in the PSS design at the BoP. We have also explored strategies used in this PSS design. We have used a case study to explain these issues and strategies. In addition, we have identified salient characteristics of the PSS design at the BoP.

Keywords Product service systems · Design at the BoP · Design for sustainability

1 Introduction

The base of the world income pyramid, generally called the 'Base of the Pyramid' (BoP), consists of poor people. About two-fifths of the world population can be categorized as poor. Their income is less than 2 dollars per day. Many researchers

S. Jagtap (✉) · A. Larsson
Innovation Engineering, Department of Design Sciences, Faculty of Engineering, Lund University, Lund, Sweden
e-mail: Santosh.Jagtap@design.lth.se

A. Larsson
e-mail: Andreas.Larsson@design.lth.se

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_46,

prefer the poverty line of 2 dollars per day [1]. About a fifth of the world population is classified as extremely poor with income of less than 1.25 dollars per day.

Poverty is multifaceted, and has three intertwined characteristics as follows [1]: (1) Lack of income and resources required to satisfy basic necessities such as food, shelter, clothing, and fuel; (2) Lack of access to basic services such as public health, education, safe drinking water, sanitation, infrastructure, and security; and (3) Social, cultural, and political exclusion.

1.1 The Fight Against Poverty

It is important to alleviate poverty. Poverty is a trap—children born to poor parents are likely to grow up to be poor adults. Mahatma Gandhi often said—poverty is the worst form of violence.

Karnani [1] has analysed poverty reduction approaches. Since the 1990s, three different poverty reduction approaches have received attention. The first approach, namely 'microcredit', envisioned by Muhammad Yunus in Bangladesh, suggests that granting small loans to the poor can help them to grow their businesses, and thereby can help them to climb out of poverty [2]. The second approach of granting formal property rights to the poor was formulated by the Peruvian economist Soto [3]. The underlying principle of this approach is that property rights will give the poor access to credit, and thereby will help in poverty reduction. The third approach, popularised by the late Prahalad [4] proposes solutions involving business development combined with poverty alleviation. These solutions, consisting of business strategy, focus on the poor people as producers and consumers of products and services. The third approach can use the elements of the first approach (i.e., microcredit), and is powerful as it efficiently uses the resources of businesses.

1.2 Business Development Combined with Poverty Alleviation

In this paper, we focus on the third approach of business development combined with poverty alleviation. According to Prahalad and Hart [5], the most visible and prolific writers in the area of the BoP, this business strategy is important in "…lifting billions of people out of poverty and desperation, averting the social decay, political chaos, terrorism, and environmental meltdown that is certain to continue if the gap between rich and poor countries continues to widen." This suggests that such a business strategy offers a potential approach to meet the challenges of social, economic, and environmental sustainability at the BoP.

1.3 BoP People: Producers and Consumers

In this paper, we focus on the BoP people as producers and consumers of products and services. The businesses at the BoP design and develop products and services to serve the BoP producers, and to market these products and services to the BoP consumers. By focusing the poor as producers, their income can be raised. This can also help to generate employment opportunities for them, and can alleviate poverty. There are two ways to focus on the BoP people as consumers.

- First involves tapping BoP markets by selling products and services to the poor with the primary aim of earning profits. This approach may not be sustainable, and may not help to alleviate poverty. Karnani [6] has rigorously argued that this approach cannot alleviate poverty, and that it can exploit the poor.
- In the second way, businesses aim at the development of the poor and accordingly market appropriate products and services to them. In this approach, innovative solutions are devised to seek financial sustainability combined with the development of the poor.

In this paper, we focus on the second way when the BoP people are seen as consumers.

2 Research Aims and Research Methodology

In the approach of business development combined with poverty alleviation, some interventions are designed, developed and implemented in the BoP. These interventions need to address complexly intertwined issues (i.e. constraints)—such as poor physical infrastructure, lack of knowledge and skills of the poor, etc—in the BoP. In order to address these diverse issues in the BoP through the design and development of interventions, an integrated approach using knowledge from technical, social and management sciences is necessary [7, 8]. In this integrated approach, the interventions take the form of product–service systems (PSS) rather than the conventional product-oriented or service-oriented solutions. PSS consists of a set of products and services that jointly fulfill the needs of users. PSS can reduce the use of resources and the generation of waste as fewer products are manufactured.

While some authors have highlighted the need and importance of PSS at the BoP, much less work has been carried out in this area. In this paper, the following questions are explored.

- What are the different issues that need to be addressed in the PSS design at the BoP?
- What are the strategies used in the PSS design at the BoP?
- What arethe salient characteristics of the PSS design at the BoP?

We have explained these issues and strategies by using a case drawn from the study of United Nations Development Programme (UNDP) [9]. The UNDP led an initiative called 'Growing Inclusive Markets' (GIM). In this initiative, they analyzed several cases from different sectors (e.g., energy, healthcare, etc.) and countries. In order to explain the issues and strategies in the PSS design at the BoP, we selected one case from the UNDP study. This case is about a project where a for-profit company, Afrique Initiatives, used Information and Communication Technologies (ICTs) to monitor health conditions of children from low-income families in Mali.

Based on our literature review in the area of the BoP, we have identified some salient characteristics of the PSS design at the BoP.

3 PSS Design at the BoP: Issues and Strategies

In our prior research, we synthesized issues and strategies in the PSS design at the BoP [8, 10, 11]. We pulled together issues and strategies in this PSS design from the reviewed literature [5, 6, 12, 13]. We compared these issues and strategies with those identified in the UNDP study [9]. We used this UNDP study as a reference because the sample size of cases analysed in this study is large, and these cases are drawn from different sectors and countries. Our research identified that the issues and strategies of the UNDP study are comprehensive and include those identified in the reviewed literature.

3.1 Issues in PSS Design at the BoP

The issues in PSS design at the BoP are as follows.

- *Market information* This issue takes into account the knowledge of businesses regarding the BoP, for example, what the poor need, what capabilities the poor can offer, etc. Businesses often lack detailed information about the BoP markets and in particular about the rural BoP. The presence of intermediaries (e.g., market research, rating services) to consolidate or distribute information on the BoP cannot be assumed.
- *Regulatory environment* The regulatory frameworks are under- or un-developed in the BoP. In addition, enforcement of the existing rules is inadequate. Complying with the bureaucracy in developing countries can be time consuming and monetarily expensive. For example, in the Latin America and the Caribbean, opening a business takes about 73 days, and in Organisation for Economic Co-operation and Development (OECD) countries, it takes on average 17 days [9].
- *Physical infrastructure* This issue considers the inadequate infrastructure (e.g., roads, electricity, water and sanitation, hospitals, etc.) in the BoP.

In developed countries, the logistics system that is necessary for accessing consumers, selling to them, and servicing products exists, and only minor changes may be required for specific products. In the BoP, the existence of a logistics infrastructure cannot be assumed. PSS at the BoP need to work in hostile environment (e.g., noise, dust, abuse of products).

- *Knowledge and skills* The poor, generally, are illiterate and do not possess knowledge and skills regarding the availability of products, usage of products, etc. Furthermore, this lack of knowledge and skills inhibits them from starting their own businesses. PSS design at the BoP needs to take into account the skill levels of the poor. The heterogeneity of the BoP regarding language, culture, skill level, and prior familiarity with the functions or features of the PSS can be a challenging task in the PSS design.
- *Access to financial services* The poor lack access to credits, insurance products, and banking services. This puts limits to the purchases made by them. In addition, they cannot protect their meager assets from events such as illness, drought, etc. The PSS design at the BoP must take into account the price-performance relationship.

3.2 Strategies in PSS Design at the BoP

The strategies in PSS design at the BoP are as follows.

- *Adapt products and processes* This strategy includes product redesign, business model innovation, and technological adaptation. PSS design at the BoP can benefit from technological 'leapfrogging'—that is—avoiding intermediate steps to replace poor technology with the state of the art. While technology helps to deal with the daunting challenges in the BoP, it needs to go hand-in-hand with innovations in business models.
- *Invest in removing market constraints* This strategy includes investing for: educating consumers; enhancing or building capacities of the poor (e.g., supporting small producers who form a part of the supply chain); and building social marketing (e.g., health campaigns to increase demand of malaria nets).
- *Leverage the strengths of the poor* This strategy builds on the knowledge, networks, and abilities of the poor and their communities (e.g., developing cooperatives of the poor, employing the poor to fulfill some tasks of a business, leveraging the knowledge of the poor to design and develop PSS).
- *Combine resources and capabilities* Through collaborations and partnerships, this strategy combines resources and capabilities of different organizations such as businesses, NGOs, charitable sector, local governments, etc.
- *Engage in policy dialogue with governments* Businesses can overcome different issues in the BoP by engaging in dialogue with relevant governments, and this can help, for example, to formulate appropriate regulations, reduce bureaucracy, etc.
- PSS design at the BoP uses one or more of these above five strategies, which address one or more of the applicable issues.

4 Case Study: Pésinet's PSS in Healthcare Sector from Mali

In Mali, one child out of five dies before fifth birthday, and about 43 % of children are underweight. There is limited access to modern healthcare. The limited number of trained doctors and nurses worsen the problems. Furthermore, 40 % of the population lives more than 15 km away from a health facility.

More than 50 % of child mortality in Africa can be prevented. 55 % of children's mortality-causes can be detected easily by periodically checking basic symptoms, for example the evolution of the weight of a child, which is an accurate indicator of young child's health status. Patients in Africa usually come too late to a doctor. If diseases are detected and treated earlier on, mortality can be substantially reduced. This can also avoid risky and expensive emergency treatment, and health spending for households would be lower.

Afrique Initiatives, a for-profit company, focuses on investing in small- and medium-sized African businesses in order to promote sustainable enterprise and private sector development. Afrique Initiatives has the following main focus areas: education and training, nutrition, health, and information technologies (IT). Afrique Initiatives established an organisation called Pésinet with the aim of monitoring health conditions if children from low-income families. Pésinet implemented an intervention in Coura, a region near the capital city Bamako in Mali. The challenges faced by the people in this region are: malaria, low income, poor or no literacy, poor sanitation, and lack of adequate water supply infrastructure. Affordability is a crucial issue as the average income of the families in this region is less than 4 US dollars a day.

This intervention, implemented by Pésinet in the region Coura, monitored health conditions of children in that region, and helped to reduce child mortality rate. This intervention addressed the complexly intertwined issues in the region. The success of this intervention can be attributed to the fact that it was in the form of a PSS rather than the conventional product-oriented or service-oriented solutions. Cocreation played an important role in the design and development of this PSS. Pésinet cocreated the PSS with the following partners.

- A drug distributor, Medex from Mali
- The people from the region Coura
- An NGO, Kafo Yeredeme Ton from Mali
- Two French universities, ESSEC Business School and Ecole Centrale Paris
- Two major French telecommunications companies, Alcatel-Lucent and Orange

4.1 The Broader PSS Concept

In order to monitor health conditions of children in Coura, Pésinet used Information and Communication Technologies (ICTs). The weight of a child is used as an indicator of its health. The pattern in the weight-change is analysed by a doctor to identify anomalies, if any, in the child's health. The child's mother subscribes to Pésinet's services by paying nominal fees. A representative from the Pésinet weighs her child(ren) twice a week. The information on this weight is transmitted to a local doctor using SMS service of mobile phones. After reviewing the weight chart, the doctor requests the visit of the mother and child if any anomalies are identified. Pésinet implemented the project in 2007. This project benefited hundreds of children.

4.2 Elements of the PSS

The elements of the PSS, aimed at monitoring the health conditions of children from Coura, are as follows.

4.2.1 Products

In Mali, there are more mobiles phones than land lines, and this helps to contact remote areas. This fact was used by Pésinet in the PSS design. The products involved the use of ICTs. Required technical systems, consisting of the use of mobile phones and specific applications for data transmission, were designed by Alcatel-Lucent and Orange. The weight reading of a child is sent to a centralized database using these applications. A computer application that can be used by doctors processes this data on weight readings, and presents the evolution of the child's weight in a visual format. The doctor sends an SMS to the Pésinet representative when he/she identifies an anomaly in the evolution of the child's weight. The Pésinet representative then provides the mother with a consultation voucher.

Mali was selected because Alcatel-Lucent and Orange were already settled in the country. Alcatel-Lucent and Orange offered their support to Pésinet on their own, motivated by the 'digital divide' issue. While their involvement was as a part of their Corporate Social Responsibility, Orange gets some profits, as it charges for the SMS sent by the doctors.

4.2.2 Business Model

A team of students from the ESSEC Business School and the Ecole Centrale designed the business plan (e.g., subscription fee-structure to cover the operating costs and child sponsoring for low-income families). In Mali, the subscription fees are 500 Communaute Financiere Africaine (CFA) per month (about US$1.05) and include access to medicines. These fees entirely cover the operation costs, consisting of the Pésinet representatives' and doctor's wages, the scales renewal, the internet connection, medicines, and the salary of one manager. The doctors are employed by public hospitals, and are either directly compensated by Pésinet or indirectly through a financial contribution made to the hospitals.

4.2.3 Marketing and Awareness Program

Pésinet's staff organised small parties to inform the community in Coura regarding issues such as diarrhoea, cholera, etc. In the initial phase of the awareness raising program, the doctors went to the elementary schools and held their consultations with mothers and their children. Pésinet then kept promoting its services through word of mouth and District Associations.

The NGO, Kafo Yeredeme Ton from Mali, raised awareness by carrying out the marketing campaign together with Pésinet, by going door-to-door for a couple of months. The involvement of women community leaders in the programme helped to raise the awareness.

The government and local authorities were informed but not directly involved. The trust of local hospitals in Mali was achieved by informing them that the Pésinet's service would be a complementary service aimed at achieving early monitoring of children, and that the children with health issues would seek help from the regular healthcare system.

4.2.4 Services

Mothers subscribe to Pésinet's service by paying a nominal fee. This service consists of weighing her children once a week at her home (twice a week for children under one) plus advice and treatment (if required) by a doctor. Children are weighed by local women called Pésinet representatives (see Fig. 1). These representatives also register symptoms such as fever, diarrhoea, vomiting, and transmit the data to the doctors using SMS service of mobile phones. The doctor makes a decision regarding the visit of the mother and child based on the pattern in the change of the child's weight. One doctor can cover about 2000 children. When the doctor identifies an anomaly in the child's health, he/she sends an SMS to the Pésinet representative, who requests the mother and child to visit the doctor.

4.3 Transformation

The Pésinet's PSS helped to achieve the following changes of state. The Pésinet's service resulted in approximately 20 consultations per week for 400 children. This service helped mothers to get necessary advice and treatment for their children in a short time-scale.

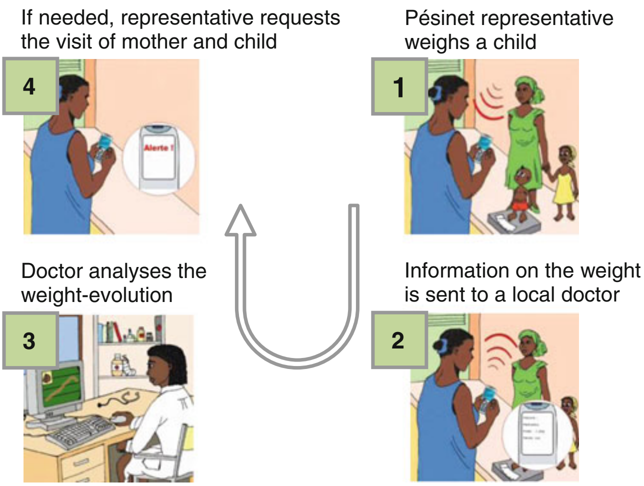


Fig. 1 Service delivery in the case of pésinet's PSS—adopted from: [9], [14]

In September 2000, world leaders adopted the United Nations Millennium Declaration. This declaration is about committing to a new global partnership to alleviate extreme poverty and fulfilling time-bound targets with a deadline of 2015. These targets are known as the Millennium Development Goals (MDGs). One of the MDGs is to reduce child mortality. The changes of state, attributed to the Pésinet's PSS in Mali, can be interpreted as a step towards achieving the MDG of reducing child mortality.

In the case of the Pésinet's PSS in Mali, the UNDP study identified that the PSS addressed the following main issues—'physical infrastructure' (e.g., limited access to healthcare facilities) and 'knowledge and skills' (e.g., poor or no literacy). The study identified that the strategies used in the PSS design were: 'adapt products and processes' (e.g., use of mobile phones to transmit weight reading of a child), 'leverage the strengths of the poor' (e.g., involvement of local women as Pésinet representatives), and 'combine resources and capabilities' (e.g., partnership with Alcatel-Lucent and Orange, two French schools, a drug distributor and a local NGO).

5 Salient Characteristics of PSS Design at the BoP

Vasantha et al. [15] review of PSS design methodologies shows that the PSS design is still in initial stages of development, and that the PSS research is not mature. While most of the studies in the PSS are focused on developed countries, much less work has been carried out in the PSS at the BoP. Based on our literature review in the area of the BoP, we can note some salient characteristics of the PSS design at the BoP.

The PSS design in mature and developed country markets is driven by factors such as: customers want availability or capability rather than the purchasing of physical artefacts [16]; companies can establish long-term relationship with customers [17]; companies can obtain improved knowledge regarding the product use [18]; and growing concerns for the environment. Furthermore, a key criterion for evaluating the PSS in these markets is user experience. In contrary, at the BoP, addressing the complexly intertwined issues requires integrated solutions in the form of the PSS. One of the key aims of the PSS design at the BoP is to alleviate poverty through economic, environmental, and social development. The PSS at the BoP needs to be evaluated using criteria such as: satisfaction of un-met or underserved needs of the poor, increase in their income, a step towards the achievement of one or more of the MDGs, etc.

Cocreation and combining resources and capabilities of different partners including the poor people and non-traditional partners such as NGOs and charitable sector play a crucial role in the PSS design at the BoP (see Fig. 2). This cocreation helps in different stages of the PSS design and development such as: gaining information on BoP markets, sales, distribution, logistics, etc.

In tackling the challenges of poverty, the actors—businesses, governments, and civil society—have tended to view each other through the lens of negative stereotypes: businesses are exploitative, governments are corrupt and inefficient, and civil society is naive and ineffective [1]. The cocreation in PSS design at the BoP is in contrast to this negative stereotype. In this cocreation, the actors take a positive view as follows: businesses have resources and are efficient; governments have the power; and civil society has passion and energy.

Jagtap et al. [11]analysed the data available in the UNDP study to gain quantitative findings on the issues and strategies in PSS design at the BoP. They analysed the data on 48 cases from the UNDP study. One of the key findings of their analysis is that—in the PSS design, the strategy 'combine resources and capabilities' is predominantly used. 65 % of the 48 cases have used this strategy in PSS design.

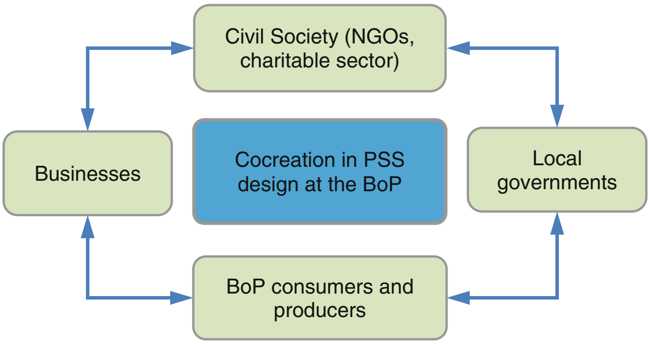


Fig. 2 Cocreation in PSS design at the BoP

Jagtap et al. [11]analysis of the data available in the UNDP study shows that the issue ‘knowledge and skills’ has frequently been addressed in the PSS design at the BoP (79 % of 48 cases). This suggests that this issue is ubiquitous in the BoP. This can be attributed to the prevalent lack of education in the BoP. Although, the field of education appears to be the responsibility of governments, the businesses have generally not used policy dialogue with the governments to address the issue ‘knowledge and skills’. Instead, they have prominently used the strategies ‘invest in removing market constraints’ and ‘combine resources and capabilities’ to address this issue.

6 Summary and Conclusions

One of the promising approaches to tackle the wicked problem of poverty is business development combined with poverty alleviation. In this approach, integrated solutions are necessary in order to address diverse issues in the BoP. These integrated solutions are in the form of PSS rather than the conventional product-oriented or service-oriented solutions.

In this paper, we explored different issues that need to be addressed in the PSS design at the BoP. These issues are: ‘market information’, ‘regulatory environment’, ‘physical infrastructure’, ‘knowledge and skills’, and ‘access to financial services’. We have also explored strategies used in this PSS design. These strategies are: ‘adapt products and processes’, ‘invest in removing market constraints’, ‘leverage the strengths of the poor’, ‘combine resources and capabilities’, and ‘engage in policy dialogue with governments’.

We have explained these issues and strategies by using a case drawn from the UNDP study. This case is about a project where a for-profit company, Afrique Initiatives, used ICTs to monitor health conditions of children from low-income families in Mali.

In some aspects, the PSS design at the BoP appears to be different from that in the mature and developed country markets. The PSS design at the BoP is driven by the need to address complexly intertwined issues in the BoP markets. A key criterion for evaluating the PSS in mature and developed country markets is user experience. In contrary, the PSS at the BoP needs to be evaluated using criteria such as: satisfaction of un-met or under-served needs of the poor, increase in their income, a step towards the achievement of one or more of the MDGs, etc.

Cocreation and combining resources and capabilities of different partners including the poor people and non-traditional partners such as NGOs and charitable sector play a crucial role in the PSS design at the BoP. It is important to understand the process of PSSdesign at the BoP, and this can be an area of future research.The issue ‘knowledge and skills’ is prevalent in the BoP. This issue needs to be addressed in the PSS design, and can pose challenges is cocreation of PSS with the BoP people. There is a need of simple and easy to use methods and tools that can help in the cocreation of PSS with the semiliterate or illiterate BoP people.

Acknowledgments This work was partly financed by VINNOVA within the Product Innovation Engineering program (PIEp).

References

1. Karnani A (2011) Fighting poverty together: rethinking strategies for business, governments, and civil society to reduce poverty. Palgrave Macmillan, New York
2. Yunus M, Weber K (2007) Creating a world without poverty: social business and the future of capitalism. Public Affairs, USA
3. de Soto H (2010) The mystery of capital: why capitalism triumphs in the west and fails elsewhere, New York: Basic Books
4. Prahalad CK (2004) The fortune at the bottom of the pyramid: eradicating poverty through profits. Wharton School Publishing, NJ
5. Prahalad CK, Hart SL (2002) The fortune at the bottom of the pyramid. Strategy and Business 54–54.
6. Karnani A (2007) Misfortune at the bottom of the pyramid. Greener Manage Int 51:99–110
7. Kandachar P, Halme M (2008) Farewell to pyramids: how can business and technology help to eradicate poverty? In: Kandachar P, Halme M (eds) Sustainability challenges and solutions at the base of the pyramid. Greenleaf Publishing Limited, Sheffield
8. Jagtap S, Kandachar P (2010) Representing Interventions from the base of the pyramid. J Sustain Develop 3(4):58–73
9. UNDP (2008) Creating value for all: strategies for doing business with the poor. Available from: http://www.growinginclusivemarkets.org/reports
10. Jagtap S, Kandachar P (2011) Design for the base of the pyramid: issues and solutions. In: International conference on research into design (ICoRD '11), Bangalore, India
11. Jagtap S, Larsson A, Kandachar P (2012) Design and development of products and services at the base of the pyramid: a review of issues and solutions. Int J Sustain Soc (IJSSoc) 5(3)
12. Anderson J, Markides C (2006) Strategic innovation at the base of the economic pyramid [cited 2008 21 November]; Available from: http://www.jamieandersononline.com/uploads/ANDERSON_MARKIDES_SI_at_Base_of_Economic_Pyramid_FINAL.pdf
13. Keating C, Schmidt T (2008) Opportunities and challenges for multinational corporations at the base of the pyramid. In: Kandachar P, Halme M (eds) Sustainability challenges and solutions at the base of the pyramid. Greenleaf Publishing Limited, Sheffield
14. Pésinet [cited 2012 16 March]; Available from: http://www.pesinet.org/wp/
15. Vasantha GVA et al (2011) A review of product–service systems design methodologies. J Eng Desi 23:1–25
16. Military of Defence (2005) Defence industrial strategy. London: Her Majesty's Stationery Office
17. Vandermerwe S (2000) How increasing value to customer improves business results. MIT Sloan Manage Rev 42(1):27–37
18. Alonso-Rasgado T, Thompson G, Elfström B (2004) The Design of functional (total care) products. J Eng Des 15(4):515–540

Re-Assignment of E-Waste Exploring New Livelihood from Waste Management

P. Vivek Anand, Jayanta Chatterjee and Satyaki Roy

Abstract E-Waste is considered as one of the most difficult wastes to manage, not only to reuse and recycle them, but also to detoxicate and make them harmless to the environment. This not only has an effect on the immediate environment, but a lot of valuable metals in E-Waste are getting wasted in landfills. Even recycling, reusing and extracting valuable metals from E-Waste requires special equipment and consumes a lot of energy, contradicting the very reason for effective management of resources. In this paper, the author has explored product re-assignment as a method to handle E-Waste, i.e. making products with E-Waste as the raw material. The author has narrowed his focus to Printed circuit boards (PCBs) for this study and developed methods to handle PCBs and make products using constructive design method. These highly finished, pre-treated and safe products were designed not only to put PCBs to use, but also such that they can be made with basic hand tools (like a drilling machine, hand saw, Pliers, etc.), minimum training and minimum production time; appropriate for cottage industries and to make new and easy livelihood from waste management. Although this paper proposes only products made of PCBs, it concludes with discussing on employing such re-assignment designs on other parts of E-Waste (not only PCBs) and in managing other types of waste.

P. Vivek Anand (✉)
Design Programme Indian Institute of Technology, Kanpur 208016, India
e-mail: ar.anandvivek@gmail.com

J. Chatterjee
Design Programme/Department of Industrial Management and Engineering,
Indian Institute of Technology, Kanpur 208016, India
e-mail: jayanta@iitk.ac.in

S. Roy
Design Programme/Department of Humanities and Social Sciences,
Indian Institute of Technology, Kanpur 208016, India
e-mail: satyaki@iitk.ac.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_47, © Springer India 2013

Keywords Waste · Waste management · E-Waste · WEEE · Printed circuit boards · Reassignment · Curio · Beautility · Constructive design research · Probes

1 The Overview

"Electronic waste" may be defined as discarded computers, electronic equipment, phones, televisions, refrigerators, etc. This can also include used electronics, which are destined for reuse, resale, salvage, recycling, or disposal [2].

Out of 400 million tons of waste produced every year from over 60 identified types of wastes, E-Waste contributes 40 million tons, i.e. 10 % of the total waste produced (2011). And is estimated to reach 93 million tons by the year 2016 (5 years from 2011). [1].

Waste electrical and electronic equipment (WEEE) is one of the fastest growing special waste types with an estimated growth of 3–5 % per year. WEEE is a very heterogeneous waste type that contains many compounds that are considered to be harmful to both humans and the environment, as well as many metals that have the potential of being recycled and reused [2].

1.1 Where is All the E-Waste Going?

E-Waste including extremely hazardous waste like radioactive material, toxic heavy metals and poisonous components are regularly being transported across continents. Most of the E-Waste is being exported to developing countries like India, China, Pakistan and Malaysia [1], as shown in Fig. 1, where laws to protect workers and the environment are inadequate or not enforced. It is also cheaper to 'recycle' waste in these countries.

Landfilling, incineration, recycling, reusing and pulverizing few of the practices followed to treat E-Waste, where landfilling and incineration are highly practiced because they are cheaper and easier. Improper landfilling practices and incineration are extremely harmful for the environment and recyclers working with and around the recycling yards.

2 Understanding the Problem

It is apparent in the earlier paper that a problem exists, and there is a need to handle this effectively in these developing countries. Rather than attributing this problem to nations and laws, the root cause of the problem can be uncovered with reverse investigation, where the user plays a major antagonist in this scenario.

Fig. 1 World's E-Waste export sites [1]

Understanding the life cycle of electronics beyond their usage played a crucial step in the research to get insights to understand the human behavior and to approach the problem. This approach to research with interviews and investigation in constructive design research was conducted to retrieve vital inputs not only in analytical possibilities but also in procuring the raw materials for the constructive studies.

2.1 The Game of E-Waste

For a better understanding, a typical lifecycle of E-Waste was plotted in a board game structure, resembling 'Snakes and Ladders' shown in Fig. 2, where the ladders denote proper usage of the resources; and the snakes denote misuse and wastage of resources. The board game not only can be used as a part of this study but also can be used as a learning tool for all ages about E-Waste.

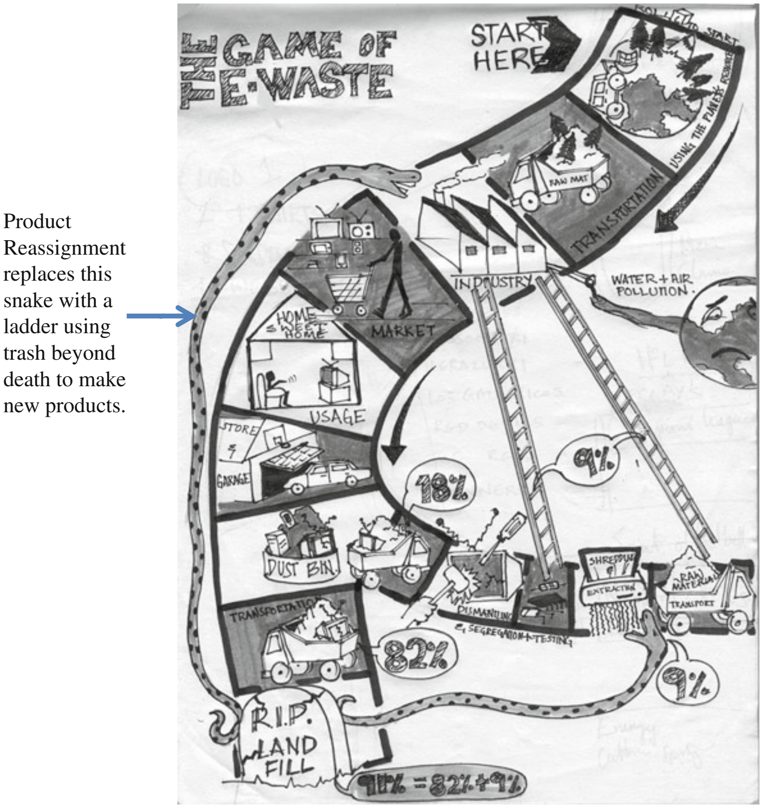


Fig. 2 The game of E-Waste

The board game based on interviews and constructive probing with the users, covered the story of E-Waste from the attaining of raw materials from nature, to usage patterns, recycling and land filling practices in detail. This exercise gave a considerable human and real perspective to the study, unlocked many opportunities for the ideation and solutions to flow.

2.2 How E-Waste can be Handled?

Using 'The game of E-Waste' as a design probe was used to initiate dialogue and discussion with the users followed by in-house brainstorming sessions. The tuning-in stage is for outlining the objective of design and understanding the phenomenon to be studied by making guesses about the causes and possible solutions. The tuning-in consists of preliminary study of the target group and phenomenon, recording the preconceived views, and examining the design challenge. These constructive design methods gave a better evaluation of the problem and fairly grouped handling methods at three stages,

1. At the manufacturing level
2. At the usage level
3. After the waste is produced

2.2.1 Handling E-Waste After the Waste is Produced

Based on the kind of measures to be taken to handle E-Waste, discarded electronics can be handled in three distinct ways. Firstly, ban hazardous waste imports and exports, secondly, proper detoxication and treatment of E-Waste before it is dumped in the landfills and thirdly, reusing and recycling.

Reuse and recycling as a huge domain include various measures that can be acted at many levels to make recycling and reusing much effective. These measures can be widely grouped in the following three groups.

– Better segregation, testing and collection
– Better reusing such that less goes to land fills, and
– Product reassignment

Extensive research was conducted to improve Reusing, testing and segregation of E-Waste. But product reassignment as a solution is not practiced widely to handle the problem of E-Waste, due to lack of design inputs and the gap between the market and production. In this study the author have attempted to design reassigned products to E-Waste, not only to put E-Waste to use, but also such that they can be made with hand tools (like a drilling machine, hand saw, pliers, etc.), minimum training and minimum production time; appropriate for cottage industries and to make new and easy livelihood from waste management.

2.3 Product Reassignment

Products in certain circumstances are transformed or reassigned from their original function and purpose into something entirely novel, a new service or utility not thought of by the original designer and manufacturer. Product 'reassignment' or 're-purposing' is a reconfiguration of an entire product through software or hardware addition that enables it to perform entirely new tasks. Not to be confused with recycled products, which are made from reprocessed materials.

3 Understanding E-Waste

E-Waste as a huge domain comprises of various types of devices and range of appliances from refrigerators to computers. This Huge domain was discussed and brainstormed on how to make it easy to handle and to contentedly apply design to reassign.

For effective and better results, the research was concentrated on computers, and further narrowed down to only Printed circuit boards (PCBs), as PCBs are a very common part of all kinds of E-Waste produced worldwide, and also one of the most difficult component to treat and handle. None-the-less this kind of constructive design approach can be applied to any province of E-Waste that needs to be reassigned.

3.1 Constructive Experiments on Printed Circuit Boards

Contemporary design research touches engineering, integrating design and research. It provides ways to justify methodological choices and understand these choices, through constructive methods. This type of research focuses on something far more concrete, which is, research that something is actually built and put to use. This not only includes concepts, but practical issues in manufacturing, making tangible opportunities for decisions [3]. The following are the practical experiments, observations and handling issues experienced working with PCBs.

Besides exploring general, physical and chemical properties, a series of constructive experiments were conducted to explore the best and optimum applications to handle PCBs. These experiments included various methods of cleaning, de-soldering, smoothening sharp edges, strategic patterning, cutting, finishing edges, protective coats and presentation techniques in the workshop. The following were the optimum methods, which were the easiest, quick and gave the best finish to the preliminary batch products (Fig. 3), which could make the product easy to produce, making opportunities for industries at cottage level, creating easy livelihoods.

3.1.1 Cleaning and Decontaminating

PCBs as internal parts of electronic devices are hardly cleaned and are usually dirty. These PCBs cannot be washed and were only cleaned with damp fabric and with a compressed air spray.

Although every PCB in the market comes with a moisture conformal protective coating, sealing all the organic and toxins used in their manufacturing, making the users almost able to be in physical contact with PCBs inside personal appliances like a phone, laptop or even kitchen appliances. However, it is the components like capacitors, which have poisonous dielectric liquid tightly sealed in them, which will be removed in the next stages carefully.

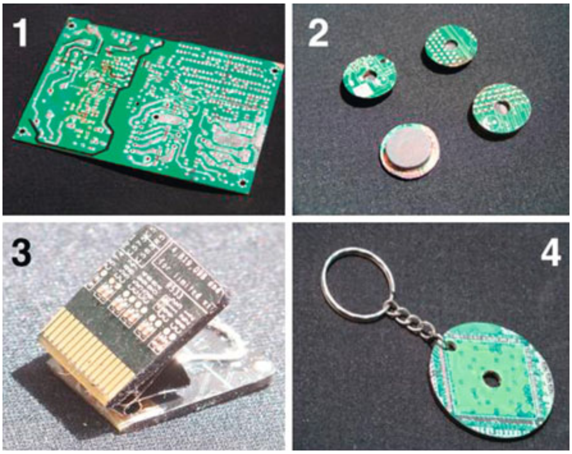


Fig. 3 Preliminary batch of products. *1* Printed circuit board (PCB). *2* Fridge magnets. *3* Paper clip with PCB grips.*4* Key chain/ring

3.1.2 De-Soldering

For further dismantling and de-soldering PCBs, extra care was taken by manually using pliers and de-soldering spike. The components are connected to the PCB in many methods, mostly by soldering, fittings and sometimes glued, sheer care was taken to keep the PCB is it's presentable state and also not to burst any capacitors.

3.1.3 Smoothening and Grinding Sharp Edges

Soldered connections to the PCB are usually untrimmed as they are intended to be inside the devices. These are usually sharp and were trimmed and ground smooth to make them suitable for usage in making products. This can be done on a drill with a grinding bit or with a sand paper.

3.1.4 Designing and Strategic Patterning

With so much of variation in the raw material, especially in E-Waste, every PCB was treated uniquely with a unique pattern plan of what is to be done with it.

Following were the things considered for patterning

1. Size
2. Evenness
3. Thickness
4. Placement of the visually interesting components
5. Color of the PCB
6. Thickness of the electronic circuits visible

Based on these constraints a cutting pattern was developed for every PCB to save time and maximize output.

3.1.5 Cutting

PCBs are non-elastic materials made of glass Epoxy, thus cutting them would leave the edges rough and chipped. The best way of cutting a PCB is grinding using either with an appropriate drill bit, or on the sander. Straight cuts for our convenience were done on an industrial trimmer but followed by further trimming on the belt sander and a grinding drill bit.

3.1.6 Finishing Edges

All the edges were trimmed and smoothened on a belt sander and with files. Any sharp edges of the products were checked and ground smooth. The edges after grounding were often left pale and were painted dark with any permanent ink marker or paint.

3.1.7 Toxin Protective Coat

A thin layer of easily available epoxy based transparent coat was painted to the finished pieces of PCBs and allowed to dry, not only to seal the toxins on the PCBs but also to add shiny finish. This epoxy protective coat can be preceded by a wash of Fenton's reagent (a solution of hydrogen peroxide and an iron catalyst that is used to oxidize contaminants) to treat any organics and metal ions from the freshly cut edges and the surfaces, which already have a conformal coating.

3.1.8 Finishing the Product

The finished pieces of PCB products were completed with other accessories needed to make the products usable and were sent to packing and retailing.

3.2 Preliminary Batch Products

While working on various constructive experiments to handle PCBs, a batch of products were made in the workshop shown in Fig. 3, which were very obvious and were used in the later stages of design as Design probes.

4 Probing and Brainstorming

4.1 Probing

Probes are used for applied research in design. These probes are equipped with instruments or objects selected to help answer research questions from the users.

A probe process intending dialogue emphasizes discussion and interpretation. Probes in Meetings, workshops and ideation sessions typically encourage the dialogue. As for sources of inspiration, they can be used without any particular outline for getting ideas [4].

Probing in this study was conducted in four stages, where the first two stages were conducted in isolation and the next two in group brainstorming sessions. In the first stage the users were left with the probes to interact with, while their comfort with the probes were watched. In the second isolated stage, the designer has interacted with the users triggering dialogue and discussion. The third and the fourth stages were conducted in groups, where the user was educated with information and constraints gradually; and the ideas were plotted, as shown in Fig. 4.

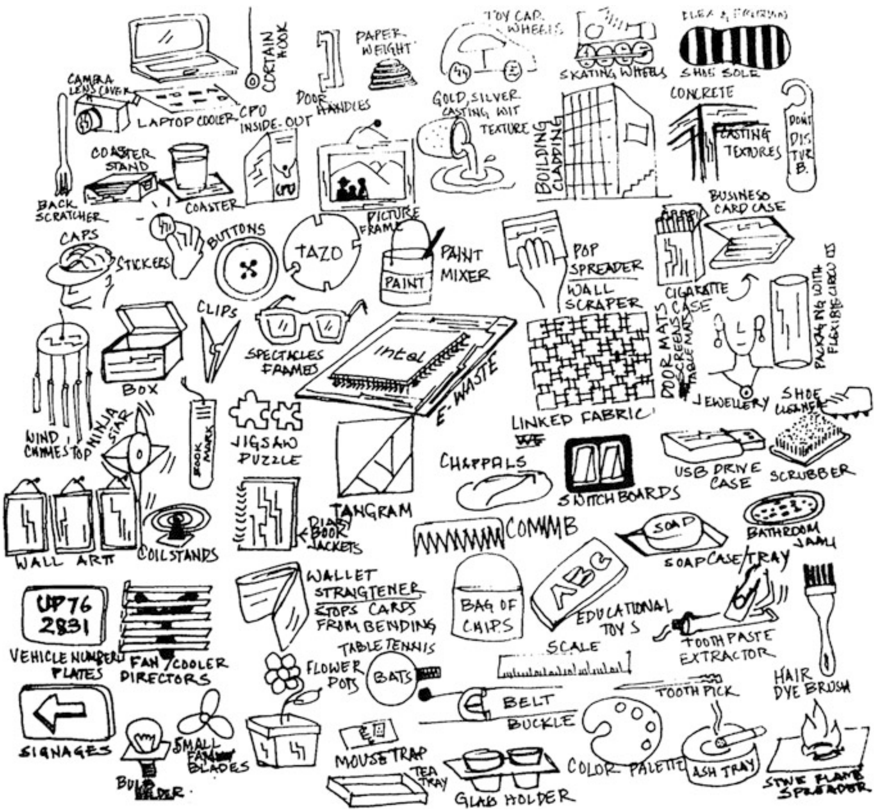


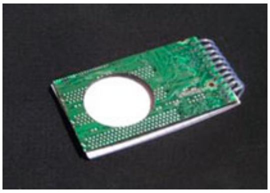
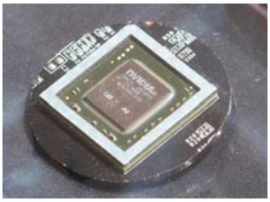
Fig. 4 Bain storming—idea mapping with basic constraints

5 Final Products

Of all the products plotted in the brain storming session, there was a need to follow a specific criterion, which can give scope for new livelihoods, starting at a cottage level using basic and cheap equipment. Following are few criterion based on which the final products were shortlisted for prototyping.

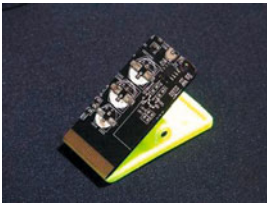
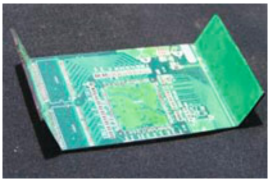
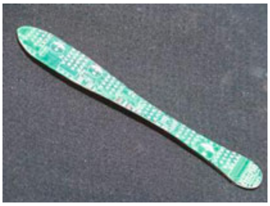
- Monolithic designs, minimizing finishing issues, maximizing finish and consistence.
- Products, which can be made with minimum number of operations and with basic tools, affordable by a cottage industry.
- Easy and quick to make, not compromising on the beauty, but saving on labor cost.
- Meeting the market needs and user preferences.
- Less skill required, thus less training.
- Beautility (Beauty + Utility) products, and total replacers of products in the market.

5.1 Products

	-A PCB has replaced the book cover with a circle cut in it, resembling an apple ipod Size—7 × 12 cm Cost of manufacturing INR 10
	-A PCB badge, circle was cut with a drill, and glued to safety pin at the back Size—4 × 4 cm Cost of manufacturing INR 2
	-Loose-hanging jewellery, crafted ring of PCB, attached by a small copper loop to a wire Size—3 × 3 cm Cost of manufacturing INR 3 each

(continued)

(continued)

	-Loose-hanging earrings, crafted ring of PCB, attached by a small copper loop to a ear hook Size—1.5 × 1.5 cm Cost of manufacturing INR 2 each
	-A PCB board replaced a common pad clip's wing Size—4 × 5 x 4 cm Cost of manufacturing INR 10
	-Non-slip soap tray, made from three pieces of PCB, glued together. The rough undulations on the surface of the PCB are used to make it non-slip Size—15 × 15 cm Cost of manufacturing INR 4 each
	-A famous product in market usually studded with PVC jewels, costs INR 30, was studded with PCB tiles, retaining it's beauty and reducing the cost Size—1 × 2 cm × 9 studs Cost of the new product INR 15
	-Wooden paint stir sticks are commonly used to mix paints, epoxies and other general coating sold in small units or in large bulk for wholesale and costs 0.12–0.18 $ (ie. INR 6.5–9.5) (www.jamestowndistributors.com, 16 May, 2012) The product was reconstructed with epoxy coated PCB Size—10 × 2 cm , cost- INR 1
	-PCB spectacle frame glued to old spectacle temples and bridge Size—10 × 5 cm Cost of the new product INR 15

6 Conclusion and Future

The products prototyped at this stage have shown their possibility to create livelihoods using E-Waste, with optimum equipment and with great ease. And also can function in a cottage industry setup, fulfilling practical and startup issues with design intervention. There is still a lot of scope for improvement in design to use the full potential properties of a PCB. As this study was only targeted at startups, it can uncover more opportunities when the scale increases.

These prototypes were an outcome of Constructive design research methods, which can be applied to any waste that needs to be re-assigned by design opening many opportunities livelihood, using waste as a resource.

However, any product of recycled, reused or reassigned will have its end, so will these reassigned products be trashed in a regular landfill one day, along with regular non-recyclable trash. Although these "epoxy coated PCB reassigned products" are partially treated at the time of reassignment, because of the scattered distribution of E-Waste along with other non-recyclable trash dilutes the toxic effect of the PCBs on the landfill soil.

Because of these re-assigned products, the pressure on the raw materials used for making similar products will be relieved and shared. As these components have served a regular lifecycle of an electronic component and also an assigned product's life, the materials live a longer life than a material in a typical product's lifecycle.

References

1. Baker E, Bournay E, Harayama A, Rekacewicz P, Catelin M, Dawe N, Simonett O (2004) United nations environment programme (UNEP) and secretariat of the basel convention. Vital Waste Graph 8–9
2. Bigum M, Christensen TH (2011) Waste electrical and electronic equipment. Solid waste technology and management, Blackwell Publishing limited, pp 961–962
3. Koskinen I, Zimmerman J, Binder T, Redstrom J, Wensveen S (2011) Design research through practice—from the lab, Field and showroom, Elsevier, Amsterdam, pp 6–7
4. Tuuli M (2006) Probes seeking human life, design probes. Gummerus Printing, Finland, pp 39–65

Conflicts in the Idea of 'Assisted Self-Help' in Housing for the Indian Rural Poor

Ameya Athavankar, Sharmishtha Banerjee, B. K. Chakravarthy and Uday Athavankar

Abstract The paper seeks to establish the influence of government policy on housing for the rural poor in India. First, literature on the self-help approach to housing over the last 50 years is summarized. Then the paper proceeds to present a comparison of the macro level view of the Indira AwasYojana for rural poor with an understanding of ground realities of rural housing acquired through ethnographic studies in five areas of rural India. The studies reveal how the rural poor live and how IAY-funded houses fall short of meeting their housing requirements. The paper argues that the main shortcoming of the IAY is its focus on housing as a product rather than a process involving peoples' participation. It concludes that policies and schemes based on a limited understanding of housing processes are likely to meet with limited success and suggests ways in which architects and designers can contribute to housing in rural India.

Keywords Assisted self-help · Housing policy · Rural poor · Ethnographic studies

1 Housing the Rural Poor

Housing is a basic requirement for human survival. It provides a comfortable living environment and serves as a source of economic and social security. Yet, a large section of rural India continues to be houseless. In 1991, nearly 3.4 million households were houseless. This figure had reached 15 million by 2001 with almost 1 million being added annually [1]. The Working Group on Rural Housing

A. Athavankar (✉) · S. Banerjee · B. K. Chakravarthy · U. Athavankar
Industrial Design Centre (IDC), IIT, Powai, Mumbai 400076, India
e-mail: ameya@iitb.ac.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_48,

Fig. 1 Self-funded local (*left*) built using local and discarded reusable materials and IAY funded house (*right*) designed and built by a beneficiary himself

for the 12th plan has estimated the total housing shortfall between 2012 and 2017 at a little over 39 million houses [2]. Over 90 % of the total shortage pertains to below poverty line (BPL) households. In spite of the large requirement for low cost houses in rural areas, no private agencies have shown significant interest in the area, largely due to the low margin on these houses and the geographical spread, which makes development untenable. As a result rural India almost entirely consists of self-help housing built over time, sometimes generations using local and often discarded but reusable material as shown in Fig. 1.

Self-help housing has been a well-documented approach in housing literature since the 1960s. However, it must be noted, that for the most part, the discussion on self-help housing has been centered on housing for the urban poor. Nevertheless, it offers insights that are very relevant to this paper.

1.1 Self Help Housing: An Overview

The term 'aided self help' was coined by Jacob Crane in the 1940s and 1950s [3]. However, it was not until the 1970s and 1980s that self-help was propagated by practitioners and academics, following the path breaking work of self-help housing pioneers like Abrams [4], Mangin [5] and Turner [6, 7]. Based on their insights, in the early 1970s the World Bank started promoting self-help in projects in Africa, Asia and Latin America. Many Third World governments also realized the potential of self-help and this resulted in a major change of approach in housing. However, as Bredenoord and van Lindert [8] note, academic attention to self-help has been minimal since 1991 with little more than a few historical reflections.

1.1.1 Dwellers Versus Authority

The 'self help school' as Bredenoord et al. call it, rejected expensive standardized housing solutions. They made a convincing plea for a drastic reduction of government involvement in housing and a more active role for the local community [9]. Self-help, as Turner [10] stated did not imply self-home-building by untrained and ill-equipped people. To him, the central issue was that of control and the power to decide. It was the dwellers’ control over the building process, he argued, which would help create settlements best suited to their needs. Turner and Mangin [11] showed how squatter settlements were well adapted to the needs and circumstances of their residents, and also improved over time.

1.1.2 Product Versus Process

The main contention of the self-help school was that people should be given the freedom to make their own decisions. They suggested that governments change their approach toward housing from building and managing houses, to the role of an enabler, providing people access to resources that they cannot provide themselves. The type of control, Turner [10] argued must be one that supports user participation and flexibility. In other words, setting limits to what may be done and giving individuals freedom to find their way within limits as opposed to mapping procedural lines that must be strictly adhered to. Turner suggested that housing should be viewed not as a noun but as a verb [12]. Housing as a noun refers to the physical shelter, a product or commodity. Housing as a verb, on the other hand deals with the activity of housing as an on-going process and focuses on what the house does rather than what it is.

1.1.3 Housing Paradigms: A Continuum

Turner’s work became the foundation for what was later called the ‘support paradigm’ by Hamdi [13]. Hamdi developed Turner’s ideas to identify what he called two conflicting paradigms of housing- provision and support. The provision paradigm, according to Hamdi, tries to deal with the housing problem by producing houses. The housing process is controlled by the provider, and it is he who is responsible for housing units being built to a certain standard. The support paradigm, on the other hand, seeks to assist users through finance, services or training helping them build their own houses, rather than controlling the production of houses. Providers typically see the housing problem as one that must be dealt with expertise in materials, design, technology etc. Supporters, on the other hand believe that solutions exist in the field and merely need to be ‘recognized and the built on’ [13]. In reality most housing processes are a combination of these conflicting paradigms. The idea of ‘support structures’ proposed by N. J. Habraken is one such example. Habraken breaks up the provision of housing into different components that can be tackled separately. In his solution, large physical infrastructure is designed and built by professionals working with the state while the ‘infill’ allow for users’ participation in the design of their homes. Similar to Turner, the housing system is viewed as a process rather than a product, allowing users to make decisions according to their needs while respecting the larger structure.

Both Turner and Habraken, as Hamdi [13] states propagated the principles of flexibility, participation and enablement. However, while Turner promoted self-help, self-management and self-build, Habraken tried to incorporate industrial production to serve the interest of providers and users alike. Turner focused on housing politics and policies, while Habraken was more interested in the structure of the built environment.

It is this relationship between housing policy and the structure of the built environment that forms the focus of this paper. More specifically, the paper seeks to establish (a) how housing policy influences the structure of the residential built environment (b) in turn how an understanding of the built environment can inform the formulation of housing policy.

2 Housing by Financial Support: Indira Awas Yojana

The next section presents two views of an assisted self-help housing scheme for BPL households in rural India- the Indira Awas Yojana (IAY). The first half is a broad, macro level view of the scheme, its design its accomplishments and its shortcomings based on documented information. The second half presents an account of the situation on the ground as revealed by our field research focusing on houses created under the IAY.

2.1 The View From Above

The Indira Awas Yojana (IAY) was launched by the Government of India in 1985. The scheme was initiated as a part of the employment generation program, but eventually made independent in 1996 [14].The IAY is an assisted self-help scheme. It seeks to reduce rural homelessness by encouraging the rural BPL to build their own houses by providing them financial support. No type design is specified and the scheme beneficiary has complete freedom in the construction of houses, procurement of materials and in the employment of labor as shown in Fig. 1.

2.1.1 IAY: Accomplishments

The IAY has consistently reported high levels of satisfaction among households that were given grants and high levels of occupancy. Some reports suggest that about 86 % of beneficiaries expressed fairly good satisfaction levels with constructed houses. This has been attributed to two aspects of the scheme- (a) there are no architectural, material and layout requirements for the houses and beneficiaries are free to build the kind of houses they want and (b) the program grants a full subsidy and has no credit component [1].

The IAY has been receiving large fund allocations over the years. A total of Rs 35,450 crores has been allocated from the 7th to the 11th Plan periods. The Union Budget 2011 allocated Rs 11,075 crores for the IAY [15]. The scheme has also been effective in utilizing its allocations, meeting and often exceeding house construction targets.

2.1.2 IAY: Shortcomings and Quick Fixes

The IAY has been not without its shortcomings. It is unable to target the poorest of the poor landless laborers. Even in cases where it has succeeded, it has been unable to improve living conditions for the poor due to the lack of access to infrastructure. Moreover, a large percentage of beneficiaries have expressed their dissatisfaction with the adequacy of funds provided to build a house, leading to housing related indebtedness. The CDF [1] scheme brief on the IAY provides a detailed account of some of the shortcomings of the scheme. The government has been trying to address these issues through isolated, quick fix measures like homestead schemes, integrated habitat development schemes and upward revision mechanisms.

2.2 The View From the Ground

The discussion up to this point presented a broad view of the IAY as a housing scheme. This section is dedicated to presenting the other half of the picture, an account of how IAY funds are used by people to build their houses. Since no systematic studies of IAY funded houses and comparable local self-funded houses were found, an extensive field study was undertaken at five sites across rural India-Pohegaon-Khopoli and Nilshi-Khandi in Maharashtra, Wadi in North Karnataka and Nallur Vayal and Velliangiri in Tamil Nadu. The sites form a sample of convenience but do address variations in climate to some degree.

Data was collected through observation, unstructured interviews with inhabitants and measured drawings of houses. The focus was on understanding (a) how people go about the process of building their houses (b) how they inhabit their houses and (c) and how one affects the other. So typical data included a documentation of current status, history and future plans for their house and relationship of activities to individual spaces in and around the house.

The results reveal many common as well as unique patterns of practices across the five sites. These patterns has been expressed as ‘insights’. The idea is somewhat similar to Alexander’s ‘patterns’ [16]. Here, however an insight refers to a recurring building or living practice rather than a problem–solution set. The results are presented in the two parts. The first part is a comparative between the processes followed by an IAY funded house and a self-funded local house while the second deals with above questions.

Table 1 A comparative of typical local self-funded and IAY housing processes

Construction phase	Self-funded house	IAY-funded house
Initial phase	Minimum unit (Locally built, usually load bearing brick or stone walls, timber rafters, clay tiles, sheet roof, plinth built up with soling)	Core unit (IAY funded permanent construction, usually load bearing brick walls and sheet roof)
	1. *Enclosed multi-functional space*: Houses activities that require privacy including cooking, sleeping, some domestic work	1. *Strong room*: Houses safe, cupboards and storage units, good quality utensils, the television, anything valuable. Also used for sleeping
	2. *Proportionate outdoor space*: Effectively serves as living space, household activities spill over from inside.	2. *Bath*: Completely detached from strong room or attached but with access from outside.
Addition 1	Enclosure and isolation	Footprint addition and isolation
	3. *Kitchen*: Cooking and related activities separated from multi-functional space. (similar to minimum unit construction)	3. *Cooking area*: Only for cooking, does not contain house articles and dining
Addition 2	Footprint addition (Similar to minimum unit construction, precast fencing and lamp posts for columns)	Footprint addition (Locally built, usually timber posts, woven thatch or sheet for wall panels and roofs, reusable material. Size of spaces often determined by the dimensions of sheet roof components)
	4. *Additional kitchen*: Second kitchen built when a member gets married or starts a family	4. *Storage and cattle sheds*: For cattle, poultry and general storage. May abut the strong room or may be independent
	5. *Cattle, storage sheds, verandahs*: for cattle, poultry and general storage.	

2.2.1 IAY Funded Versus Self Funded

Generally, it was found that there were more shared insights in IAY houses as compared to local houses. A comparison of the typical process in an IAY dwelling as opposed to a traditional or self-funded dwelling is shown in Table 1 and Fig. 2. It must be noted that the example shown below is illustrative and does not account for the many regional and climatic variations in house forms. However, it is representative enough to demonstrate typical building and inhabiting processes.

2.2.2 Key Insights

Of the many shared insights and sub-insights, only two overlapping insight sets (a) multi-functionality (b) incrementality are presented here. Multi-functionality and incrementality have an inverse relationship but only to some extent.

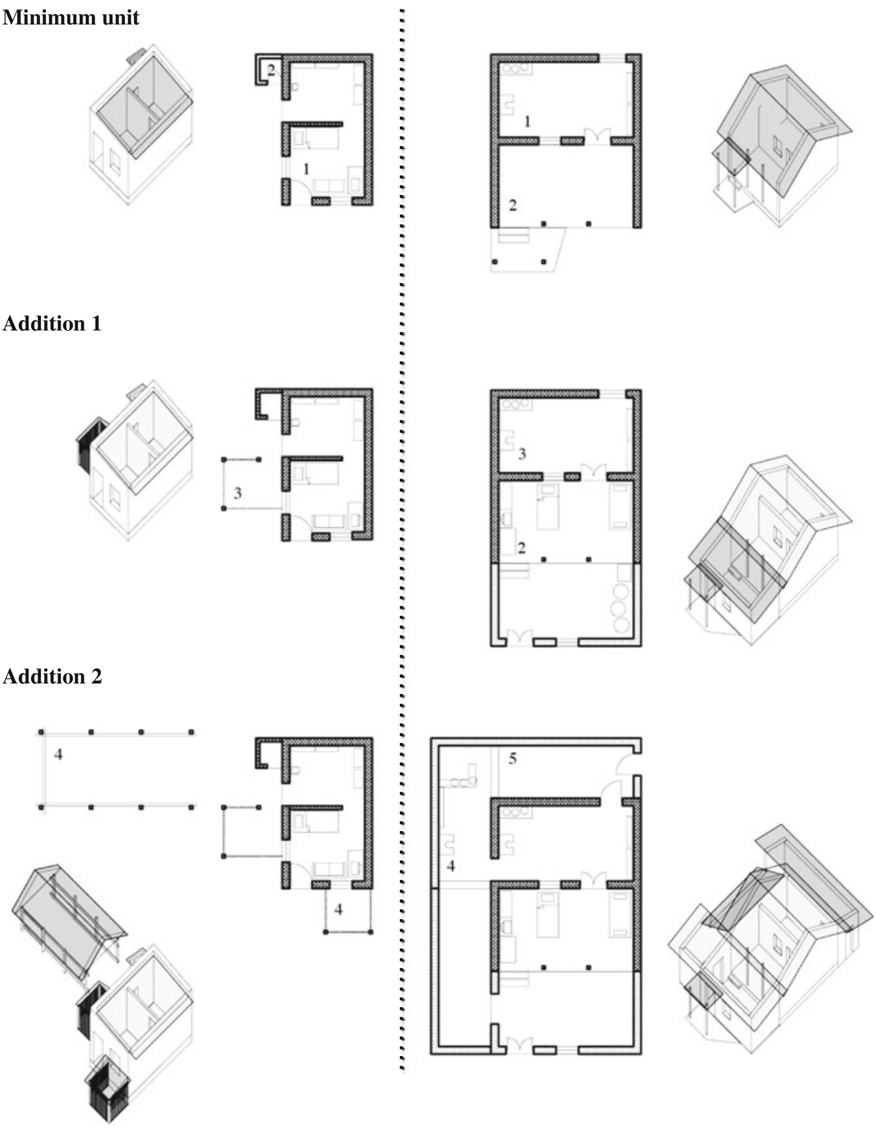


Fig. 2 Growth of a typical IAY funded house (*left*) compared to self-funded local house (*right*)

Incrementality, *Enclosure*, *Isolation*, *Footprint addition*: Rural households often do not have a regular income and this influences the way they build their houses. Initially, a household builds only the Minimum house needed to meet its requirements. The house is developed over a series incremental additions and extensions. Incrementality can be seen in gradual progression toward durable and modern materials as well as addition of extra spaces and internal lofts. Typical incremental changes include:

- *Enclosure* involving the complete or partial enclosure of a semi-open or open outdoor space for private use.
- *Isolation* involving separation or isolation of an activity from the multi-functional space, usually cooking from the rest of the house as this is primarily the woman's domain and needs to function relatively independent of the rest of the house. This separation is critical since cooking, washing and related activities start early in the day and need to be isolated from the rest of the household.
- *Footprint Addition* involves construction of adjacent or separate structures on previously unutilized ground, usually as the household acquires more assets, particularly cattle or poultry.

Multi-functionality, *Proportionate outdoors*, *dedicated kitchen*, *additional kitchens*: The use of space for activities is prioritized over its use for arranging related objects. Apart from the bath, the minimum house consists of a single multi-functional space with proportionate outdoors *See Enclosure*. As the house grows, *See Footprint addition* some activities are isolated from the multi-functional space *See Isolation*.

3 The Uncut Picture

With a more complete understanding of the IAY, it is now possible to examine the relationship between the IAY and the built form of the house. The first section discusses influence of the design of the IAY on the way people build and inhabit their houses. The second section discusses how this understanding can contribute to creating better rural housing policy.

3.1 IAY: The Conflicts

This section discusses the approach of the IAY as an assisted self-help housing scheme. It focuses on the adequacy, structure and method of fund disbursement and the very idea of financial support for the construction of a permanent house.

3.1.1 Funding What

The need to allocate more funds to the IAY beneficiary cannot be disputed. However, it is the IAY's focus on permanent houses that requires discussion. Clearly, the IAY funded 20 m^2 one room structure does not nearly meet the requirements of a rural BPL household. In fact, in most cases, a 20 m^2 room does not even constitute a minimum house. The overriding concern for building a permanent house with limited funds produces a scaled down house that uses far too much funding for the requirements it fulfills. The focus on the one room structure sidelines the need for a separate kitchen and finished outdoor space that are essential components of the minimum house.

The IAY presents a case where a user is being granted financial 'support' to deliver a product built to 'provider' standards at the cost of its ability to serve him. This conflict is one of the major reasons for the inadequacy of funds to build a good living environment.

3.1.2 Funding How

The incremental nature of the housing process does not find a corresponding response in the one time funding of the IAY. The lack of response to incrementality also extends to the funding structure of the scheme. IAY grants are disbursed in three to four installments. The release of these installments is conditional to the completion of pre-decided stages of construction, typically foundations, plinth, lintels and the roof. The method of disbursement is appropriate only for the construction of a finished structure. Again, the undue focus on finished house sidelines the need both for an initial structure that is supportive of incremental additions as well as funding for these additions.

The IAY's one time funding is characteristic of payment for a complete house. Even the stage-wise release of funds is suggestive of a monolithic structure instead of a series of connected structures built over time as per the need of the household. This is major reason for the asymmetry in quality and lack of cohesion between structures built under the IAY and additions made henceforth.

3.1.3 Only Funding

The IAY emphasizes the use of modern materials for the construction of the permanent house. This requires skills and training. For an IAY beneficiary, it is very difficult to employ skilled labor considering his location and the total value of work involved. The use of modern material by untrained workers results in poor quality construction prone to weather conditions. Off-the shelf components ensure some durability, but often create unusable spaces.

The rural poor do aspire for permanence and durability. This partially justifies the IAY's insistence on the use of modern materials. However, considering the amount of funding being provided, this must be accompanied by proper resources and training. Also, rejecting a wealth of local building skills seems rather unwise. The IAY, with its limited involvement of providing financial assistance cannot expect to create quality permanent housing.

3.1.4 Neighborhoods Versus Service Provision

In order to ease the provision of services such as electricity, water supply and sanitation, the government has been trying to propagate the 'cluster approach' to IAY housing. There is no doubt that cluster based development has distinct advantages over individual houses. It can not only facilitate provision of services, but also make it easier for beneficiaries to procure material or recruit skilled labor and share know-how on house construction. However, the cluster approach is often misconstrued as a colony of houses organized so as to save material or to ease the provision of services.

Cluster based development has potential to create rich neighborhoods and communities, provided the households participate in the process and share more than just services. If the IAY seeks to create good neighborhoods, it will need to develop a more participatory housing process and rethink its approach to the provision of services.

3.2 Challenges and Opportunities

The IAY, in many ways is characteristic of a scheme that seeks to reduce housing shortages and meet targets rather than create good living environments. This paper has gone to great lengths to show the limitations of the IAY's focus on the permanent house. This is perhaps the single largest shortcoming of the scheme, rooted in its view of housing as a product or a commodity rather than a process where the user is an equally, if not more, important participant.

The process of housing must be centered on the user and his capabilities. The government's role should be restricted to providing financial and technical support and setting 'limits' to how funds can be used. Architects and designers are well equipped to research and understand housing processes. They are also good judges of environmental quality and can make valuable contributions to the structure of financial packages, identification of areas that require technical support and drafting of context specific guidelines to define the limits of how IAY funds can be used.

The idea of 'support structures' proposed by Habraken [17] is another line of work that is worth exploring in rural India. Instead of building a finished house, IAY funds could be used to create a durable 'starter structure' that is weatherproof, offers good ventilation and allows additions and in-fills in local material. This could not only reduce cost but also utilize local building skills and materials. The role of the designer would be to conceive such a starter structure and its interaction with a variety of in-fills.

Building construction in India is yet to fully realize the immense potential of standardization and mass manufacturing, in bringing affordability and quality. Standardization does not always come at the cost of choice and individual preference. It is possible for architects and designers to create standardized building

Fig. 3 Precast fencing posts with random rubble in-fills (*left*) and a building material supplier showing palm leaf panels to be used as in-fills in local houses (*right*)

components that require simple skills to assemble. Such an approach can also effectively handle the incremental nature of rural housing. Rural India’s faith in prefabrication and standardized components can already be seen in Fig. 3.

Architects and designers can also assume what Hamdi [13] called ‘teacher’s’ or ‘enabler’s’ role in the housing process. With their ability to understand local building processes, their benefits and limitations they can effectively disseminate knowledge, impart training and help create participatory design processes to bring about incremental improvements in houses.

These are just few of the many ways in which design can contribute to rural housing for the BPL. However, it is important to remember that people have been in-charge of building their own houses for the greater part of history while the participation of professionals in housing is a recent phenomenon. It is the professional class, as Habraken [18] pointed out that is participating in the age-old process of housing and not the other way around. The professional’s role must involve providing expertise in areas that no one else is capable of handling better.

Housing the rural population of a nation of India’s size is an enormous and complex task. But it is the conviction of this paper that architects and designers can play an important role in housing the Indian rural poor.

Acknowledgments We would like to extend our gratitude to ACC Ltd for supporting this research and to the many families of Pohegaon-Khopoli, Nilshi-Khandi, Wadi, Nallur Vayal and Velliangiri for welcoming us into their homes and openly sharing their views and experiences.

References

1. Raman NV (2012) Indira Awaas Yojana (IAY) scheme brief. Cent Dev Finan
2. Planning Commission Government of India (2012) Working group on rural housing for the twelfth five year plan (2012–2017). pp 7, 12, 15, 26
3. Harris R (1991) A burp in church: Jacob L. Crane’s vision of aided self help housing. Plann Hist Stud 11:3–16
4. Abrams C (1966) Housing in the modern world. Faber and Faber, London

5. Mangin W (1967) Latin American squatter settlements: a problem and a solution. Lat Am Res Rev 2:67–98
6. Turner JFC (1967) Barriers and channels for housing development in modernizing countries. J Am Inst Planners 33:167–180
7. Turner JFC (1983) From central provision to local enablement, new directions for housing policies. Habitat Int 7(5/6):207–210
8. Bredenoord J, van Lindert P (2010) Pro-poor housing policies: rethinking the potential of assisted self-help housing. Habitat Int 34:278–287
9. Abrams C (1971) The language of cities: a glossary of terms. The Viking Press, New York, p 63
10. Turner JFC (1978) Housing by people: towards autonomy in building environments. Ideas in progress. Marion Boyars Publishers, London, p 133
11. Mangin W, Turner JFC (1968) Barrida Movement. Progressive Archit 37–56:62–154
12. Turner JFC, Ficher R (1972) Freedom to build. Macmillan, New York, p 151
13. Hamdi N (1995) Housing without houses: participation, flexibility, enablement. IT Publications Ltd, London, pp 27, 36, 45, 177–179
14. Ministry of Rural Development Government of India (2012) Rural housing. Web
15. HT Correspondent (2012) Indira Awas Yojana Receives Rs. 11,075 crore. Hindustan times
16. Alexander C, Ishikawa S, Silverstein M (1977) A pattern language: towns, buildings, construction. Oxford University Press, New York
17. Habraken NJ (1972) Supports, an alternative to mass housing. The Architectural Press, London
18. Habraken NJ (1986) Towards a new professional role. Des Stud 7(3):102–108

A Method to Design a Value Chain from Scratch

Romain Farel and Bernard Yannou

Abstract Value chain concept and methods has assumed a dominant position in studying industry from management point of view. Decision supports methods using value chain require the acquisition of data from various existing corporate databases or data warehouses. In design research discipline, the subject of value chain design is emerging. Only a few of published research took a wide scope comparable to theories used today in engineering design. As an effort in developing the methodology and as a result of research within a national industrial consortium, this paper proposes and discusses a general value chain design approach which opens up a promising perspective to provide a new direction for research and application of value chain from scratch for multi-stakeholder industrial systems. It introduces value chain design as a way to determine, model, and analyze and evaluate the industrial ecosystems, in order to generate future scenarios and provide evaluation criteria for decision makers. To illustrate its application, the establishment of end of life vehicle recycling subsidiary at national level is explored to identify potential values stakeholders.

Keywords Value chain · Structural analysis · System dynamics · Scenario · Matrix · Simulation

1 Introduction

Traditionally, organizations seek to streamline their processes and improve customer service by improving connectivity between both business processes and key operational units. The supply chain of the industry dominates the value generation chain

R. Farel (✉) · B. Yannou
Grande Voie des Vignes, Ecole Centrale Paris, Chatenay-Malabry 92290, France
e-mail: romain.farel@ecp.fr

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_49, © Springer India 2013

[1]. Porter has defined the value chain as a chain of activities for a firm operating in a specific industry [2]. Products pass through all activities of a chain from conception through the different phases of production, delivery and disposal, and at each activity the product gains some value [3]. Kaplinsky in [4] point out three key elements of value chain analysis: Barriers to entry, Governance, and Different types of value chains. Essentially, the primary returns (arising from design, production, marketing, etc.,) accrue to those parties who are able to protect themselves from competition. This ability to insulate activities can be encapsulated by the concept of rent, which arises from the possession of scarce attributes and involves barriers to entry. The economic rent arises in case of differential productivity, and takes various forms including technological capabilities, organizational capabilities, etc. Build on similar works [5] governance ensures that interactions between firms along a value chain exhibit some reflection of organization rather than being simply random. Value chains are governed when parameters requiring product, process, and logistic qualification are set which have consequences up or down the value chain encompassing bundles of activities, actors, roles, and functions.

Along with the increasing need of todays' enterprises for value chain analysis for integrating into new business models, industrial researchers study and explain adapted concepts, methods, and tools in different sectors. In IT and telecommunication [6, 7] and chemical industry [8] for example, the paradigm shift and new requirements in enhanced value chain design was discussed. Papazoglou proposed an integrated value chain model in order to create and enhance customer-perceived value by means of cross-enterprise collaboration [9]. However, the question of design a value chain from scratch seems to remain unsolved. First, the developed methods are based on existing workflows and their stakeholders. Second, the creation of a future multi-actor value chain has not been investigated from a design point of view, considering both technical and organizational issues. This paper proposes a first try on formalizing a methodology for design a value chain for multi domain industrial projects. The research question is formulated in what process is needed to design a large scale industrial system with stakeholders in different domains of activity, in which key decisions and strategic choices are supported with qualitative and quantitative data and analysis of the whole system. The detail of this method is illustrated using the data of an ongoing national level case of design the value chain for a non-existing End of Life Vehicle (ELV) material recycling. Data has been collected through interviews, field observation and investigation and developed models have been validated by project actors meeting and industrial experiments.

2 Methodology

In light of the evolving need and the limitations of existing approaches and methods, the main objective of this paper was to understand how to provide key decision indicators for stakeholders of a future value chain. The research behind this paper was conducted in a national consortium for establishing a future recycling subsidiary for End of Life Vehicle (ELV) materials. In a bottom–up approach, several industrial stake holders have been asked why they would be interested to take part in a future collaboration. They have also been asked what kind of information would help their decision making. The cost and benefit of the future activity, along with environmental impact was evoked. However, stakeholders needed to have simulated data, showing the requested variable (e.g., cost of recycling) in a long term future perspective, following the various possible situation. Those situations, called scenarios, should be generated intelligently from the crossing of dynamic evolution of key variables of the system. Thus, a system view should be established, and a method should be employed to identify key variables. The reason is in a systemic approach, generally a considerable number of variables can be found having interconnection, yet those relations remain unknown and impossible to be mathematically formulated.

A system view uses the basic flow model of the activities, characterized with variables, and determines the relation between those variables within the system and with external variables. Accordingly, it is necessary to model the physical flow (for production) or information flow (for service) using a modeling approach. What is important in modeling is to identify the operation activities, and parameterize each activity with requested variables such as economic (cost or benefit) and environmental (CO_2, waste). In the following each step is formalized and explained in detail. The method demonstration with a real case application is presented in the next section.

2.1 Modeling Material and Information Flow

Material flow can be defined as the description of the transportation of raw materials, pre-fabricates, parts, components, integrated objects and finally products as a flow of entities. In the same way, information flow is any tracking of referential information passing through operational units.

The interdisciplinary nature of the most of the today's consortium is fundamental to the task of modeling. It is required to:

- Identify the main process and sub-processes
- Define system boundaries
- Identify operational task alternatives
- Find/consider new innovative solutions that will result in value generation.

To perform the modeling task, one is free to choose or even define his own modeling approach. Hence, the body of literature in modeling approaches is simply immense. A valuable inventory of methods has been put together in [10]. Here, the most important issue is to parameterize input and output variables. At the end, variables value change in operation units are to be formulated mathematically, for example mass transfer in an operational unit of separation, or economic flow in a selling unit.

2.2 Establishing Value Network

The goal of this task is to identify and formalize the added value on each step of the process model, and for different stakeholders. While the main value is readily accepted to be the economic value or the cash balance, other form of measurable value types could be of the interests of the stakeholders. Environmental impact, such as carbon dioxide emission and waste production are two examples. To perform this task, firstly the value framework should be defined and be approved by stakeholders. Secondly, the value change should be formalized using the same variables and operation structure as of the previous step. For instance, a given operation of raw material purification through melting process would have a mass transfer equation between input and output material. The cost of this operation, the mass of by-produced waste, and the carbon dioxide mass in result of heating process are value measures.

2.3 Structural Analysis

Godet introduces the structural analysis as a method to determine the key questions concerning the future and to identify the influence of various stakeholders, in order to establish the relationships among them, as well as the stakes involved [11]. The reason of using structural analysis in this step is to add the stakeholders' point of view and interpretation of how the system works or would work to the technical model of previous steps. Structural analysis begins with a group made up of both internal personnel and outside expertise in the field under study. It includes three successive phases:

- Creating an inventory of variables
- Describing the relationships among the variables
- Identifying key variables.

The inventory of variables is of course closely linked to the value network. Establishment of system view on the process model using cause and effect relation proposed in Systems Dynamics [12] is helpful. The system view can also be a key enable in the necessary alignment of business logics, and is also helpful to address effectively the need for active and open-minded communication between stakeholders.

While a list of variables is obtained and their relationships are determined, it is essential from practical point of view to identify key variables to set up scenario generation and further simulation on variable dynamic estimation.

The key variable identification consists of identifying and re-ranking the key variables, i.e., those essential to the evolution of the system. Very few methods with similar matrix based techniques exist for this task. Here are two better known: MDM and MICMAC.

Multiple Domain Matrix (MDM) is an analyze method and tool which allows analyzing a system's structure across multiple domains. Matrix-based approaches integrating multiple views ("domains") become more and more accepted to manage several perspectives onto a system, especially when it comes to large structures. Detail on MDM can be found at www.dsmweb.org.

Matrix Impact Cross-Reference Multiplication Applied to a Classification (MICMAC) is method and tool that helps using direct classification (easy to set up from interviews with stakeholders) for primary analysis. Then through using indirect classification, obtained after increasing the power of the matrix, more structure analysis can be elaborated. Information on this method is available at http://en.laprospective.fr.

Both methods have their pros and cons. By MDM it is possible to describe and analyze a whole system, including multiple domains and several relationship types concurrently. This way MDM allows for systematic application of all available algorithms by compiling several matrices into aggregated views. On the other hand, comparing the hierarchy of variables in the various classifications (direct, indirect and potential) is a rich source of information. It enables one not only to confirm the importance of certain variables but also to uncover certain variables which, because of their indirect actions, play an important role (yet were not identifiable through direct classification).

2.4 Scenario Generation

Stakeholders always wonder the evolution of a given value system in future time horizon. Representing the future evolution in terms of a set of scenario is particularly effective strategy for achieving this objective. Scenario generation is a convenient tool with a broad application if different domains [13]. The more precisely the scenarios span the set of possible future events, the more accurate are the simulation calculated from the scenarios. The goal is to generate meaningful scenarios based on key variable evolution and their impact on the value chain. In this task, it is important to communicate the nature of a scenario set to stakeholders, because they should find a scenario set accessible. This task is simplified by focusing on single variables dynamics, for example increase of fuel price and consequently transportation cost, and generate a set of single variable scenario. Then, classify those single scenarios to generate new scenarios with multi-variable dynamics. An example is shown in the next section.

2.5 Simulation and Evaluation

Simulation is the simplest task in this method if previous modeling, formulation, and scenario generation are done correctly, while it is the most important one facing the stakeholders. Simulation of the value of the system in the future scenarios gives direct and tangible information to a decision maker. A parameterized and/or dynamic simulation can provide real-time simulated response to a decision alternative for each decision makers. Also, this provides a common understanding in the consortium of future trends of the collaboration.

In a former publication, we proposed a segmentation method for scenarios in order to generate a reduced number of multi-variable scenarios [14]. In this approach, a distinction should be made between endogenous and exogenous variables, and classify single scenarios according to the general effect of that scenario on the global value chain. Then cross those classes (for example best case and worst case) of both endogenous and exogenous to generate complex scenarios with two state dimensions. See the example in the following section for more detail.

3 Value Chain Design for ELV Recycling Network

Reuse, recycle and recovery of End of Life Vehicles (ELV) materials are increasingly of interest to researchers and industrial companies, mainly because of the application of an EU directive on ELV [15]. The directive sets the ultimate goal of reuse and recovery at a rate of 95 % of the ELV weight; furthermore, from 2015 on certain materials including glazing must be separated during dismantling from the ELV. Contrary to previous directives, this directive penalties car manufacturers if target reuse and recovery rate is not reached.

Within the boundaries of this study, recycling ELV glazing is defined as the process of dismantling, collection, storage and transportation, treatment, and ultimately reuse of recycled glass called cullet. Cullet is regularly used for making glass products, glass wool, or as a substitution for other raw materials. Beyond the price advantage, each 10 % increase in cullet usage in a glass furnace results in a 2–3 % energy saving in the melting process: and each ton of cullet used saves 230 kg of CO_2 emissions. This has created an increasing demand for high-quality cullet by the glass industry. However, neither the demand for cullet, nor that of post-consumer recycled glass, is satisfied by current supply.

3.1 Modeling Material Flow

Figure 1 shows an ELV glazing recycling network in the form of a directed acyclic graph of value chains linking stakeholders dedicated to specific activities. The stakeholders of this network are the car manufacturers, the ELV dismantlers and shredders, the collecting and transporting companies, and the glass treatment companies. If the glazing network is considered as a whole, the cost and benefit can be stated as follows: the costs arise from dismantling, collection and

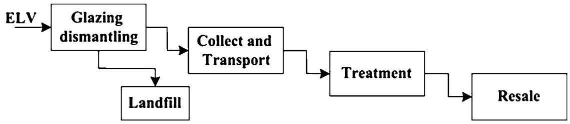


Fig. 1 ELV glazing recycling scheme

transportation, treatment, and the penalty paid by the producer in case of non-achievement of the directive target rate. The benefit of the network is from selling the produced cullet in the market, and the cost of not landfilling and shredding residual waste.

3.2 Establishing Value Network

For dismantlers, the interest to remove the glazing is questionable for two reasons. First, the dismantling procedure of glazing (itself) implies extra time and thus extra costs. After dismantling, the dismantled glass needs to be transported to a treatment unit, which costs more than the buyer can offer. Alternatively, the dismantled glass can be transported to landfill, which has its own costs. Meanwhile, none of these extra costs are compensated.

Second, with a proven market demand for cullet, treatment of the dismantled glazing and sale of the cullet could potentially make a profit for treatment units and for the glass production industry. However, in the absence of a large scale recycling network to share profit and finance the up-stream costs, it is not strategically justified for dismantlers to invest on a network with no future profit. Table 1 shows the motivations and disincentives of each stakeholder for a future ELV glazing recycling network.

Table 1 shows that the interests of stakeholders diverge. It is therefore difficult to establish the overall interest of the creation of this value chain. This is why we propose a Cost Benefit Analysis (CBA) of this value chain to make sure that the gains to the winners exceed the losses to the losers. This result will be employed to examine the possibility of a redistribution mechanism for benefits, assuring that being a member of recycling network is economically viable for each stakeholder.

3.3 Structural Analysis

We use Systems Dynamics approach to show the cause and effect diagram of the glazing recycling network (Fig. 2). There are two main mechanisms here, which have direct influence on the CBA of the network. The first mechanism concerns itself with the benefits of glazing recycling, composed of the sale of produced glass cullet and the savings in terms of landfill cost. The second mechanism deals with the glazing recycling cost, composed of the operational and logistic costs of the network, in addition to the potential penalty. The aforementioned CBA is the sum

Table 1 Individual motivation and disincentives of stakeholders for a future ELV glazing recycling network

	Individual motivation for recycling network	Disincentive for performing activity
Car manufacturer	Meet the 95 % target and avoid penalty	None
Dismantler	Attain a higher dismantling rate and use commercial benefits and potential government subsidies	Extra cost
Shredder	Less landfill cost	None
Collection and transportation	Improve the logistical operation	Volume issues
Glass treatment	Increase in feed and product flow	None
Cullet buyer	Satisfy the demand	Quality issues

of benefits minus the sum of cost. There are, however, a number of interconnections between two mechanisms. For example, the increase in benefits encourages more stakeholders to join the recycling network. Thus, the network coverage increases and this leads to a decrease in logistic costs, which then ripples into a decrease in total cost of the recycling network. The latter, influences motivation for joining the network, and results in a positive loop.

Creating a national recycling network and increasing the coverage rate is an endogenous change of the model. This change positively influences the saved cost of landfill, and decreases the logistic and the total cost of establishing this network. This aside, there are several time-varying elements from different exogenous sources that influence the behavior of the system. The first category of exogenous variables is the raw-material market evolution: change in cullet price and cullet demand. The dynamic of this change is explained in the following section. The second category is the politico-environmental decisions, which result in change in landfill tax, and in applying a penalty if the minimum recycling rate is not reached. The EU directive penalty on ELV reuse and recovery minimum rate of 95 % is one

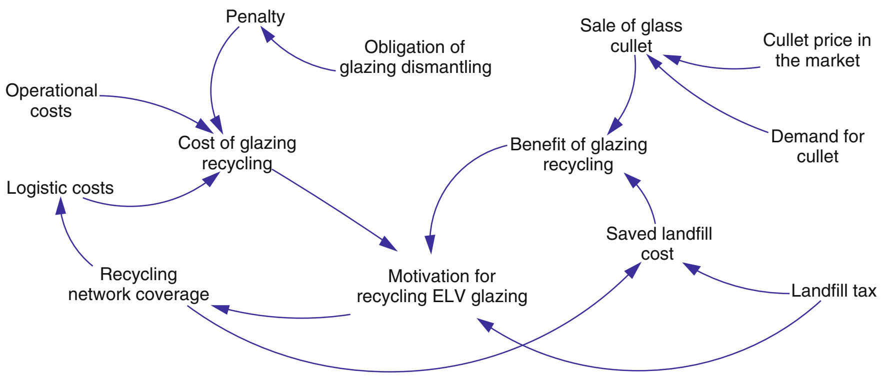


Fig. 2 System dynamics model of ELV glazing recycling network

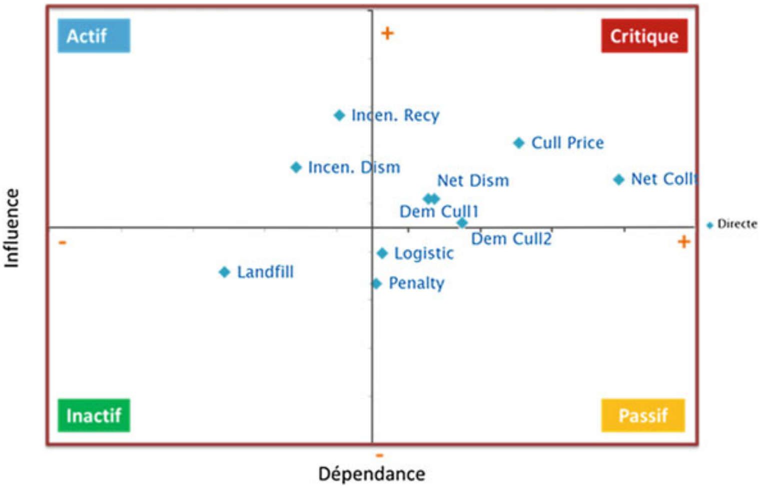


Fig. 3 Direct influence-dependence graph

example of this category. In this stage, with the inventory of variables, we used MICMAC method to identify key variables. In a series of interview, each stakeholder has been asked to fill a direct influence matrix, answering the following question: Is the variable A influence directly variable B? If yes, how?

The interview result has been transformed to numbered matrix with input standard of MICMAC software. With a considerable number of matrix calculations, several interesting demonstration of influence and dependency relation between variables was elaborated. Figure 3 shows a single frame result of the direct influence dependence graph.

3.4 Scenario Generation

Evolution of aforementioned system variables would have influence over the Future ELV glazing recycling network dynamics and consequently its cost and benefit. In a top–down approach, two trends can be imagined for the future network: first, generation of network revenue, and second decrease the operational costs. Cullet price and landfill cost as two exogenous variables, and logistics cost and network coverage as endogenous variables were chosen for the scenario generation. It is possible to consider at least three typical dynamics for each of these key variables, which produce three situations for the cost and benefit of the recycling network, namely best case, expected case, and worst case. Therefore 81 possible scenarios can be generated. Hence, in order to reduce the number of scenarios, a solution is to focus on how any of three situations (best, expected, worst) can happen for a variable category, here endogenous and exogenous. In result, nine scenarios can be generated as shown in Fig. 4.

Fig. 4 Nine scenarios for the ELV glazing recycling network

				Endogenous			
				Best case	Expected case	Worst case	
				D3.2 (exp)	D3.1 (lin)	D3.3 (noch)	**Logistic cost**
				D4.2 (log)	D4.1 (lin)	D4.3 (exp)	**Network coverage**
Exogenous	Bestcase	D1.2 (exp)	D2.3 (no ch)	**S1**	**S2**	**S3**	
	Expected case	D1.1 (lin)	D2.1 (lin)	**S4**	**S5**	**S6**	
	Worst case	D1.3 (no ch)	D2.2 (exp)	**S7**	**S8**	**S9**	
		Cullet price	**Landfill cost**				

These two trends are explained as sub-systems in this section. Analysis of the cause and effect relationship between network variables reveals the importance of political decisions from outside of the system, and strategic decisions from within on the dynamic. As a result, a third trend emerges into identify the dynamics of internal and external motivation and decision variables on the network functions.

3.5 Simulation and Evaluation

The costs and benefits of the future ELV glazing recycling network in France depends on the values of time sensitive variable of the cost-benefit model. In order to estimate the cost and benefit in a time horizon, we build a simulator using the data obtained in the first and second tasks. The simulator uses the key variables

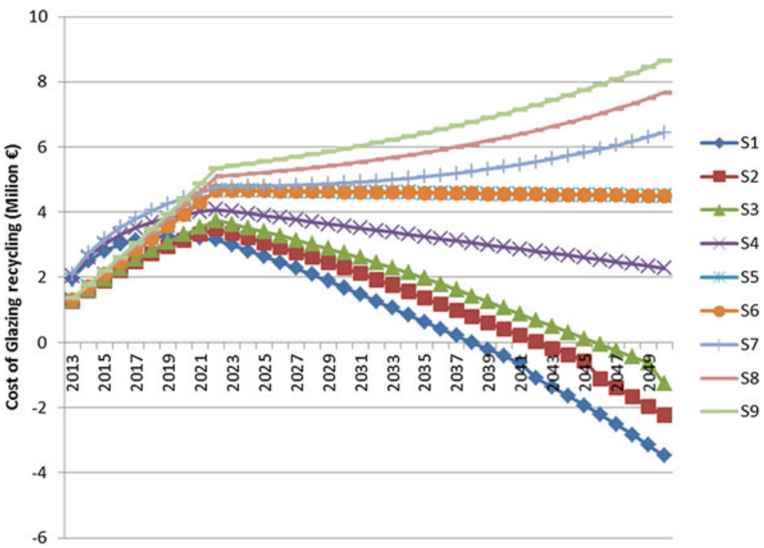


Fig. 5 Economic balance of the ELV glazing recycling at national level in nine scenarios

values change dynamic as input and reports total cost and benefit of recycling. Figure 5 shows the result of following the nine scenarios generated previously, and entering four variable dynamics for each scenario.

The figure demonstrates the cost of ELV glazing recycling in France for each scenario in a 50 years horizon. From a general perspective, three categories can be extrapolated: the first category, scenarios 1, 2 and 3 in which the CBA curve crosses the horizontal axe. There is an observable change in value from cost to profit. Scenario 1 is the best case scenario, in which the network revenue is at its greatest and the time it takes to reach break-point is at its least. In this category the external variables are experiencing in the most favorable conditions for the network. The performance of the network being at its best, expected or worst condition only modifies the slope of reaching the break point. In the second category, scenarios 4, 5 and 6 present a fixed scenario, albeit in the case of scenario 4, a decreasing cost for the network in the future. Scenario 4 would possibly reach the break point in the horizon of 100 years. In this category the external variables are in within the expected framework. The best case for internal variables present a significant cost savings, while S5 and S6 show no difference in cost and revenue of the network. In the third category, scenarios 7, 8 and 9, show an increasing cost for the recycling network. Scenario 9 is the most costly scenario where the external variables and internal variable are at their worst.

4 Conclusion

The need of developing methodology for value chain design is essential, and more and more increasing in multi domain industrial projects. The proposed method described in this paper can be summarized in three categories.

Stakeholders of an industrial consortium need concrete information about the future evolution of the value in the system by which they are concerned. The future changes are absolutely unknown to a design researcher, nonetheless using a method for generating scenarios and simulating the expected value in those scenarios is one of the best decision-making aids to the decision makers.

In a complex system with engineering, social and political disciplines, it is almost impossible to identify all variables and the exact relation among them. Hence, structural analysis approach brings techniques and tools to build a system view of the whole stakeholders and their operations and values, and identify the key variables out of all variables. Finally, in the first place, the value chain design is an engineering design problem, and like for other problems in this discipline, modeling is a fair choice. Last but not least, visualization is essential for providing transparent results. It is also important for communication between project stakeholders and having a common understanding of what the method provides.

References

1. Al-Mudimigh AS, Zairi M, Ahmed AMM (2004) Extending the concept of supply chain: the effective management of value chains. Int J Prod Econ 87(3):309–320
2. Porter M (1980) Competitive strategy: techniques for analyzing industries and competitors. Free Press, New York
3. Porter M (1985) Competitive advantage: creating and sustaining superior performance. Free Press, New York
4. Kaplinsky R, Morris M (2003) A Handbook for Value Chain Research: IDRC
5. Gereffi G (1994) The organization of buyer-driven global commodity chains: how U. S. retailers shape overseas production networks, in commodity chains and global capitalism. In: Gereffi G, Korzeniewicz M (eds) Praeger, London
6. Peppard J, Rylander A (2006) From value chain to value network: insights for mobile operators. Eur Manag J 24(2â€3):128–141
7. Dedrick J, Kraemer KL, Linden G (2011) The distribution of value in the mobile phone supply chain. Telecommun Policy 35(6):505–521
8. Vogt C et al (2005) Paradigm shift and requirements in enhanced value chain design in the chemical industry. Chem Eng Res Des 83(6):759–765
9. Papazoglou MP, Ribbers P, Tsalgatidou A (2000) Integrated value chains and their implications from a business and technology standpoint. Decis Support Syst 29(4):323–342
10. Heisig P, Clarkson PJ, Vajna S (2010) Modelling and management of engineering processes. Springer, London
11. Godet M, Durance P (2011) Strategic foresight for corporate and regional development, UNESCO
12. Sterman JD (2000) Business Dynamics: Systems Thinking and Modeling for a Complex World, Irwin/McGraw-Hill
13. Schwartz P (1996) The art of long view. Crown Publishing Group, USA
14. Farel R, Yannou B, Ghaffari A (2012) A cost and benefit analysis of future end-of-life vehicle glazing recycling in France: a system dynamics approach. Submitted to resources, conservation and recycling
15. EU-Directive, Directive 2000/53/EC of the European parliament and of the council. Official J Eur Commun, 2000

Part VI
Design Collaboration and Communication

Developing a Multi-Agent Model to Study the Social Formation of Design Practice

Vishal Singh and John S. Gero

Abstract This paper describes a computer simulation based approach to investigating the longitudinal patterns in social emergence of design practice. Legitimation code theory is adopted as the underlying framework to develop the model. The design practices in this model emerge and evolve under the influence of the social structure as well as the knowledge structure. This model simulates a society of designers with different design backgrounds, affiliated to different teams and organizations. Design agents interact with each other and the concepts associated with the different disciplines. Design agents within each discipline are modeled to be attracted towards concepts, i.e., knowledge mode, as well towards the other design agents, i.e., knower mode, which collectively influence design practice. The force of attraction towards the knower or concepts varies across disciplines. The emergent social pattern is plotted in a two dimensional space defined by the social and knowledge axes. The simulation environment allows studying the longitudinal emergence of design trends resulting from varied initial conditions and what-if scenarios that are difficult to study in the real-world. Exemplary results are presented.

Keywords Common ground · Legitimation theory · Identity · Influence · Emergence

V. Singh (✉)
School of Engineering, Aalto University, Espoo, Finland
e-mail: Vishal.Singh@aalto.fi

J. S. Gero
Krasnow Institute for Advanced Study, George Mason University, Virginia, USA
e-mail: John@johngero.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_50, © Springer India 2013

1 Introduction

Design involves multidisciplinary faculties, including technical and social know-how. The widespread use of the term 'Design' across different disciplines often leads to debates over 'art' and 'science' distinctions. While such debates may never have clear outcomes, a common understanding and acceptance of design typically emerges over time through social processes within a given discipline. Over an extended period of time, society develops mechanisms and processes to recognize and legitimise design practices within its community or discipline. Since this recognition and legitimation of design practice is a longitudinal process and as a consequence is difficult to study empirically, the understanding of social emergence of design practice is currently limited. Therefore, this research adopts a computer simulation based approach to investigate the longitudinal patterns in social emergence of design practice. Agent based studies have evolved as a powerful research method to conduct what-if studies for scenarios that are difficult to study in the real-world, and allow longitudinal studies with greater control of the parameters [1, 2].

This research reported in this paper adopts legitimation code theory [3] as the underlying framework to develop the model. LCT is based on five principal dimensions that include autonomy, density, temporality, specialization and semantics, of which the last two are most developed. According to the specialization principle of legitimation code theory, design practice and recognition within a social group are driven through both the knowledge and knower modes [4], i.e., the design practices emerge and evolve under the influence of the social structure as well as the knowledge structure. This model simulates a society of design agents with different design backgrounds affiliated to different teams and organizations. Design agents interact with each other and the concepts associated with the different disciplines. Following legitimation code theory, design agents within each discipline are modeled to be attracted towards concepts, i.e., knowledge mode, as well towards the other design agents, i.e., knower mode, which collectively influence the design practice. The force of attraction towards the knower or concepts varies across disciplines. The emergent social pattern is plotted in a two dimensional space defined by a social axis and knowledge axis such that design agents higher up the social axis exert higher knower force while the concepts higher up the knowledge axis exert higher knowledge force.

The simulation environment allows studying the longitudinal emergence of design trends resulting from varied initial conditions such as the number of design agents in the society and level of interdisciplinary interactions. The objective of this research is to investigate questions such as:

How does the design practice emerge over an extended period in a society? How do design trends vary across disciplinary and multidisciplinary communities?

This paper presents the theoretical basis for developing the computational model and provides preliminary simulation results to demonstrate the usefulness of an agent based approach in understanding complex social behaviors that emerge at global level from simpler local interactions.

2 Social Emergence of Design Practice

Design concepts and capabilities such as creativity have been argued to be social constructs [2]. Similarly, Bourdieu [5], Nonaka [6] and others have discussed the social creation and emergence of knowledge in a broader context. In this respect, legitimation code theory provides a useful conceptual framework to study the emergence and acceptance of knowledge in a social-cultural context.

Legitimation code theory is built on the premise that in any society the prevalent practices, beliefs and knowledge are driven towards something and or someone, such that there is an epistemic relation to an object (ER) and a social relation to a subject (SR) [7, 8]. The epistemic relation pulls the agents in the society towards knowledge, i.e., knowledge mode while the social relation pulls the agents towards the socially dominant agents, i.e., knower mode, Fig. 1.

Figure 1 represents the legitimation codes. The values (±) along the X-axis represent the strengths of epistemic relation, and the values (±) along the Y-axis represent the strengths of social relation. Each quadrant of the model corresponds to a specific LCT code. The knowledge code emphasizes concepts, while the knower code emphasises design agents. The elite code emphasises both the conceptual and social dispositions, while for the relativist code neither conceptual nor social dispositions are required.

These legitimation codes conceptualize the dominant basis of success in any particular social context. While there is always a knowledge and knower dimension in any social context, the knowledge or knower dimensions may dominate the other based on the established norms within the context. In design disciplines, even

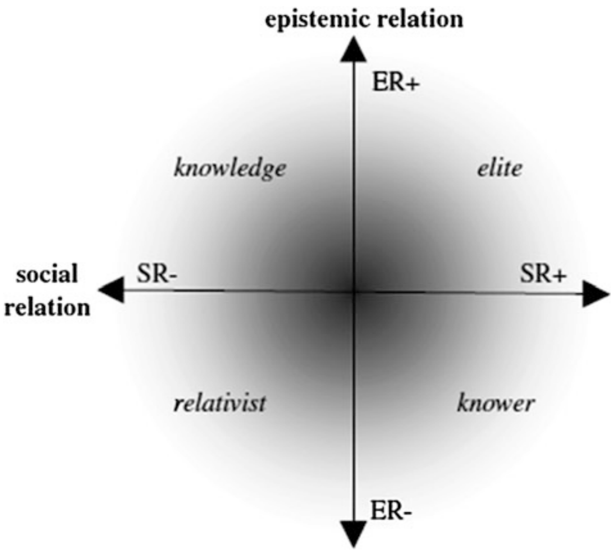


Fig. 1 Modes of legitimation of design practice (After [7])

Table 1 Legitimation codes across different design disciplines (based on [9])

Discipline	Epistemic relation (knowledge mode)	Social relation (knower mode)
Architecture	+	+
Fashion design	−+	++
Engineering design	++	−+

though such debates are common, there is little research in this area. More recently, [9] have compared the legitimation codes across different design disciplines including architecture, fashion design and engineering design, Table 1.

According to [9], while architecture tends to show greater balance between the knowledge and knower modes, in fashion design the knower mode tends to dominate, while in engineering the knowledge mode tends to dominate.

3 Why Computational Simulations as the Research Method?

Though [9] have shown that the relative contributions of the knowledge mode and the knower mode in legitimation and recognition of design practices varies across the studied disciplines, the understanding still remains subjective and abstract. For example, while [9] have established that legitimation of design practice in fashion is more knower driven than knowledge driven, it is currently difficult to establish how do these relative values compare, i.e., whether the relative contributions are linearly related or exponentially. The difficulty in establishing such relationships is further exacerbated because of the socially emergent nature of legitimation mechanisms, which are gradual and longitudinal processes, requiring observations and data collection over an extended period of time. In such a complex longitudinal scenario if the research were to rely entirely on real-world observations and case studies, the progress of our understanding of the legitimation practices and their relationships with associated parameters will remain rather slow and partial because of the time, cost and resources needed to build a comprehensive theory. Computational simulation test-beds using agent based models provide a complementary research method and infrastructure that can reduce the time, cost and resource constraints towards generating and testing the promising theories. Building such a research infrastructure, i.e., computational model may be a challenging task but once the initial infrastructure is created, it allows rapid extensions and explorations across different parameters and scenarios of interest.

Hence, this research adopts computational simulations to study the emergent social patterns across different design disciplines for what-if scenarios, based on informed assumptions derived from subjective understanding of the role of knowledge modes and knower modes across the different design disciplines. Since the underlying assumptions in the computational model and parameter values at

Table 2 Research questions, requirements and parameters

Research questions	Simulation requirements	
	Assumptions	Parameters
How does the emergent social pattern of design recognition vary across disciplines?	Forces between parameters	Design agents with different disciplinary backgrounds
How does the social pattern in multi-disciplinary design society compare to uni-disciplinary social environment?	Initial state (starting positions of design agents and concepts)	A set of concepts associated with different disciplines
		Demography, i.e., population mix, population size

time t = 0 are known in the simulations, the observed causal effects can be stochastically established with high confidence levels.

This research is planned bottom-up such that the initial simulations are conducted with as few assumptions and as few parameters as needed to generate and test meaningful hypotheses about the emergent social patterns across different disciplines. Table 2 lists the key research questions, and the corresponding minimal requirements to enable investigating these questions.

In order to compare the emergent social patterns resulting from differential knower and knowledge modes across different disciplines, we need to make informed assumptions about the relative knower and knowledge force of attractions across the different disciplines. Once force values are assumed they are kept constant across the different simulations, while the demography of design society is varied such that resulting patterns can be compared. Typically, designers work within teams and organizations, and affiliation to such teams creates a nested structure. These teams may have varied inclinations towards knowledge mode or knower mode and in the process affect the emergent patterns. Further, in order to understand the effects of scale, simulations are conducted with different population sizes, including more concepts and teams.

Once the findings of these simulations are known, additional parameters and assumptions can added to create complex scenarios. The research outcomes are intended to inform future empirical studies by identifying promising and potentially interesting hypotheses.

4 Computational Framework

The computational model is implemented in MASON [10], a java based multi-agent system. Each entity in the model that needs interaction, i.e., the designers, concepts and teams are implemented as agents within the simulation environment such that there are dynamic connections and forces of attraction between design agents, between design agents and concepts, between concepts, between design agents and teams, and between teams and concepts.

Representing each entity as agents gives them agency, which allows design agents, concepts and teams to move within the two dimensional space as per their interactions with other design agents, concepts and teams. Each entity has an influence radius such the force of attraction between any two agents is directly proportional to their influence radius.

Following the two modes in Legitimation Code Theory, the two dimensional space is defined by orthogonal axis with epistemic (knowledge) mode along the ordinate while the social (knower) mode is represented along the abscissa. As the interactions take place, the emergent social pattern including the knowledge and social dimensions of the design agents, concepts and teams are recorded and can be graphically observed. Following are the key assumptions and considerations in the model.

4.1 Forces of Attraction and Disciplinary Effects

Based on [9], three disciplinary backgrounds are considered to include architecture, fashion design and engineering. Design agents, teams and concepts are assumed to be associated to belong to one of these three disciplines such that the disciplinary background of a design agent determines how much it is influenced by knower mode and knowledge modes. Table 3 displays the assumed forces.

Following the findings in [9], forces corresponding to knower modes are highest for fashion disciplines and least for engineering disciplines. For example, constant **K** in agent–agent (knower) attraction is highest for fashion design agents and least for engineering design agents. On the other hand, forces corresponding to knowledge mode are highest for engineering design agents and least for fashion design agents. Accordingly, constant **E** in agent-concept (knowledge) attraction is highest for engineering design agents and least for fashion design agents. Similarly, other forces and constants are assumed using similar arguments.

4.2 Starting Conditions

At the start of the simulation, i.e., at $t = 0$, all the entities in the simulation environment including design agents, concepts and teams start with a pre-defined position the two dimensional space, defined by their social dimension and knowledge dimension. The initial scenario across all the entities, i.e., where the different agents, concepts and teams start from may influence the emergent social pattern. However, since the focus of the study reported in this paper is the effects of disciplinary backgrounds and not the initial conditions, in all the simulations the starting conditions remain the same.

Table 3 Assumed values for knowledge and knower attraction forces

	Entities	Force	Discipline conditions
1	Agent (A^1)–Agent (A^2)	Constant **K** × (InfluenceRadius A^1 × InfluenceRadius A^2)/ (Square of social distance between A^1 and A^2)	For design agents IF discipline is architecture **K** = 100 IF discipline is fashion design **K** = 1000 IF discipline is engineering **K** = 1
2	Agent (A^1)–Concept (C^1)	Constant **E** × (InfluenceRadius A^1 × InfluenceRadius C^1)/(Square of distance between A^1 and C^1)	For design agents IF discipline is architecture **E** = 100 IF discipline is fashion design **E** = 1 IF discipline is engineering **E** = 1000
3	Concept (C^1)–Concept (C^2)	Constant **D** × (InfluenceRadius C^1 × InfluenceRadius C^2)/(Square of distance between C^1 and C^2)	IF C^1 and C^2 belong to same discipline **D** = 100 ELSE **D** = 1
4	Agent (A^1)–Team (T^1)	Constant **K** (Similar to 1)	Same as 1
5	Team (T^1)–Concept (C^1)	Constant **E** (Similar to 2)	Same as 2
6	Team (T^1)–Team (T^2)	Constant **K** (Similar to 1)	Same as 1

4.3 Analyzing the Outcomes

Given that there are limited prior study to benchmark the findings, this research poses challenges in analyzing the outcomes. Hence, visual representations of emergent patterns across different scenarios provide useful preliminary comparison across different cases. Developing the model requires iterations to calibrate the assumptions.

5 Simulation Results and Discussion

The first set of simulations was conducted to compare the effects of disciplinary backgrounds. A summary of the conducted simulations is presented in Table 4.

For each simulation case, 30 simulation runs were conducted. A snapshot of the typically emergent social pattern for the different cases is presented on the left hand side of Fig. 2, while the plot on the right hand side of Fig. 2 shows a pattern created by averaging the results from 30 simulation runs for each case.

Table 4 Simulations conducted to compare patters across different disciplines with population of 32, 6 teams and 12 concepts

Case	Distribution/Demography
1	All design agents, teams and concepts associated with architecture
2	All design agents, teams and concepts associated with fashion design
3	All design agents, teams and concepts associated with engineering design
4	Mixed population with equal distribution of architecture, fashion design and engineering design agents, teams and concepts

As seen in the first three cases of Fig. 2, the computational model simulates distinct patters of social emergence of design practice across different disciplines. A society with only architectural design agents (red), teams (black) and concepts (blue) grows towards the knowledge dimension but there is increasing pull for design agents towards the knower (social) dimension once higher levels of knowledge dimension is achieved. The knowledge leaders in architectural design society also grow along the knower dimension, becoming attractors for other agents to follow them through the knower mode. Though this pattern appears to be the result of assuming balanced knowledge and knower forces for architectural design agents, unlike the observed pattern, it was expected that the architectural design agents, teams and concepts would move at approximately diagonal across the two axes.

A society comprising of only fashion design agents, teams and concepts also shows a trend towards leaders and followers. However, unlike the architectural design society, in fashion design society agents at lower levels of knowledge tend to have greater diversion and attraction towards the knower mode. As a result, the knowledge divide between fashion design leaders and followers tends to increase over time because some of the followers at lower knowledge levels develop greater attraction for social dimension. While fashion design agents were assumed in the model to have greater attraction towards knower mode, we had not expected the emergence of differential knower level pulls corresponding to agents' relative knowledge levels. Furthermore, simulation results indicate that in the fashion design society the rate of growth of design agents (brown) may outpace teams (black).

A society of engineering design agents primarily follows the knowledge dimension, and the design agents (grey) and teams (black) grow at comparable rate. The society of engineering design agents shows patterns that were expected and are consistent with the assumptions.

Given that the three different design societies show distinct emergent patterns that broadly conform to the underlying legitimation code theory of design practice for the known disciplines, the findings from case 4 should provide insights into emergent social patterns of design practice in a multidisciplinary design society, which has not been empirically studied so far. It was expected that the multidisciplinary design society will show a greater balance between knowledge and knower driven design practice, with design agents distributed along both

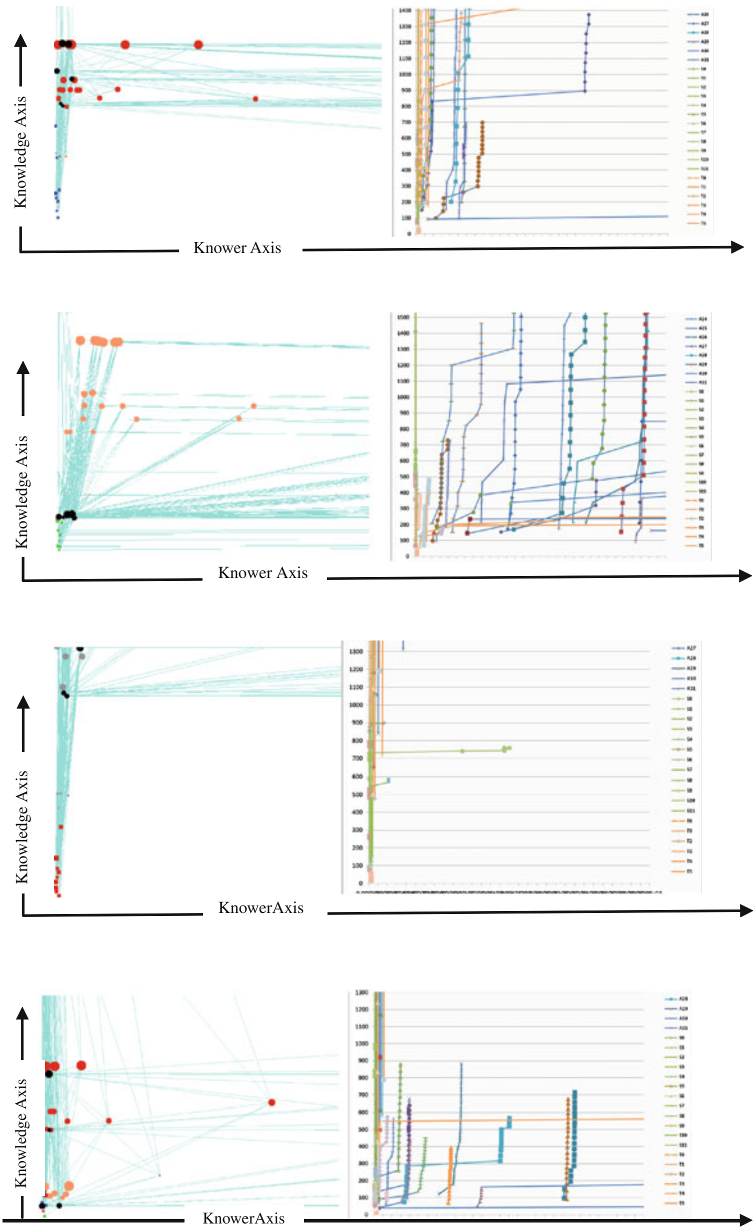


Fig. 2 Emergent social patterns across different simulation cases for cases in Table 4 *Case 1*: Only architecture design agents. *Case 2*: Only fashion design agents. *Case 3*: Only engineering design agents. *Case 4*: Multidisciplinary society with architecture, fashion and engineering design agents

dimensions. Though the emergent patterns in multidisciplinary design society does create a balance (compare right hand side of case 4 with the right hand side patterns of cases 1, 2 and 3), the design agents from different disciplinary backgrounds tend to cluster along different knowledge levels. Engineering design agents grow faster towards the knowledge dimension (being knowledge driven), during the same period the fashion design agents remain at lower knowledge levels as compared to the architecture design agents. Similarly, the growth of architecture and fashion design agents along the social dimension is greater than engineering design agents during the same duration. Thus, the simulation results in case 4 suggest that unless there is greater overlap in design concepts and practices across the different design disciplines, segregation of design agents across disciplinary groups is likely to emerge creating knowledge and social gaps that will widen over time.

In order to test whether the social pattern observed across the different cases depends on the number of design agents, teams and concepts, all the simulations listed in Table 4 were repeated with double the number of entities, i.e., 64 design agents, 12 teams and 24 concepts. The emergent social patterns in simulations with 64 design agents are similar to the observed patterns in simulations with 32 design agents. Findings suggest that the differential social pattern of design practice across different disciplines is potentially scalable, which can be tested further by varying the population sizes by higher order. Similarly, by changing the initial values of the parameters we can investigate how this pattern varies with the position of the influential design agents?

In the reported simulations, design agents are affiliated to teams and organizations, and the legitimation practice in the design society is mediated by this nested structure such that the teams and the design agents within these teams both influence the emergent legitimation practice. The role of this nested social structure in shaping the legitimation practice can be better understood by comparing these findings with results from simulations where the nested structure is not considered.

6 Conclusion

A computational model of legitimation of design practice is developed as a simulation test-bed, based on the specialization principles of legitimation code theory. The computational model is developed as a research infrastructure that supports generating and testing what-if scenarios with various design societies, starting with the comparison of the legitimation practices in uni-disciplinary design societies against multi-disciplinary design society. The emergent social patterns across the different cases involving design agents associated with architecture, fashion design and engineering are broadly consistent with the expected patterns, as known from the literature. The consistency of the simulation results with empirical data provides internal validity of the simulation platform, suggesting that the assumptions within the model can be relied upon for further studies. Findings from the simulation results suggest that irrespective of the social composition and disciplinary backgrounds, clusters of design agents are created at different knowledge levels. This clustering of agents in a multidisciplinary society is marked by disciplinary segregation. Though the assumptions and the simulations were based on relative epistemic and social code values for the studied disciplines, i.e., architecture, fashion and engineering design, the studies can be extended to study and compare the legitimation practices across other design disciplines and sub-disciplines.

Nonetheless, the primary challenge at this stage is to externally validate the model and simulation results because there are no empirical studies to benchmark the comparative patterns of legitimation practice across uni-disciplinary and multidisciplinary design societies. Thus, the current scope of the computational model is limited to simulate what-if scenarios and generate potentially interesting hypotheses to be investigated empirically. The primary contribution of this paper is to describe the development, and demonstrate the usefulness, of an agent based simulation model in studying the legitimation of design practice as a socially emergent phenomenon.

Acknowledgments This work is supported in part by a grant from the US National Science Foundation under Grant no: NSF SBE-0915482. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

1. Carley K (1994) Sociology: computational organization theory. Soc Sci Comput Rev 12:611–624
2. Sosa R, Gero JS (2005) A computational study of creativity in design. AIEDAM 19(4):229–244
3. Maton K (2000) Languages of legitimation: the structuring significance for intellectual fields of strategic knowledge claims. Br J Sociol Educ 21(2):147–167
4. Carvalho L (2010) A sociology of informal learning in/about design. Ph D Thesis, Department of Architecture Planning and Design, The University of Sydney
5. Bourdieu P (1983) The field of cultural production, or: the economic world reversed. Poetics 12(5):311–356
6. Nonaka I (1994) A dynamic theory of organizational knowledge creation. Organ Sci 5(1):14–37
7. Maton K (2006) On knowledge structures and knower structures. In: Moore R, Arnot M, Beck J, Daniels H (eds) Bernstein: policy, knowledge and educational research. Routledge, London, pp 44–59
8. Maton K, Muller J (2007) A sociology for the transmission of knowledges. In: Christie F, Martin JR (eds) Language, knowledge and pedagogy: functional linguistic and sociological perspectives, Continuum, London pp 14–33
9. Carvalho L, Dong A, Maton K (2009) Legitimating design: a sociology of knowledge account of the field. Des Stud 30:483–502
10. Luke S, Cioffi-Revilla C, Panait L, Sullivan K, Balan G (2005) MASON: a multiagent simulation environment. Simulation 81:517–527

Improving Common Model Understanding Within Collaborative Engineering Design Research Projects

Andreas Kohn, Julia Reif, Thomas Wolfenstetter, Konstantin Kernschmidt, Suparna Goswami, Helmut Krcmar, Felix Brodbeck, Birgit Vogel-Heuser, Udo Lindemann and Maik Maurer

Abstract In collaborative engineering design research projects, the efficient and effective collaboration between the individual research groups is an important factor for the overall success of the project. However, different disciplines, research foci and personal backgrounds influence successful collaboration. The work presented in this paper focuses on the collaboration concerning models developed by individual subprojects and proposes a framework to support the necessary collaboration. Existing shortcomings are identified within a large scientific project in combination with an extensive literature review. The developed framework is based on two checklists in form of a model requirements document and model specification containing important aspects of models that need to be considered and communicated during the research project. Beyond the successful application for supporting collaboration in engineering design research projects, the insights and implications of this paper can be transferred to all other collaborative projects, where models are to be communicated between individuals or teams.

Keywords Modeling · Collaboration · Engineering design · Communication

A. Kohn (✉) · U. Lindemann · M. Maurer
Institute of Product Development, Technische Universität München, Munich, Germany
e-mail: kohn@pe.mw.tum.de

J. Reif · F. Brodbeck
Organisational and Economic Psychology, Ludwig-Maximilians-Universität München, Munich, Germany

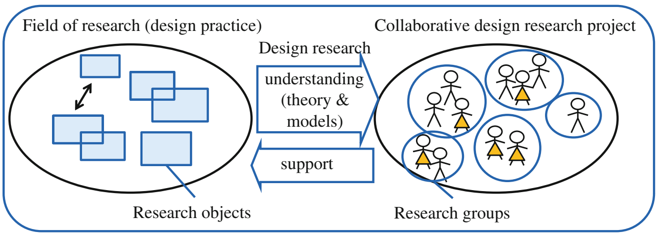
T. Wolfenstetter · S. Goswami · H. Krcmar
Chair for Information Systems, Technische Universität München, Munich, Germany

K. Kernschmidt · B. Vogel-Heuser
Institute of Automation and Information Systems, Technische Universität München, Munich, Germany

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_51, © Springer India 2013

1 Introduction: Motivation and Problem Statement

In collaborative research projects, individual research groups work together in order to achieve common project goals. Efficient and effective collaboration plays an important role for the overall success of a project [1]. However, several barriers exist and have to be overcome to ensure the success. In this paper, we focus on the barriers, and the support mechanisms for overcoming these barriers in collaborative engineering design research projects. In general, the main goal of design research is to make design more efficient and effective in order to enable design practice to develop successful products [2]. The development of understanding (via models and theories) and the subsequent development of support are most important results of design research [2]. Several challenges emerging from the nature of design research occur in collaborative engineering design research projects (see Fig. 1). As design research is strongly linked to design practice, trends and changes in design practice influence design research. For example, today's products and corresponding innovation processes are characterized by increasing level of complexity [3]. Furthermore, a trend from "normal" mechanical products to a combination of products and services (Product-Service-Systems) is observed [4]. As a consequence of these trends, the research field splits up into different interrelated research objects which in turn increases the number of disciplines and research groups involved in research projects. Each of these research groups holds very different views (such as models) on certain research objects. As the research objects are interrelated, the need for communication and mutual adjustment of the emerging models is important. However, models evolve and change over time as the research progresses which might impede efficient collaboration. Additionally, different disciplines, research foci and diverse personal backgrounds influence collaboration concerning the emerging models. For example, one discipline builds a model which is misinterpreted by another discipline as the semantics of the model is unknown.



Causes and resulting challenges in collaborative engineering design research projects	
Increasing complexity in the research objects (product and processes)	High number of research groups
Trend from traditional products to PSS	High number of involved disciplines
Strong interrelation of the single research objects	Need for shared understanding about the field of research (shared theory and model understanding)

Fig. 1 Causes and resulting challenges in collaborative engineering design research projects

As models play an important role in design research, we propose a framework to support collaboration in design research projects by providing a more efficient and effective way of communicating emerging models among the various research groups. The framework is developed and tested within the collaborative research center 'SFB 768—Managing cycles in innovation processes—Integrated development of product-service-systems based on technical products'. In this paper, this collaborative research center serves as a use-case for deducing requirements and evaluating the proposed framework. The overall aim of the project is the understanding and design of innovation processes concerning the specific characteristics and interdependencies of cycles in innovation processes. The project consists of 14 subprojects (research groups) within 7 institutes at 4 faculties (mechanical engineering, psychology, economics and computer science). For details about the project SFB 768 please refer to [5] or www.sfb768.de.

This paper is organized as follows: First, the scientific method of our research is described. Second, we provide the theoretical and conceptual background for our work such as the necessary definitions and a state of the art overview concerning model theory, model quality and collaborative modeling. We then explain requirements for collaborative modeling in engineering design research projects based on our use-case. Next, we summarize our main findings and show the developed framework that bases on two checklists in the form of a model requirements document and a specification document. The framework is tested within the use-case and our main findings are presented in the next section. We conclude the paper with a discussion of our findings and provide an outlook for future research.

2 Method

We first conducted an extensive literature review in order to gain a deeper understanding about scientific modeling in diverse research disciplines, good modeling practices and the fundamentals of collaborative modeling. The results were structured and summarized. Second, we carried out three workshops in which participants discussed different aspects of 'modeling' in the context of the SFB 768. Participants (31 members of the SFB 768) circulated through the workshops so that everyone took part in each workshop. Participants' inputs were documented via written protocols. At the end of the workshops, a plenum discussion with all participants was held in order to integrate the results of the workshops and deduce requirements for the framework. The developed framework was tested within the SFB 768 iteratively. In a first step, it was tested for its applicability by 12 members of the SFB and revised accordingly. Then, it was applied by all the members of the project. Qualitative feedback was collected and potentials for improvement were derived.

3 Theoretical and Conceptual Background

3.1 Model Theory and Variety of Models Between Disciplines

In our context, we use the term "model" in a general definition according to [6]: "a model is a representation of an original. It represents relevant attributes for a model user and is used for a certain period of time to serve a certain purpose." Various types of models exist, differing in their purpose, representation, language, validation or application. Each discipline uses its own models and has a different interpretation of this term. For example, a scientific model as used in psychological research is "a set of representations, rules, and reasoning structures that allow one to generate predictions and explanations" [7]. In contrast, product models in engineering design always contain product-related information [8]. The modeling languages used to represent a model also differ between disciplines. A modeling language consists of a textual or graphical notation, called syntax, and the defined meaning of the notation, called semantics [9]. Basically every 'real' language can be used for a textual modeling. However, formal modeling languages avoid ambiguities, facilitate the computer-based model interpretation and make the models easier understandable for people of other disciplines [10].

3.2 Good Modeling practice

There are several rules and guidelines for good modeling. Perhaps the most important aspect about modeling is that a model has a clear purpose (e.g. to develop knowledge and understanding about a system) and not just to create the model itself [11]. The process of modeling should therefore be evolutionary since information about the system is obtained step by step during the act of modeling [12]. In this context modelers should start with simple assumptions and add complications only as necessary [13]. A basic trade-off in modeling is that models should be comprehensive but yet be sufficiently detailed to reflect important characteristics of a system in a realistic way. The amount of details should be based on the modeling objectives and only components that are relevant for decision-making need to be included [12]. When complex systems are to be mapped to a model one should refer to the divide-and-conquer principle. In general it is easier and also more useful to develop a set of simple interrelated models than to squeeze everything into a large and complex model. This applies especially to situations in which modeling is done by a team of people [13]. Different approaches for supporting modeling activity exist in various contexts. For example, [14] proposes that the development of simulation models can be supported by using a model requirements document and a model specification.

3.3 Collaborative Modeling: Challenges and Support

In order to use the knowledge and various perspectives from different experts to foster problem solving, good decision-making in complex contexts, and to innovate products and services, it is becoming more and more important to create multidisciplinary project teams [15]. A modeling project in an interdisciplinary team should involve close interaction and information sharing among the various project participants when formulating a problem and building a model. This interaction causes inaccuracies that need to be identified early and corrected efficiently [12]. Also, barriers concerning information and knowledge sharing as mentioned in [16] should be considered adequately. As support for collaborative modeling for distributed teams, IT-support can be a prime enabler for successful collaboration [17]. In order to facilitate distributed teamwork, so-called groupware tools should support communication, document sharing, group discussion and decision-making, as well as calendaring and scheduling. Furthermore teams need access to organizational and external information sources [18].

4 Deduction of Requirements for Collaborative Modeling in the Use-Case

Based on the above described background, we analyzed the needs of individual researchers and deduced requirements for supporting collaborative modeling in the context of our use-case—the transdisciplinary project SFB 768—through workshops. The workshops were grouped according to three main aspects of modeling that influence collaboration: The purposes of the individual models in respect to the overall goal of the project, the intended modeling languages to be used, and further boundary conditions for model integration were discussed. In each workshop, the requirements of the individual research groups were collected and discussed. At the end of each workshop, directives for supporting collaboration were deduced and combined through a plenum discussion.

In the first workshop, the interrelation between the purposes of the individual models and the overall purpose of the research project was discussed. It was identified, that different purposes of the models from the individual research groups as well as different views on the research field exist. This correlates with the initial situation in collaborative projects described above. Most importantly it was concluded, that each model clearly shows its connection to the overall purpose of the research project.

In the second workshop requirements for a modeling language in the single subprojects and the goals and benefits of a jointly used modeling language were discussed. As the different subprojects belong to different domains, and thus the modeling subjects differ strongly, a multitude of requirements for adequate modeling languages exist. While many requirements for a modeling language are discipline specific, it was identified that it would be beneficial to use a common modeling language in order to reduce complexity, understand models of other subprojects more easily and to present the entire research project more cohesively to other researchers and experts. Depending on the number of involved disciplines, it is possible that a single modeling language is not sufficient for all subprojects. In this case, model-clusters should be identified and within these clusters a common modeling language should be chosen.

The third workshop focused on model integration. The analysis of the discussion shows that efficiency is a basic purpose of model integration: redundancies may be reduced, mistakes can be eliminated, time and effort can be saved. A further purpose of model integration is transparency: modelers can develop a meta-understanding of the landscape of models, thus can broaden their knowledge of the whole model system which in turn fosters an advanced communication between the different disciplines. A third purpose of model integration is interconnectedness: relationships between models can be generated and dependencies can be illustrated. Finally, it is a purpose of model integration to enable a holistic perspective on the object of investigation. The following requirements concerning model integration were mentioned: models that are to be integrated should have a clear model type, a defined model context, internal and external interfaces and clear signals at the interfaces. Interfaces between models should be standardized so that they can be applied more easily. There should be a common or shared way of describing inputs and outputs and the models' level of abstraction should be clearly communicated.

The workshops showed that there is a strong need for supporting collaboration concerning the emerging models. In the three aspects a huge variety between the individual models of the subprojects concerning both the modeling process and the expected result was identified. As a conclusion of the workshops, the following aspects were identified as main requirements for supporting the collaborative modeling activities:

- Enable a continuous overview of the models in the individual subprojects.
- Enable a standardized description and documentation of the individual models.
- Provide a guideline and checklist for the modelers to identify which important aspects of modeling have to be considered.
- Identification of synergies between the single models of the projects. For example, common access to needed information or common evaluation scenarios can be identified to reduce the effort within the individual subprojects.
- Enable and identification of interfaces between the individual models.
- Improve deduction of requirements for possibly project-spanning modeling languages or tools.

5 Framework for Improving Common Model Understanding

This section shows the developed framework for supporting common model understanding in collaborative engineering design research projects. It was developed on the basis of the presented literature review and the identified requirements within the use-case SFB 768.

The core elements of the framework are two model checklists (a model requirements document and a model specification) that are exchanged between the researches via a data exchange platform (see Fig. 2). They contain aspects of the models that are most important for the communication between the research groups (see next sections for details). Those two checklists are to be filled out by the individual researchers for each emerging model. The model requirements document is to be filled in the early phase of the project; the model specification in later phases. Organizational aspects (meetings, involvement of experts, milestones, personal support and room for discussion) serve to support the successful application of the framework. Individual and team aspects (motivation, team processes and emergent states as trust or cohesion) complement the organizational aspects. The overall goal of the project (here: managing cycles in innovation processes) serves as "roof" for the framework and influences all tasks.

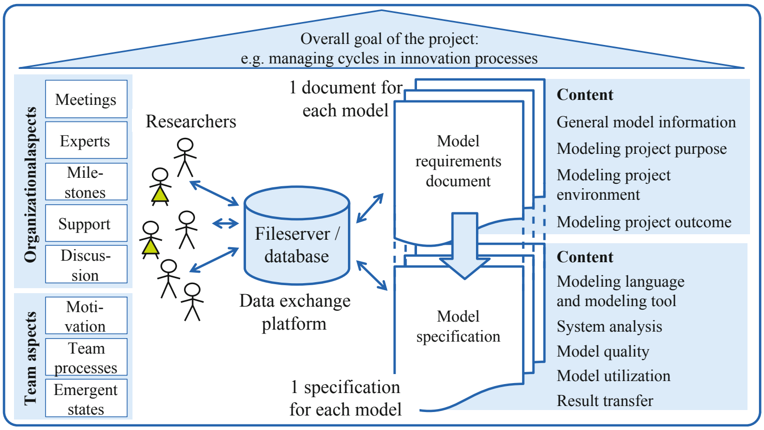


Fig. 2 Components of the framework for improving common model understanding

5.1 Model Requirements Document

The first of the two checklists is the "model requirements document" which is used to describe general specifications of the model and the modeling project at an early stage. The items are grouped based on their subject (Fig. 3). Basically, the

General model information	
Model name	A clear and unambiguous name should be chosen for each model
Subproject	Name of the subproject, which carries out the research
Modeling project purpose	
Purpose of the model	Which goal shall be achieved through the model? Are there any subgoals?
Original and system boundary	What is the original of the model (object of observation)? Can a model boundary be drawn already?
Classification of the model in the objective of the subproject	Which role plays the model in the objective of the subproject
User of the model	Who will use the developed model? (e.g. use in industry or science)
Relation to other models within the subproject	If other models exist or are planned within the subproject, which relations exist between this model and the other models?
Relation to models of other subproject s	Which relations between this model and existing/planned models of other subprojects already exist?
Requirements of the interfaces to other models	Which requirements for the interfaces to other models already exist?
Minimum requirements of the functionality of the model	When is the functionality of the model reached? What are the minimum requirements of the model concerning its functionality?
Timetable	When shall the model be completed? When shall the results of the model be used? What are important milestones during the development of the model?
Modeling project environment	
Institute/subproject	Which institute is responsible for the subproject/model?
Responsible person	Which persons are involved?
Previous knowledge	Which existing information/knowledge can be used for the modeling project? Hereby knowledge of the institute, previous projects and personal knowledge should be considered
Modeling tool/language	Which modeling languages and tools are available and which one shall be used? Are certain languages/tools already determined (reasons)?
Modeling project outcome	
Presentation of results	Where and in which way shall the results be presented? (Graphical/verbal…)
Documentation	In which way shall the model/its usage/experiments be documented?
Requirements for a further use	Which requirements have to be fulfilled if the model shall be used beyond its main purpose? (e.g. regular updates, transfer to other projects…)
Necessary effort for maintenance and care	Is a regular maintenance and care necessary for the use of the model?
Visualization	
Illustration of the model	An illustration of the model should be added for a better understanding. As many details are not yet defined in the early stage the illustration should focus on the modeling purpose or expected goals.

Fig. 3 Model requirements document

definition of requirements and constraints is conducted in the model requirements document while concrete activities are described in the model specification (see Sect. 5.2).

If necessary, the single aspects of the 'Project purpose', the 'Project environment' and the 'Project outcome' have to be specified during the project realization. Hereby the traceability of changes will be ensured by marking changes accordingly.

5.2 Model Specification

In the “model specification” checklist, detailed information about the elaboration of the model has to be provided. The focus lies on the description of the actions and execution of the necessary steps. The model specification can be complemented and added during the modeling project. It is structured according to the main steps of the modeling project in “modeling language and tool”, “system analysis”, “model quality”, “use of the model” and “delivery of results” Fig. 4). Again, for each item within the three groups, a detailed description is given in the figure below.

Modeling language and modeling tool	
Selection of modeling language	How will the modeling language be selected? Are any adaptations of an existing modeling language necessary?
Selection of modeling tool	How will the modeling tool be selected? Are any adaptations necessary?
System analysis	
Information / data requirements	What are the requirements regarding information / data that are needed for modeling? (range/ quality/ format, etc.)
Data- / information transfer	How will existing and available data be used? Is there any format conversion necessary?
Data collection /execution of system analysis	In which way shall data/information about the original be acquired? Description of the implementation of experiments / studies to obtain data.
Presentation and documentation of information	How is the necessary information shown? Description of processing and documentation of the collected data.
Model quality	
Model verification	Is the model consistent to the mental model and the requirements? How shall the model be verified? (also cross-verification with interrelated sub-projects is necessary)
Model validation	Is the model consistent with reality? How shall the model be validated? Which limitations arise regarding the model scope?
Model applicability	How can the practical applicability be assured? (e.g. Case-Study)
Model utilization	
Determination of the experiment-plan / utilization-plan	Please provide a detailed plan stating: Who will use the model? How will the final model be used? What is the intended time frame?
Model adaption and improvement	How will the model be used, adapted and improved? (e.g. iteratively)
Evaluation of results	How will experiments / utilization of the model be evaluated? How will user experiences be captured?
Result transfer	
Working- and presentation documents	How will experiment results and the experiences regarding model utilization be documented? (Description of the intended approach)
Archival storage of model description, parameter sets and results	How will the model description, the necessary data and the results be documented or archived? (Description of the intended approach)
Model- and result transfer	How will the results be transferred to other sub-projects? How can be assured that the model is used in the designated way?
Compatibility of interfaces	How can the cross model functionality be assured regarding interfaces to other sub-projects?

Fig. 4 Model specification

5.3 Application of the Framework and First Experiences

After establishing the basis of the framework and the first drafts of the checklists, the members of the collaborative research project were asked to fill in the checklists. Within each institute, one “expert” was trained in the use of the checklists and the communication platform and served as multiplier for training the other members. So far, both checklists were filled in for 32 models. The content of the checklists was discussed within team meetings und the individual models were presented to the team. It was identified, that the grouping of the single aspects serves well for a structured discussion about the models. Two month after the checklists were filled in, a workshop with all project members was conducted. The positive qualitative impressions of the participants encourage the originally intended purposes of the framework. The usability of the data exchange platform was identified as a potential for improvement as there is currently no automatic versioning available. Furthermore, the individual entries in the checklists can be misinterpreted and sometimes needed personal explication. Despite some room for improvement, the above described requirements for advancing collaboration concerning the emerging models were commonly judged positively.

6 Discussion and Future Work

The problems that are faced by society and academia today are often not solvable by a single research discipline, and therefore call for the establishment of large multi-disciplinary research projects. However, researchers coming from different disciplines work with different research paradigms and this results in significant difficulties in collaborating with researchers from other disciplines. This can have a negative effect on the success of the overall research project. The objective of this paper was to provide a mechanism that facilitates collaboration and common understanding in trans-disciplinary research projects.

We achieved this by developing a framework that allows the diverse research groups to articulate and formalize their requirements regarding models, and a common platform for exchanging this formalized specification of models. Our framework, and in particular the proposed model checklists (requirements and specification documents) serve as initial step in facilitating collaboration in trans-disciplinary projects. Intensive workshops with a diverse group of researchers regarding what they understood and expected out of the models formed the basis for the framework. The usefulness of the checklists were further validated by asking researchers from various disciplines to fill out the checklists with their understanding and expectations regarding the model, and also to comment on the relevance and usefulness of the checklists.

While our use-case allowed us to identify the salient features that are important for a common understanding on models and modeling, the generalizability of the developed framework needs further research investigating its usability in the context of other collaborative projects. Further, the two checklists developed should be tested in different contexts and by different users and refined iteratively based on their feedbacks. This will enhance their completeness for capturing all requirements. In our use-case and evaluation, these checklists were filled in the initial stages of the project. It will be more interesting to see how the model requirements and specifications changes over time as the project progresses. Therefore, to be more useful, the checklists will be updated in regular intervals to reflect current state of understanding within the project or its various sub-projects. This can have significant implications on how the checklists help in creating a shared common understanding, as the understanding evolves over time.

Another potential shortcoming of the developed framework is, that it was both developed and tested within the same research project. The external validity of the framework therefore will be increased by testing it in the context of a different research project, or getting independent experts not involved in the project to review and evaluate the usefulness of the checklists. Moreover, it is planned to evaluate the framework through a longitudinal study. Participants working in collaborative projects fill out the checklists at the beginning of the project and then semi-structured interviews are carried on in later stages to measure the extent to which their overall understanding regarding models in the project have improved because of applying the checklists.

Acknowledgments We thank the German Research Foundation (Deutsche Forschungsgemeinschaft—DFG) for funding this project as part of the collaborative research center 'Sonderforschungsbereich 768—Managing cycles in innovation processes—Integrated development of product-service-systems based on technical products'.

References

1. Mostashari A (2011) Collaborative modelling and decision-making for complex energy systems. World Scientific, Singapore
2. Blessing LTM, Chakrabarti A (2009) DRM, a design research methodology. Springer, London
3. Clarkson PJ, Eckert CM (2005) Design process improvement: a review of current practice. Springer, London
4. Bitner MJ, Brown SW, Meuter ML (2000) Technology infusion in service encounters. J Acad Mark Sci 28(1):138–149
5. Hepperle C, Orawski R, Langer S, Mörtl M, Lindemann U (2011) Temporal aspects in lifecycle-oriented planning of product-service-systems. In: International conference on research into design (ICoRD11), Bangalore
6. Stachowiak H (1973) Allgemeine Modelltheorie. Springer Wien, New York
7. Schwarz CV, White BY (2005) Metamodeling knowledge: developing students' understanding of scientific modeling. Cogn Instr 23(2):165–205
8. Kohn A, Lutter-Günther M, Hagg M, Maurer M (2012) Handling product information—towards an improved use of product models in engineering design. In: 12th International design conference (DESIGN 2012), Dubrovnik

9. Harel D, Rumpe B (2004) Meaningful modeling: what's the semantics of "semantics"? Computer 37(10):64–72
10. Witsch M, Vogel-Heuser B (2012) Towards a formal specification framework for manufacturing execution systems. IEEE Trans Ind Inf 8(2):311–320
11. Crout N, Kokkonen T, Jakeman AJ, Norton JP, Newham LTH, Anderson R, Assaf H (2008) Chapter two good modelling practice. Dev Integr Environ Assess 3:15–31
12. Pritsker A, Henriksen J, Fishwick P, Clark G (1991) Principles of modeling. In: Proceedings of the 1991 winter simulation conference, pp 1199–1208
13. Pidd M (1999) Just modeling through: a rough guide to modeling. Interfaces 29:118–132
14. VDI 3633 (1997) Performance specification of the simulation study. Technical Rule, Germany
15. Brodbeck FC, Guillaume YRF (2012) Effective decision-making and problem solving in projects. In: Wastian M, Braumandl I, v. Rosenstiel L′, West MA (eds) Applied psychology for project managers: a practical handbook for successful project management. Springer, Berlin
16. Riege A (2005) Three-dozen knowledge-sharing barriers managers must consider. J Knowl Manage 9(3):18–35
17. Krcmar H (2010) Informationsmanagement, vol 5. Springer, Berlin u.a., p 658
18. Vick RM (1998) Perspectives on and problems with computer-mediated teamwork: current groupware issues and assumptions. J Comput Documentation 22(2):3–22

Issues in Sketch Based Collaborative Conceptual Design

Prasad S. Onkar and Dibakar Sen

Abstract Sketch is the primary mode of concept exploration and development in the early stages of design. In a global product development scenario, collaboration in the early fluidic stages could minimize design conflicts and enhance design understanding. In this work, the potential modalities of interactions among the collaborating designers in early stages using 3D articulated sketch based concept models are proposed. Depending upon the spatio-temporal characteristics, issues related to the hardware, software and network infrastructure in four possible collaboration scenarios are identified. It is argued that the 3D sketching techniques, earlier developed for haptics-enabled, articulated, conceptual designs, can be extended to support design collaboration using evolving concept sketches. The attributes of the 3D sketches and the requirements of the different collaboration scenarios seem to have an implicit and synergistic relationship. Results of initial experiments using TCP/IP based view sharing and interaction on an articulated 3D concept-sketch for elemental collaboration exercises are also reported.

Keywords Conceptual design · Collaborative design · 3D sketching

---

P. S. Onkar · D. Sen (✉)
Center for Product Design and Manufacturing, Indian Institute of Science, Bangalore, India
e-mail: dibakar@cpdm.iisc.ernet.in

P. S. Onkar
e-mail: prasad@cpdm.iisc.ernet.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_52, © Springer India 2013

1 Introduction

Product design is becoming pervasive and ubiquitous. Product design and development activities have become distributed. The products are being developed in different places by different people at different time [1]. Designing of products is becoming more complex to serve better to the increasing customer needs. Increasing complexities call for expertise from different domain. Collaborative design [2] is one of the important strategies which help to improve the overall productivity of the organization by enabling interaction between different stakeholders of the product being designed.

In the conceptual design process, interactions happen between the designers about the product concept and also with the design representations of the concept like sketches, CAD models and physical models/prototypes. Collaboration in the crucial phase of conceptual design has been envisaged to improve the design outcome [3].

In a global product development scenario, complex products are designed and developed in a distributed environment. It is, therefore, imperative to have effective collaboration among the participating teams which are often from diverse domains of expertise. Collaboration is about interaction among agents to work toward a common objective. It is characterized by leveraging the complementary core competencies of participating agents.

Collaborative creative exploration of the product concept is shared based on the domain expertise viz. structures, systems, controls, styling etc., of the participating parties. Further subdivision is limited by the meaning associated with a chunk of work. For example, when creating a concept sketch of a product, each designer in a team cannot be assigned the responsibility of drawing some strokes. Rather, each designer would individually explore a meaningful entity of the product, subassembly or component. A system for facilitating collaboration should support, record and assimilate the interaction among the agents. In the context of product design, product is the central theme for all interactions; clarifying and disambiguating the appearance, structure, behavior and function of the product. Thus, it is a peculiarity of collaborative design that we need to consider not only the interactions *about the design* but also that *with the design*. Queries about design require interaction among the designers; interaction with the design requires the representation to be responsive enough to support independent exploration. Such independent explorations are naturally supported by physical prototypes. However, the 2D rendered sketches of the product as presently being used as the reference, can barely support any query related to interaction with the design. Designers use sketching for different purposes in the early stages of design like, *visual externalization of ideas*, *capturing fleeting ideas* and for *exploration of ideas and concepts* [4]. Also, sketching is used as an aid for mental simulation of the physical behavior of the concept called as ***behavior simulation*** [5]. In this, the sketched components provide the visual feedback about the feasibility of the perceived combination and help a trained designer to visualize the component interaction and to evaluate if the product would work as desired. Apart from this, sketching is used as a medium of interaction in design ***collaboration***. In this, sketch forms a platform for negotiations and propositions on the ideas.

Concept sketching is a designer centric rather than a collaboration centric activity. Even today, designers prefer "paper and pencil" type sketching in the early stages of design for concept exploration because of their training, experience and skill. However, such 2D sketches of 3D products have inherent limitations such as (a) it requires special skills to represent the 3D objects on 2D paper with right view point and perspective (b) designers spend major portion of the time and skill in generating impressive *3D effects* and (c) sketch has no representation for the behavior that produces the *functionality*. Designers represent the *expected* motion and behavior of the components using *annotations* on the sketch which are *unverifiable*.

A CAD model, created from the concept sketches, overcome these drawbacks and facilitates the *engineers* to perform engineering analysis. Based on the analysis, engineers may suggest modifications. This cycle of "*designers generate* (*modify*), *engineers evaluate*" repeats until the required functionalities are achieved. Similarly, PDM systems support collaboration, but they require well-defined geometric models and other data related to different domains. However, such a crisp representation is not available in the early fluidic state of conceptualization. By the time the crisp representation of the product is available, majority of the design decisions are already made, and the cost of reversing them would be high. On the other hand, in the early fluidic state of conceptualization, in absence of the support for analysis, the designers may not be able to foresee if the product would deliver the required functionality! If one could intuitively explore the components, structure and behavior of a design systematically, with a little knowledge/expertise in the domain, many communications about the design would be redundant and collaboration would be more efficient and effective. Hence, the goal of the present work is to support design collaboration right from the conceptualization stage.

Methods developed for component identification [6], behavior simulation [5] and constraints specification [7] provides a tentative embodiment of the product concept which additionally supports easy and natural interaction with the design. These methods, though, developed for standalone concept exploration, have synergistic relationship with the requirements for collaborative conceptual sketching. Hence, in this work, we explore how these capabilities developed in-house enable a novel sketch based collaboration system to provide better means of interactions among collaborating designers.

2 Literature Survey

Kvan [2] gives a brief overview of the literature on collaborative design. Starting from the etymological perspective of the word *Collaboration*, he clarifies the distinction between words of similar meaning like co-operation and co-ordination. He also discusses its importance in the design process and computer based implementation. Maher et al. [8] studied the designer's behavior in a computer mediated collaborative design exercise. He observed that designers tend to document more information during non-collaboration and also exclusive collaboration gave more productive results.

Wang [3] reviewed the literature for collaborative conceptual design and mentioned several approaches and technologies for collaborative conceptual design. It also highlighted that the decisions made in the early stages have more impact on the design.

Sketching plays an important role in the early stage of design [4]. There has been growing interest to understand sketches in the context of design thinking and creative exploration. Some approaches focused on identifying geometric shapes and diagrams in sketches [9, 10]. Some other methods focused on generating 3D models from 2D sketches [11–13]. As the technologies developed to access 3D space, devices like Phantom, trackers and motion capture systems became popular. Direct 3D shape creation methods in 3D virtual environment have been proposed using such devices [14, 15]. Some of the issues related to feel of control, depth perceptions and visualizations have been addressed with the use of haptics and stereovision [7, 14].

Techniques are being developed to perform engineering analysis, which are typically carried out in the later stages of design, using sketches themselves viz. strength analysis [16], static analysis [17] and dynamic analysis [18] using a sketch. Concepts can also be evaluated for their behavior [5]. All of these systems are standalone applications and not used for collaboration. In a complex collaborative environment the creation and evaluation has to happen concurrently to reduce the concept development time. Huang and Mak [19] demonstrated the use of formal design methods in a web based collaborative design. NetSketch [20] is a sketch based collaborative system which supports distributed sketch creation. Fan et al. [21] has shown the use of freehand sketching and CAD modeling in distributed environment. Most of the existing literature focused only on the generation phase during the collaboration experiment.

However, the generative phase of the conceptual design is highly individualistic, involving introspection, creativity, visualization and understanding; wherein, the designers are unlikely to solicit collaboration. Interaction among designers is required for acceptance, conflict resolution, cross domain verification, etc. Hence, a sketch development environment should support the first (generation) and the collaboration environment should support the second (interaction). This paper explains the issues in developing an environment for collaborative conceptual design.

3 Requirements in Collaboration Scenarios

In collaborative product development, the aim is to support interaction with the designer and also with the design. As indicated in Sect. 1, interaction with design needs an embodied model of the product. In the initial phase of conceptualization, mostly physical principles and their interactions are explored which has limited scope for detailing. Sketches are rich in information because they contain data pertaining to the product's shape, behavior, functionality and usage details. Capturing these salient features of the sketch helps in better understanding of the design process. The techniques in [5–7], helps in constrained exploration with better insight into the product's behavior.

Designers use traditional methods to communicate like, talking with each other, write, makes gestures, etc. during their interactions which may not be enough when discussing *about a product*. Typically designers use some representation of the product model like sketches, CAD models, and physical models/prototypes to support the discussion. They enhance the communication by providing visual feedback and making the discussion more focused. Therefore, interaction *with the concept* model should be supported in a collaborative environment.

The requirement for collaboration in the early stages of design arises because product development needs knowledge from diverse domains. The expert designers may not be available at a single place at a particular time to resolve issues and conflicts of interest. They could be located at different geographic location and time zones. Based on the spatio-temporal relationships among the stake holders, collaborative interactions are categorized [22] into *co-located synchronous*, *distributed synchronous*, *co-located asynchronous* and *distributed asynchronous* modes. Approaches reported in literature aim at making two collaborating designers feel the presence of each other to perform a common task such as collaborative sketching [23]. The need for such tasks in the process of real designing is hardly elaborated. We believe that the types of interactions need to be supported for each category is different, and that different categories co-exist in a hierarchy.

3.1 Co-located Synchronous

In this scenario the designers are located at a common place simultaneously and are interacting with a common concept model. The designers discuss the proposed concept by communicating face-to-face, and interacting using white boards, sketches, CAD models and other supporting documents. In a sketch based collaboration interface, direct interactions with the proposed concept would clarify many doubts related to the form, structure and behavior of the product. The sketch is created with strokes but interpreted in terms of components and behaviors; direct access to the strokes therefore is irrelevant. Only the *functionally segmented* view of the sketch needs to be presented for view transformations and tangible kinematic *behavior exploration*. Additionally, the system should allow collaborating designers to scribble and comment on the sketch in an interactive environment to support natural interactions and future referencing. One challenge here is to manage the *identity* of individuals contributing to these *annotations*.

3.2 Distributed Synchronous

In this modality, the designers are located at different geographic location places are interacting in real-time. It is evident that the informal and natural modalities of communications such as gesture and eye-contact are not available. The interaction between the designers is facilitated through communication-tools like audio, video, e-mails and text messages. The deficiency can be supplemented by referring to CAD/physical models which are available at advanced stages of development. In collaborative concept development, CAD models are not available and hence concept sketches can be accessed simultaneously in the distributed environment. It should not only facilitate viewing, manipulation and annotations on the sketches by the designers but also maintain the integrity of the information presented on multiple (possibly diverse) display systems. The system could be augmented with technologies like audio/video chat with text messaging which provides effective communication among designers. The issues like network latency, bandwidth and group size have to be addressed to maintain concurrency.

3.3 Co-located Asynchronous

In this category, the collaboration happens at a single place, using the same infrastructure, but the information sharing happens at discrete interval of time. This is typical where the designers work in shifts to develop a common product, or the product is too complex to be solved in a single sitting by a single designer. The person working in the next shift can be the designer himself or any other designer who continues the exploration. The product development information related to one shift needs to be communicated to the designer working in the next shift. When starting, the designer need to know the current status of the design in terms of the issues encountered and changes made in the previous session and correspondingly he need to report similar information when a design is checked out for the day. A systematic procedure for monitoring, recoding and reporting significant modifications, developments and issues need to be in place for effective continuity of the multi-session design tasks.

When designers are sketching over *multiple sessions*, at the beginning of a session, designers may not recall the state of the thoughts at the end of the previous session. Hence, one of the important requirements for sketch based collaborative design is to support the continuity of the thought process of designers. For *multi-agent* explorations, identity of the person concerned and the dates need to be maintained for traceability of the development and accountability of the changes made.

For a sketch based collaborative system, it is required to support the saving the data of the concept generation process and also capture important events so as to restore the continuity of the thought process. Thus, a mechanism to maintain the temporal evolution of the product is necessary.

3.4 Distributed Asynchronous

In this scenario, one designer works on a design problem for some time and some other designer located at an alternate place might work on other aspects of the same design, or continue the design already initiated by others. Here, it is required to capture the design process, produce a compact summary of the major decisions taken during the development process and make it available to the other designer. Therefore, in addition to the features discussed in the previous categories, a facility to manage the design process information in a distributed environment is needed.

4 Issues in Sketch Based Collaboration

It can be observed that the requirements for the different collaboration scenarios are different. But the design in question is the same. The issues in all these different type of collaborations have to be addressed for development of a better design faster and also facilitate seamless transition into the subsequent review, concretization and analysis stages of the design.

Collaborative concept development is distinctly different from the collaborative sketching, as available in literature, wherein sketch strokes are created and viewed simultaneously by the collaborating designers. We believe that a sketch is the rendering of a mental imagery which therefore is very personal to the designer. The designer has the flexibility to create and modify the sketches as per the problem at hand. Each designer would explore based on his understanding and domain knowledge pertinent to the problem at hand. Collaboration has to enable assimilation and integration of the diverse views to improve the design. We envisage the following issues to be addressed in developing such an environment.

4.1 Data Storage

In a complex concept exploration a sketch needs to be created in multiple sessions. This necessitates for organizing and saving the sketch so as to facilitate the designer to create the sketch in multi sessions. Apart from the geometry described in the form of sequence of strokes which are represented using coordinates and the timestamp, the data required to support collaborative interaction need to be captured and stored. In a collaboration session, designers perform different activities like viewing creating other components, commenting on the existing components. For capturing the process of exploration, from the perceptive of the designer, it is necessary to record the view transformation with the sketch data. It is observed that when the designers are sketching they do not transform the view by pan zoom and rotate. Hence in the data file the geometry and transformation details are stored in alternate sequences. In collaboration, interactions are more focused on the components. Hence, information related to the associated strokes, accessibility and comments pertaining to different components have to be stored. In a distributed environment, different designers share and contribute to same data representation. Thus, it is important to record the individual identity and the location of the designer and their contribution toward the central database. Also, the sketches created from different devices needs to be identified separately because the device capabilities like working volume, number of actuators, magnitude of force and torque feedback, etc. will be different.

4.2 Data Manipulation

The designers can create strokes, components, constraints, articulation and animation of the components. On the other hand, during interactions for collaboration, view manipulation and annotations would be the primary manipulation activities. The data pertaining to a design exploration has to be created, accessed and modified in a controlled manner based on the permissions given to the designers. This philosophy of data management is similar to the version control in software development but requires custom changes to effectively implement for collaborative conceptual design.

4.3 Data Transmission

Data transmitted between the two terminals is pertinent mainly for the distributed synchronous collaboration scenario and it depends on the relationship between the two collaborating agents and the nature of interactions. One of them is to transmit the sketches created in one terminal to the other. Other interactions are typically cursor movements. View transformations are typically triggered through mouse events. Hence, communicating mouse position and button status could constitute the data which is decoded locally to display the information on the other terminal. For this the demand on the bandwidth is not expected to be very high but for sketch data transmission, load obviously depends on the complexity of the scene. In asynchronous mode, the sketch data has to be transmitted the centralized data server which houses the entire sketch data created across different terminals. For the implementation, different network topologies like peer to peer, client-server, and multicast can be employed depending on the requirement for different categories.

4.4 Event Logging

An event is an action performed by the designer in the design process. Every event initiated by the designer changes the state of the design. The event may be as simple as accessing a sketch in the repository and viewing or as drastic as deleting some components. Although a continuous recording of activities may be unnecessary, activities that lead to significant change in the design or view must be logged for future review and investigations. For example, simple interactions like click of a mouse button trigger some events like creating a sketch stroke or saving the sketched data. Therefore, logging of mouse events is important. A coding scheme for diverse actions of the designers is reported in [24] which may represent a high level event good for logging.

4.5 Data Viewing

In collaboration, designers are only allowed to view or comment on a particular section of the design which they are authorized. In such scenarios, designers should have restricted access to the data allowing the designers to view selectively. Domain specific simulations can be made accessible for viewing by the other designer. To facilitate viewing from diverse display devices like stereovision with head mounted display, desktop and mobile displays, layout and rendering methodologies have to appropriately design. In distributed asynchronous interactions, remote designers may be provided with recent development activities in the context. To support this, a quick view of the major events that happened in the previous session may be useful. Moreover, for multi-session concept sketch development, continuity of the thought should be facilitated; e.g. replay the sequence of the last few strokes created by the designer in real-time speed may help.

The event log represents the full history of the concept developed and viewed by multiple agents. Hence it is large and heterogeneous. A list view of all the events may not useful. To analyze and view different aspects of the development, meaningful queries and filters need to be supported. For example, “when was the component ‘X’ redesigned last and by whom?” is a meaningful query to be answered from the event log.

4.6 Hierarchy Control

In every organization, a hierarchy of people is involved in the product development activity where one has to follow the instructions of their higher authorities. In a sketch based concept exploration tool, this hierarchy need to be supported by providing control on the exploration process through the specification of constraints. These constraints may pertain to the space allocation, scope of view, access rights on data, time and other statutory requirements. The designers at the higher level have to make decisions based on the sketches made by the subordinate designers or guide the exploration by providing constraints. The designers can develop multiple concepts of the different components and the design managers can explore the design with the different components of the product. The system should help in the evaluation of the product concepts. As in case of a design of a car, multiple designers develop diverse concepts for different parts like body, interiors, dashboard, headlight cluster, front-grill etc. The manager can select the components from different designers and tryout different combinations to decide on a particular higher level concept. Though, we believe it would be of immense value, we are not aware of any such existing system that allows one to explore variety right from the early development phase.

5 Sketch Based Collaboration Experiment

Aim: To study the effectiveness and usefulness of sketch based collaboration in conceptual design.
Objective: (a) To develop a collaboration environment that support sketch based interaction, (b) demonstrate a distributed synchronous collaboration scenario, and (c) identify tools and methods used during the interaction.
Experimental setup: The experimental setup consists of two computer terminals with haptic devices and head mounted displays placed in two separate rooms to emulate a distributed interaction, and are connected to the Internet through LAN in a client-server configuration. Each system runs the client application and one of them acts as a server. The communication using TCP/IP protocols is enabled through network programming using Boost Pro™ ASIO library. The client application is the sketching program developed for direct 3D interaction [7]. A mobile-phone is used for audio communication.
Methodology: First, a designer creates a 3D concept sketch of a leisure-chair and stores it on the server. He then solicits the opinion from the co-designer in the remote system by making a phone call. Co-designer logs in into the sketch based collaboration system and load the shared sketch in the view synchronized mode. Both the designers now have identical images of the 3D sketch during the interaction. First the designer explains the design by showing the sketch from different views and asks the co-designer to respond. The co-designer suggests a change in the backrest angle for better comfort and indicates it by drawing 3D strokes over 3D sketch to explain what he meant (Fig. 1).
Observations: The time lag between user interactions to remote view updating was insignificant for the example tried. Verbal communication over mobile continuous but integrated with the interactions on the model. It is observed that the changes suggested to the concept are explicitly provided by direct interaction with

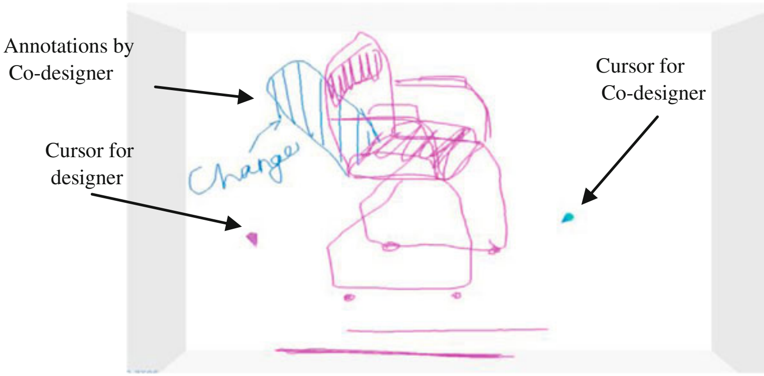


Fig. 1 Screenshot showing the annotations of one designer on a sketch created by other designer

the concept sketch supported by verbal communication through phones. Synchronized view transformation is used to explain the concept. The network bandwidth was sufficient to make the view transformations appear as real time.

Inference: Direct annotations on the sketch help in easy and natural communication. The strokes generated during interaction are only overlaid with the sketch and encapsulates the designer's identity. It acts as a record and helps in modification of the concept later on. Since after loading the model, only mouse interactions are exchanged over internet, which is a lean data, bandwidth issues did not arise.

Conclusions: Though the experiment carried out is elemental and indicative of the capabilities, it demonstrated that sketch based collaboration can be focused and effective in conveying the design intent. A designer centric *generation* and collaboration centric *evaluation* of product concepts is a viable sketch based collaboration model for the early stages of design.

6 Conclusions and Future Work

The work presented here shows that with small modifications to the existing 3D sketching interface, distributed collaboration can be facilitated. Further infrastructure based on information technology need to be developed around the existing methodologies to support different modes of collaboration as identified. The issues identified in this work form broad outlines for future enhancements. Further experiments have to be formulated and performed with real-time data to test the efficacy of such a system.

References

1. Eppinger SD, Chitkara AR (2006) The new practice of global product development. MIT Sloan Manage Rev 47(4):22–30
2. Kvan T (2000) Collaborative design: what is it? Autom Constr 9(4):409–415
3. Wang L et al (2002) Collaborative conceptual design—state of the art and future trends. Comput Aided Des 34(13):981–996
4. Onkar PS, Sen D (2009) A review of product sketching in early phases of design. International conference on research into design, pp 472–479
5. Onkar PS, Sen D (2012) Behaviour simulation in computer aided product concept sketching. 22nd CIRP design conference, Bangalore
6. Onkar PS, Sen D (2010) Functional segmentation of strokes for product sketch understanding. Int J Shape Model 16(1 and 2):9–38
7. Onkar PS, Sen D (2012) Constrained 3D sketching with haptics and active motion annotation. TMCE 2012, Karlsurhe
8. Maher ML, Cicognani A, Simoff S (1996) An experimental study of computer mediated collaborative design. In: Proceedings of 5th ETICE Workshop, pp 268–273
9. Jorge JA, Fonseca MJ (1999) A simple approach to recognise geometric shapes interactively. LNCS 3rd international workshop graphics recognition, vol 1941, pp 266–276
10. Kara LB, Stahovich TF (2004) Hierarchical parsing and recognition of hand-sketched diagrams. In: Proceedings of 17th ACM Symposium UIST '04, pp 13–22
11. Igarashi T, Matsuoka S, Tanaka H (1999) Teddy: a sketching interface for 3D freeform design. SIGGRAPH 26th CGIT, pp 409–416
12. Diehl H, Muller F, Lindemann U (2004) From raw 3D Sketches to exact CAD product models concept for an assistant-system. Eurographics SBIM
13. Lipson H, Shpitalni M (2007) Optimization based reconstruction of a 3D object from a single freehand line drawing. In: ACM SIGGRAPH 2007 courses
14. Keefe D, Zeleznik R, Laidlaw D (2007) Drawing on air: Input techniques for controlled 3D line illustration. IEEE Trans Vis Comp Graph 13(5):1067–1081
15. Schkolne S, Pruett M, Schröder P (2001) Surface drawing: creating organic 3D shapes with the hand and tangible tools. In: Proceedings of ACM-SIGCHI conference HFCS, pp 261–268
16. Murugappan S, Ramani K (2009) Feasy: A sketch-based interface integrating structural analysis in early design. In: Proceedings of ASME IDTC/CIE Conference
17. Atilola O et al. (2011) Mechanix: A sketch recognition truss tutoring system. ASME IDETC-design education conference
18. Alvarado C, Davis R (2001) Resolving ambiguities to create a natural computer-based sketching environment. IJCAI, pp 1365–1374
19. Huang GQ, Mak KL (1999) Web-based collaborative conceptual design. J Eng Des 10(2):183–194
20. Laviola J et al. (1998) Collaborative conceptual modeling using the sketch framework. IASTED International Conference of Computer Graphics and Imaging, pp 154–157
21. Fan Z et al. (2004) A sketch-based interface for collaborative design. Eurographics workshop on sketch based interfaces and modeling
22. http://en.wikipedia.org/wiki/Computer-supported_cooperative_work
23. Sallnas EL et al. (2000) Supporting presence in collaborative environments by haptic force feedback. ACM Trans Comput Hum Interact 7(4):461–476
24. Suwa M, Purcell T, Gero J (1998) Macroscopic analysis of design processes based on a scheme for coding designers' cognitive actions. Des Stud 19(4):455–483

Strategies for Mutual Learning Between Academia and Industry

Margareta Norell Bergendahl and Sofia Ritzén

Abstract The number of challenges facing companies in their development activities is numerous, some coming from new markets and technologies, and some more abstract, like conflicts between short term efficiency and long term innovativeness. Improving collaboration between industry and academia is considered critical—the aim of this paper is to contribute to the discussion on long term learning collaboration between academia and industry, being a core competence area in itself. Another purpose is to form a platform for experience sharing, and increased integration capability for sustaining common knowledge—and practice development. The paper includes an analysis of several collaboration programs between academia and industry conducted in Sweden, resulting in conclusions and advises concerning what to consider for collaborative work.

Keywords Learning collaboration · Product development · Academia and industry · Knowledge triangle

1 Background

The list of challenges facing companies in their development activities is almost endless, some concrete, like opportunities coming from new technologies, and some more abstract, like conflicts between short term efficiency and long term innovativeness. Product development is certainly today characterized by high

M. N. Bergendahl (✉) · S. Ritzén
Integrated Product Development, School of Industrial Engineering and Management, KTH Royal Institute of Technology, 100 44 Stockholm, Sweden
e-mail: maggan@kth.se

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_53, © Springer India 2013

complexity from several perspectives: strong interconnections between technologies and competence areas and consequently between people and organizations. Parallel to this, the need to develop learning relations to academic institutions is increasingly more articulated, and very much related to the perception of possible competitiveness, and delivery of competent employees. Deiaco et al. [1], expresses it as that the university plays a particular set of roles in the global knowledge economy by delivering research, education and applied problem solving. Collaboration that may appear of obvious importance at an overarching level, though need special attention to become successful at the level of an individual firm or research institution [2].

The goal of design research, according to Blessing and Chakrabarti [3] is to make the product development more effective and efficient in order to enable practitioners to develop successful products. Research not only aims to create knowledge, but is also assumed to cover implementation of tools, methods and procedures that improve the design process, and thus the competitiveness, in industry. Expected effects and implementation of research results in design practice have, however, been poor [3, 4], due to lack of mutual understanding between academia and industry and the way studies are performed. Improving collaboration between industry and academia is considered critical and is actively encouraged by authorities, e.g. the European Union [5].

Increasing complexity in product development makes integration capacity in development organizations a general and further increasing demand, especially when the need to be both effective and innovative is identified [6]. One used concept is Integrated Product Development, IPD, including different processes and working methods for improving efficiency and effectiveness [7]. *Integration* is to take into account the many aspects of how to optimize customer value (function, attractiveness, cost, environment etc.) in parallel and iteratively within the product development process. The integration requires collaboration between functions and competencies within and between organizations. There is also an increased demand for learning between companies and academic institutions. Thus, researchers in the fields of design, specially focusing on processes and methods for improved ways of working, have a double interest in this field, one to develop successful working procedures for integration for competitiveness, the other to develop the research based competence to collaborate for mutual learning.

This paper builds on empirical cases and experiences from collaborative initiatives in Swedish environments through the last 20 years, and forms a potential forum for discussion. We share some recent work on forming processes for strategic partnership between KTH management and important industrial and societal stakeholders. We will discuss experiences and reflections on the ENDREA program (Engineering Design and Education Agenda) in the 90s, including many IPD projects being action learning based; PIEp, the Product Innovation Engineering program running from 2006 including collaborations efforts both in research and more specifically in results dissemination; reflections from Industrial PhD students relations [8], and the work with Faculty for Innovative Engineering on University level at KTH, to further make the collaboration-learning effort stronger.

The aim of the paper is to contribute to the development of fruitful and long term learning collaboration between academia and industry, being a core competence area in itself. Another purpose is to form a platform for experience sharing, and increased integration capability for sustaining common knowledge—and practice development, addressing future challenges. The paper includes an analysis of several collaboration initiatives between academia and industry. The analysis combines experiences from each initiative, identification of strengths and challenges will be made.

2 Collaboration Between Academia and Industry: Theoretical Outlooks

Collaboration has been stressed as a key issue in product development for a long time. Several streams of intra-firm and inter-firm collaboration efforts can be found. One stream quite frequently addressed is the collaboration between developing firms and manufacturers/suppliers [9–11]. Another stream addressing collaboration is strategic alliances in R&D between firms of less mandatory dependencies than in the buyer–supplier relationship, exemplified by Uppvall [12] stating the importance of inter-organizational relationships when supporting innovation. Reoccurring issues concerning creating successful collaboration are trust between partners, commitment to the joint effort and a certain consistency in building and sustaining relations and thus collaboration.

Also collaboration between academia and industry is found as a stream of specific research interest. A rationale to academic-industry ventures is from academia to test and verify results and from industry to reach many more researchers than otherwise possible. Caravannis et al. [13] express many more reasons to such ventures and define benefits of collaboration between the sectors government, industry and academia to be sharing of risk and cost, access to complementary capabilities, access to specialized skills and access to new suppliers and markets. Beckman et al. [14] support these reasons and further express the significant benefits correlated to the different positions of academia: engaged in long term research and education, and industry: engaged in commercialization and applied research and development.

Barnes et al. [15] identified in a number of case studies factors for a successful University-Industry interaction, factors categorized into six main areas for attaining a good practice: Choice of partner, project management with progress monitoring and clear objective setting, management of environmental factors, building relations including securing trust and commitment, defining measures for keeping commitment and planning of tangible outcomes and achieving balance between academic objectives and industrial priorities. Further, their findings placed significant emphasis on the need to manage the inevitable cultural differences between academia and industry. The main cultural issues were related to the need to agree on priorities and timing.

Tartari et al. [16] studied barriers to academia-industry collaboration specifically from the perspective of academics and found it to be a 'non frictionless' process. Differences in timescales are the most important barrier they found (long term versus short term research) followed by timing of disclosure and conflicts regarding topics of research. They also saw that in order to overcome barriers related to timescales, difficulties in finding appropriate partners for mutual interests in research and mutual understandings about expectations, experience from former collaboration are crucial. They conclude in that an encouragement of academics to engage with industry requires an alignment of collaboration policies to individual incentives and that face to face meetings are key in this. Level or trust is reoccurring as a key for overcoming most barriers (ibid).

Since trust takes considerable time and effort to develop among partners the continuity of personal as well as organizational relations is important to support. The importance of facilitating tacit knowledge transfer (e.g. experiences, skills and mental models) was shown to be critical in a study investigating knowledge transfer from engineering research centers to companies [17]. Successful tacit knowledge transfer should focus on individuals involved in the process and the steps needed to ensure the development of close relationships. However, trust can face some challenges when differences in expectations are not aligned.

3 Experiences from Collaborative Initiatives

3.1 Endrea

In Sweden's manufacturing industry in the late 80s, there was a low recognition of the benefit of research educated people in the area of Industrial Product Development. At that time a strong initiative was taken within the national program Endrea (Engineering Design Research and Education Agenda) including the areas: Design Theory and Methods, Modeling and Simulation, and Engineering Management. Endrea was generously funded by the Swedish Foundation for Strategic Research; SSF and was designed as a Graduate school, based on collaboration between four major technical universities and a large number of industrial companies. The program built on the combination of technical disciplines and process-oriented, interdisciplinary research within industrial product development practice. The purpose was to increase the benefit of common knowledge development between industry and academy for long term competitiveness to be enhanced. A large number of engineering doctors were educated within the program (during 1995–2003), all with close relation to industrial practice, many of whom are now active in leading roles in industry and in different universities. A lot of experiences were drawn from Endrea [18], some of which are mentioned here:

Several large and medium sized companies were introduced to new forms of collaborative work with academia during the program; several of them (mainly large companies) started then strategic programs for Industrial PhD students as part of their long term development. More than 70 Engineering Doctors were examined, making a large impact in the companies where they were employed, one-third of the doctors made their careers in academia.

Today the Endrea-doctors are important ambassadors for collaborative work between industry and academia; they carry the understanding and bring interest in development of new collaborative and learning relations. Several of them are adjunct professors at a university; others have now upper management positions in manufacturing industry.

One of the learning is the time and effort consuming in building trustful and beneficial relations, not only between academia and industry, but also between the different, normally competing, universities. Endrea was funded for 5 years, plus the start and the close period. Due to a change in strategy at the funding body, the next period asked for programs where the universities was to compete, which turned to be negative for the well-grounded collaboration and trust built between the academic partners within Endrea.

It is eligible to say that the Endrea has brought a lot of learning to the Swedish engineering design and research system, by that forming a solid base for following initiatives, such as ProViking and PIEp (see below).

3.2 Product Innovation Engineering Program, PIEp

In 2006, PIEp was developed by KTH and Vinnova (the Swedish Governmental Agency for Innovation Systems), as a proactive initiative to develop innovation capability—to further develop an area of strength in Sweden. Increasing and further strengthening of innovation capabilities within existing organizations as well as among engineers educated at Swedish universities was defined as of utmost importance for long term competitiveness. An agenda for research and actions for change was developed jointly by academia and industry, led by academia. Vinnova agreed to fund the program, planned for 10 years. Five years later PIEp is a research and change program, constituted by 15 research projects, all in collaboration with industrial partners and partial funded by industry, including a Research School of about 50 doctoral students. In parallel actions to deploy research results, in order to induce change for increased innovation capability and actions for developing new education of engineers and designers are conducted. The program includes five academic partners in Sweden and several international partner institutions at Stanford, TUM, Cambridge, and Aalto University.

PIEp research projects build on collaboration where researchers in academia and engineers in industry have goals that mainly coincide, i.e. increasing innovation capability in organizations. However, goals are also somewhat diverging since researchers aim for general knowledge building, while industry aim for direct changes in their specific organization. Since PIEp as a program has the ambition to actually make change these somewhat divergent goals are of minor problem, though has to be dealt by researcher in relation to the research community as traditional measures rather refer to publishing than to action in industry. In this context two potential challenges emerge, based on the experiences within PIEp: researchers are many times too vague in defining the applicability of their research results and companies expect often research to be at a minimum of resources and cost for them.

Within PIEp a specific action for transferring research results has been performed during 2012, the Innovation Pilots. Carefully selected students have been trained in PIEp developed approaches for increasing innovation capability in R&D organizations and conduct an innovation screening as well as a few workshops initiating an action plan for increasing innovation capability in a company. The pilots have proven to be an effective means for inducing change in companies based on research results. A grand challenge for researchers coordinating this effort has however been to promote the pilots to companies. In order to reduce resources used and to build a sustainable structure, networks of companies has been approached; however, a striking finding is that the pilot projects build on direct personal relations between individuals in research and in companies. This experience further strengthens the need to consider and develop sustainable structures for long term collaboration.

3.3 Strategic Relations, Innovative Engineering

Most technical universities have strong habits and experiences of working relations with industry and surrounding society. Often these are developed on personal relations and trust built between professionals. Since, the last years KTH has increased the ambition for common pro-active knowledge development and defined the Faculty for Innovative Engineering including two major set of activities:

- To develop a strategic program to form long term learning collaboration with selected partners.
- To substantially increase the number of persons moving between KTH, industry and the surrounding society.

The strategic partnership is defined as a continuous dialog, the discussions are held on top management level, yearly meetings taking place between the Vice-Chancellor and the CEO of the partner. The implementation of the collaboration is about forming a Memorandum of Understanding for long term common development work in several fields, and to follow up a target document including specified goals for the coming year(s). The strategic partners all have several areas of interest of collaboration with KTH, from student recruitment, industrial PhD-commitments, adjunct professorships, and different areas of research interest.

Strategic partners in the Faculty for Innovative Engineering initiative today are large organizations: Scania, Ericsson, Stockholm City Council, Skanska, ABB—there are several more to come—and the development of a process for long term collaboration with SMEs and research institutes is in progress. The basic ideology behind the work with Innovative Engineering is the Knowledge Triangle: Education, Research and Innovation: increased quality in both research and education develops innovation capability for partners in a crucial collaboration.

The intention to increase the number of persons moving is based on the perception that the 'best way to exchange experience and knowledge is to move heads'. The goal is to double the number of adjunct professors, and the number of industrial PhD students in 3 years, and further more to increase the number of moving persons on mid-levels. Another interesting challenge is to increase the number of researchers/teachers to spend more time in environment outside the University, which will make important impact on teaching, research and innovativeness. To make this realistic the rules of the game are considered and changed, for example it must be possible to become an adjunct professor with somewhat different merits than an ordinary professor, and it must be valued and rewarded to move between academy and industry/society.

3.4 Industrial PhD-Positions

A specific kind of collaboration between academia and industry is the industrial research student. Industrial PhDs are employed by a company, associated to a research institution and conduct scientific research of interest both for the company and for academy. Cultural differences become surficial in this kind of collaboration as PhD students have clearly defined requirements with regard to their research work, which hence constrain their role within industrially-orientated projects. Experiences from this collaboration setting reveal that this is an important dialog to be held before starting an Industrial PhD. The industrial partner has a specific research interest that must be integral to the research institution; however, their educational goal must also be aligned to the interest of the company. This is most often the case as assigning a person for a PhD position has long term goals.

Being an Industrial PhD Student is an opportunity, but also often means being in a conflict, since the Industrial PhD student is expected to handle the research work, and at the same time work in the employing company: long term research, along with short term project work with tight deadlines at the companies. Lack of understanding for what constitutes doctorate level research at some industrial companies is a challenge, as is the understanding from academy for the industrial reality. Possible conflicts regarding publishing and IPR must be clarified as publishing is mandatory for research, however might interfere with opportunities to patenting, which could be a key in doing business.

The overall experience shows that Industrial PhD-positions is a very powerful instrument to ensure collaborative work lasting for several years, if handled in a proper way. In a former work [8], some conclusions regarding Industrial PhD student relations are drawn:

- Be careful (and take the effort needed) to reach common understanding for academic freedom and quality, rules for publication etc.;
- Discuss balancing of time between operative industry projects and research project/education—time for 'reflexivity';
- Search ways to anchor research results in the industrial organization;
- Select an academic advisor with experience from close work with industry;
- Plan for exchange of information and communication between the partners;
- Place the PhD student in the functional engineering organization (not staff) at the company, plan for a substantial proportion of time in the academic organization.

4 Experiences from Collaborative Initiatives

The work to develop sustainable learning relations between academy and industrial companies is as difficult as to create win–win integrative work procedures in any human relation. Not surprisingly it is very much about how to develop trust between people and partner organizations as also is stated in [17].

From our experiences with the initiatives presented in this paper some highlights can be made: It is of major importance to build a sustainable financial infrastructure, not to say that all funding must be front-loaded, but a relatively safe 5 years start is a strong recommendation. The risks and responsibilities should be shared, to motivate carefully delivery and reflection.

A successful collaboration relies many times on long term relationships with partner organizations, therefore the organizing of the collaboration has to be relying on several persons, and expected deliveries and roles should be defined. Also commonly defined processes for continuation are of highest value to make the collaboration less person dependent. Normally it is helpful to have a management organization not only including the active researchers/teachers, but also people giving administrative support—effective supporting structures as defined in [16].

An increased mobility, people from a company acting within a research group at an university and vice versa, is both a means for building long term relationships and for reaching the actual goals of collaboration: increased quality of research and education, and following on that innovation capacity. We have already mentioned adjunct professors from industry to university, other positions are affiliated faculty and adjunct expert as well as industrial post-docs. Often a trust-building relation can build on one or a number of master thesis work performed by students, advised by an industrial PhD student etc. Mobility could be further widened as experiences reported here reveal: both extended to include also people at doctorate level and increased concerning academics spending (limited) time in companies. In mobility settings as well as in other settings the three corners tones of the Knowledge Triangle should define a common vision.

It is of major importance to build not only trust, but understanding and respect from both parties concerning expectations on what are relevant deliveries, such as publications, change management practices, continuous education, or other applicable deliveries. A general discussion on how to value impact on practice is needed (recently introduced in a major Research Assessment Exercise, RAE, at KTH in June 2012 being one of three headlines), and how this can be understood as a merit in the academic career.

Researchers also need to develop skills to communicate research and package it in a way that makes research results applicable in practice, or to find the right collaborative partners that can be the 'carrier' or the 'implementer'—this being part of a more general discussion on what are the skills to expect from an academic person.

One underestimated challenge is how to choose the 'right' partner, and how not to continue a non-successful partnership. Selecting partner is also emphasized in [17]. First in this is to try to be brave, realistic and focused—there has to be real potential winnings of some magnitude for both sides if the work to form a strategic alliance with a partner is worth doing.

5 Conclusive Advices

Here we summarize a number of advises as 'what to do, and what not to do', based on the initiatives presented and related research efforts and our identification of strengths and challenges from these experiences. It is our hope that this could be a platform for an interesting experience exchange.

Opportunities—to develop:

1. *Articulated terms and concepts*

   Clearly articulate and define a common view on the terms, concepts, and possible results as well as how these will be followed up (long- and short term);

2. *Role definitions*

   Define and discuss the roles and the responsibilities of all the engaged persons to build commitment;

3. *Trustful relations*

   Develop personal relations and trust, start with smaller projects and/or exchange—follow up—expand the common work and fields of collaboration;

4. *Search a sponsor*

   For long term relations—search a high level sponsor in each partner organization, take time needed to anchor the collaboration and the interest in the organizations;

5. *Planning and delivery*

   Plan realistically, always deliver on time & budget;

6. *Reflection and learning*

   Include all partners in feedback, reflection and how to implement learning;

7. *Long term relation with several instruments*

   Design the strategic relation on several different kind of instruments and level of actions, develop a bunch of collaboration activities, including education, research, innovation as well as exchange of experts;

8. *Maintenance*

   Organize for operation and survival of the relation, be aware of the budget needed and the budget processes for partners;

9. *Common vision*

   Define a common vision for the collaboration, where to be in 1-3 years;

10. *Communicate*

    Plan how to communicate and implement findings to develop the relation and results

Challenges—not to do:

1. Start a 'collaboration' without a clear management sponsoring;
2. Underestimate the understanding of difference in industrial goal, research goal and education goal, as well as expectations on results;
3. Promise short term winnings, but communicate about mutual winnings;
4. Compete with consultant companies;
5. Start with finance talk, if there is perceived benefit to come, financing will come;
6. Start without any thoughts from the partners on resources and budget needed;
7. Mix the duties and responsibilities from the different partners;
8. Start the process without a clear commitment and general plan for the continuity and for the coming years.

Our aim is to invite to discussion, we think that sharing experiences and results of learning collaborations will both increase the benefit of our research, and also make this area of research interesting for academics as well as practitioners. Further work in the area is emphasized, specifically on the complexity on building strategic long term relationships and in parallel launching operational projects delivering results beneficial in academia and industry.

Acknowledgments We would like to acknowledge The Strategic Foundation of Research (SSF www.ssf.se) and Vinnova (www.vinnova.se), funding partners making the research and collaborative initiatives possible. We would also like to express our gratitude to partner companies and all the people in these organizations that have been open to challenging joint effort, the actual base for mutual learning. Specifically we would like to mention Scania, Ericsson, Volvo Cars and St. Jude Medical.

References

1. Deiaco E, Huges A, McKelvey M (2012) Universities as strategic actors in the knowledge economy. Cambridge J Econ 36(3):525–541
2. Liyanage S, Mitchell H (1994) Strategic management of interactions at the academic-industry interface. Technovation 14(10):641–655
3. Blessing LTM, Chakrabarti A (2009) DRM a design research methodology. Springer, London
4. Cantamessa M (2003) An empirical perspective upon design research. J Eng Des 14(1):1–15
5. European Commission (2007) Improving knowledge transfer between research institutions and industry across Europe, EUR 22836 EN, Luxemburg
6. Teece DJ (2007) Explicating dynamic capabilities: the nature and micro foundations of (sustainable) enterprise performance. Strateg Manag J 28(13):1319–1350
7. Norell M (1999) Managing integrated product development. In: Mortensen NH, Sigurjónsson J (eds) Critical enthusiasm, Trondheim/Lyngby
8. Kihlander I, Nilsson S, Lund K, Ritzén S, Norell Bergendahl M (2011) Planning industrial PhD projects in practice: speaking both ‘Academia’ and ‘Practitionese’. In: Proceedings of ICED11, international conference on engineering design, Copenhagen
9. Monczka RM, Petersen KJ, Handfield RB, Ragatz GL (1998) Success factors in strategic supplier alliances: the buying company perspective. Decis Sci 29(3):553–577
10. Eneström P, Ritzén S, Bergendahl MN (1999) Co-operation between supplier: buyer in integrated product development. In: Proceedings of 12th international conference on engineering design, Munich
11. von Corswant F, Tunälv C (2002) Coordinating customers and proactive suppliers: a case study of supplier collaboration in product development. J Eng Tech Manag 19(3–4):249–261
12. Uppvall L (2010) The collaborative challenge of product development: exploring sustainable world systems through critical incidents in R&D alliances, PhD Thesis, industrial economics and organizations, KTH, Sweden, ISSN 1100-7982
13. Caravannis EG, Alexander J, Ioannidis A (2000) Leveraging knowledge, learning, and innovation in forming strategic government-university-industry (GUI) R6D partnerships in the US, Germany and France, Technovation, vol 20, pp 477–488
14. Beckman K, Coulter N, Khajenoori S, Mead NR (1997) Collaborations: closing the industry-academia gap. IEEE Softw pp 49–57
15. Barnes T, Pashby I, Gibbons A (2002) Effective university—industry interaction: a multi-case evaluation of collaborative R&D projects. Eur Manag J 20(3):272–285
16. Tartari V, Salter A, D’Este P (2012) Crossing the Rubicon: exploring the factors that shape academics’ perceptions of the barriers to working with industry. Cambridge J Econ 36(3):655–677
17. Santoro MD, Bierly PE III (2006) Facilitators of knowledge transfer in University-industry collaborations: a knowledge-based perspective. IEEE Trans Eng Manag 53(4):495–507
18. ENDREA, Final report, 2004, published for the Swedish Foundation for Strategic Research, Stockholm 2004

Participatory Design for Surgical Innovation in the Developing World

Florin Gheorghe and H. F. Machiel Van der Loos

Abstract The field of surgery is very much a technology-mediated practice. Unfortunately, locally appropriate medical equipment is largely unavailable, or in the case of Western donated devices, is non-functional in much of the developing world. This paper presents two critical challenges that face medical device manufacturers and designers looking to innovate in international surgery, and proposes a methodology to address these concerns. First, designers approach the process with a set of embedded assumptions and biases that are rooted in their experience of traditional markets, thus delimiting the solution space too narrowly. Second, designers working cross-culturally with expert users face numerous difficulties in understanding the problem space. Through a reflective process within both a Canadian and Ugandan context, this study proposes that the assumptions Western designers hold can be challenged to co-create and uncover innovative technology solutions in international surgery.

Keywords Medical device · Design · Emerging markets · International surgery

1 Introduction

The global burden of disease from trauma and injury is estimated at 5 million deaths annually and contributes upwards of 20 million disabilities, with over 90 % of those deaths taking place in the developing world [1, 2]. This problem is largely

F. Gheorghe (✉) · H. F. M. Van der Loos
Department of Mechanical Engineering, University of British Columbia, Vancouver, Canada
e-mail: gheorghe.florin@gmail.com

H. F. M. Van der Loos
e-mail: vdl@mech.ubc.ca

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_54, © Springer India 2013

aggravated due to the lacking technical capacity to safely and efficiently manage surgical cases across these regions.

This epidemic is expected to grow in the coming decades, with injury from traffic accidents alone estimated to move from 8 to 4th place as leading cause of disability in the world by the year 2030 [3]. This untreated burden of disease unfortunately has a disproportionally negative role in overall social and economic development, as those killed and disabled for life are often the breadwinners on whom families and entire communities depend.

While much of this disability and mortality can be prevented through timely access to surgical intervention, there is currently a major gap in provision of surgical care in the developing world [1]. Hospitals in these regions lack the technical resources to manage and effectively treat the vast numbers of patients who present with trauma every day [4].

Efforts over the past decades to equip developing world hospitals with donated medical technology have largely failed. In some cases, developing countries depend on foreign donations for up to 95 % of their equipment, though studies from 16 countries across Asia, Africa, and South America have found that 80 % of these donated technologies fail within the first year [4]. As many as 39 % of all donated technology never worked at all once arriving in the recipient country. The reasons for failure are sometimes technical, as in the case of an inappropriate power supply, but often arise from a lack of foresight into the appropriate design, use, and maintenance of technology. Technology that is designed for use in a highly developed Western medical context simply does not fit that of a developing world hospital. The WHO's report *Medical Device Mismatch* identified that, although medical technologies of all sorts are created by industry to treat and manage a wide variety of disease states, a significant mismatch exists between what is needed in the developing world and what is being designed currently for Western markets [5]. This gap is one of availability, accessibility, affordability, and appropriateness for local needs of developing world users.

This paper examines two major challenges of designing medical technology for international surgery, which we define as taking place in a developing world context. Firstly, it is argued that there is a Western bias inherent when models of medical device design are applied in non-traditional markets. This issue arises from assumptions that designers may hold about the design space. Secondly, there is a difficulty in this field of becoming familiar with and understanding the nuances of the problem space, due to the expertise required to understand the field of surgery. This, combined with power dynamics that often accompany cross-cultural projects in low-resource settings, makes for great difficulty in understanding and defining the problem. A method is proposed for uncovering the assumptions that are inherent in traditional medical device design, validating, and then moving past them to co-create technologies that can benefit international surgical practice.

2 Understanding the Mismatch

It is critical to ask why such a mismatch exists between what the medical device industry is producing and what billions of people around the world need desperately.

The Bottom of the Pyramid (BOP) market, defined by Prahalad as the four billion people in the world living on under $2 a day, presents one of the greatest challenges to medical device innovators [6]. This gap in access to technology-mediated health care is not only an opportunity to bring the benefits of modern day technology to underserved populations, but also to gain an economic foothold in some of the fastest growing economies of the world. Although the United States currently makes up 40 % of the global market for medical technology, emerging markets in Brazil, Russia, India, and China (BRIC nations) are expected to more than triple their health expenditure between 2010 and 2020 [7, 8]. India and China alone are predicted to increase health spending by a compounded annual growth rate of 15.5 and 14.5 % respectively, compared with only 4.0 % for the G7 nations during this same period. Though Asian giants have taken the spotlight of emerging market projections, African economies such as Ghana and Rwanda are ranked impressively as the 4 and 13th fastest growing economies in the world, with 2011 estimates of 13.6 and 8.8 % annual GDP increase respectively [9]. Medical device manufacturers, like other sectors, are beginning to take note of this trend, with companies such as GE Healthcare, Johnson & Johnson, and most recently Covidien opening R&D centers within these target markets and investing heavily to find appropriate solutions [10–12].

Despite these efforts, many established manufacturers are finding great challenge in reaching the true Bottom of the Pyramid. The socio-economic stratification and geographic separation of the poor majority within developing countries presents two consumer tiers. The wealthiest within these populations are not much different from their Western equivalents. They have access to international standards of healthcare, trained physicians, and cutting-edge technology. For this reason, they are a familiar and welcome sight to Western medical innovators, and have typically been the primary target of companies seeking to enter emerging markets [13]. In contrast, the poor majority of these populations have little access to healthcare. Despite spending a disproportionately higher percentage of their income on health [14], the system that serves them is lacking even the most basic of technology. This second tier of consumers is greatly underserved by the medical device industry to date.

To understand this problem further, it is necessary to look at the way in which medical device design takes place in the wealthy, developed world. Exploring the basis of these methods that lead to success in the first world may reveal why these steps cannot achieve a similar result in emerging markets. At its root, the problem lies not only in how we approach the design process, but also in how we understand the problem space. It is these two challenges that this paper will further address.

2.1 Uncovering Assumptions that Guide Traditional Design

Western biomedical engineers and designers are trained to navigate a rigorous, step-wise process of design for medical technology, based on directives set out by regulating bodies such as the United States FDA [15].

Although there are a number of guidelines and representations of this process, including the waterfall model and the stage-gate model [16], these examples may not deliver successful products in BOP markets. Such models have been developed through the lens of Western designers, and with experience within the complex Western medical device environment. Designers themselves apply these steps and procedures within a particular technology design paradigm, based on a set of expectations and assumptions about the users and context of use that are unique to traditional markets.

This can include, for example, assumptions around the information flow throughout a surgical procedure. In a Western setting, a great deal of information is available to the operating team about the patient and the progress of the surgical intervention. Real-time patient monitoring and past medical records allow operating staff to proceed through the surgery with confidence, and to anticipate any complications they may face. Not having this information means that a surgeon must rely more heavily on clinical skill, while delaying the operation and practicing more conservatively due to the increased risks.

Visualization of injuries through imaging is a key aspect of information flow that is often missing as well. The procedures, implants, and specific techniques that have advanced the field of orthopedic trauma are all dependent on certain information that is commonly accessible in a Western operating suite. These problems of information flow can highlight opportunity areas for innovation, and can become leverage points rather than deficiencies. The starting point is to understand how practice is currently adapted to manage this uncertainty, and how it could be supported with a locally appropriate technological approach. A further summary of systemic differences and assumptions is described in Sect. 5: Expected Results.

The paradigm we are designing for in the Western medical world features a different set of characteristics than those of resource-constrained countries. What is needed then, is a shift in this technology design paradigm, and a change in how designers and engineers approach the design of medical technology for the developing world. In order for this shift to take place, we must begin to understand and catalog the differences present in each system, specifically how Western assumptions surrounding technology design may or may no longer apply in a developing world context. Shedding light on our assumptions about the design, delivery, and use of medical technology can also uncover the values and priorities that inform designers on appropriate trade-offs that can be made in the new medical technology paradigm.

2.2 The Challenge of Expert Users

A further challenge present in medical device design exists in understanding the complex needs of expert users, a task made more difficult than designing in common consumer focused sectors such as home electronics or kitchenware.

There is a distinct asymmetry of information present between user and designer. Expert medical users have a depth of understanding of the practice and associated challenges that is rooted in their own experience and education. Designers on the other hand typically have a depth of knowledge in the solution process and method, but have only a common understanding of the problem space. Von Hippel labels this a problem of "sticky information", which has a high cost of transfer from users to the designers who need it in order to work effectively [17]. The information is hard to transfer for a variety of reasons, but primarily due to the complexity and nuances that exist in practice. To the users, the necessary information may seem second nature and obvious among their peer group, thus resulting in their not sharing of certain critical details with designers. Other times the information may not be encoded and the users themselves may not recognize their own habits and needs, such as the manner in which surgeons use bracing strategies to improve manual dexterity and precision during an operation. Sure terms these valuable but unconscious adaptations to one's environment as "thoughtless acts" [18].

Manufacturers try to move past this challenge of understanding the problem space by maintaining close relationships with doctors, nurses, and other medical users. Methods borrowed from the field of human centered design are used to understand the user's context, challenges, and subtle needs. However, applying many of these techniques, such as contextual inquiry, where users are interviewed and use a think-aloud approach to verbalize their decisions, are often not appropriate for the trauma setting, where users are intensely focused on a life or death situation. Some work on developing techniques for needs-finding in trauma surgery has been done. In the field of human factors, Brown presents a process specifically for use in trauma settings consisting of expert interviews, observation, as well as getting feedback on prototypes through usability testing and heuristic evaluation [19].

Despite progress made on the development of trauma-specific methods for the early stages of design, this practice within a low-resource setting provides an additional challenge in the power dynamic that exists between designer and user. Evident in international development projects, the dichotomy of the rich, Western donor and a poor, suffering beneficiary intensifies problems in communication, trust, and partnership [20]. A similar perception may exist in a design context where the medical users, working in a resource-constrained environment and struggling both personally and professionally, may perceive a designer to be arriving with money, technology solutions, and the significant backing of a foreign entity or company. The real or imagined incentives in this scenario may then become a barrier to hearing truthful comments from users and require a designer to enter with a heightened sense of skepticism and situational awareness.

3 Background on the Study Approach

Overcoming these two issues—a Western-biased design approach and an asymmetry of information among expert users—is the focus of this study into the medical device design mismatch.

This study proposes that it is possible to address such barriers, and that the methods used to do so actually have a complementary effect on the two challenges.

While they may be hidden to the individual, Adams identifies various conceptual blocks that can hamper the designer's ability to see important information [21]. Perceptual blocks may cause a designer to stereotype—to see only what they expect to see. They may have a difficulty in isolating the problem, or a tendency to delimit the problem area too closely. In the case of a medical device designer, these blocks result in an embedded bias toward the characteristics of a Western medical system that we have come to know and take for granted, such as culture, infrastructure, as well as human and technical capacity. All of these expectations, which manifest as blocks, are implicit in the approach and perspective brought to a design activity.

It may be possible to overcome these perceptual blocks by becoming aware of the design assumptions that we hold. Surfacing such assumptions by examining past and current design practice allows one to then question and validate them against the realities of a design space. Understanding whether these same ideas apply in a new context allows one to step back and look at the broader system, possibly uncovering new opportunities for innovation. Indeed, Stefik suggests that, "for routine problems, previous experience helps us work through the problems effectively. For novel situations, however, our experience can get in the way of having a breakthrough" [22]. Thus, by stepping back and uncovering pre-existing biases, it is possible for an expert mind to approach a situation with beginner's eyes. This is especially important when approaching the design of medical technology for a complex and unfamiliar environment.

Through the process of validating preconceptions, a designer begins to also uncover priorities among different design attributes. This type of prioritization is required in the model of frugal innovation. Sehgal suggests that consumers of products in the developing world are not seeking low-cost, low-quality alternatives to what is available to more wealthy customers. Rather, they are a value-conscious group that demands—and deserves—affordable alternatives that still meet a competitive performance standard [23]. Understanding and validating design assumptions inform designers on which compromises are acceptable in a given context, and where trade-offs can be made to still achieve a reasonable outcome.

The approach proposed in the following section not only addresses the first problem of an inherent bias in the process of needs finding and design, but also partially begins to address the information asymmetry problem faced when designing for expert users. Identifying and questioning the built-in assumptions in a traditional system and examining them in the context of a novel and lesser-known system is a way of gaining deep insight on the new problem space too. This process of reflection and critical thought enables a shift in the source of information from users to designers, thereby partially overcoming, but not negating the need and difficulty in learning directly from users. This, combined with the use of methods borrowed from the field of human centered design, such as observation and cultural probes, can contribute to a better understanding of the problem space and life context of an expert user.

4 Proposed Methodology

In order to shed light on the challenges posed in this paper, the authors are collaborating with the Uganda Sustainable Trauma Orthopedic Program (USTOP).

This project of the University of British Columbia in Vancouver, Canada conducts annual trips to Mulago Hospital in Kampala, Uganda to provide capacity building training for local medical staff. This partnership provides access for investigators to study the environments, people, and interactions in both a Canadian medical setting at Vancouver General Hospital (VGH), and also in a Ugandan setting at Mulago Hospital.

In the first phase of this study, which is in progress, data are being collected at VGH in order to catalog the assumptions present in how technology currently in use was designed. The following six questions guide the search for embedded design assumptions:

1. What technology interdependencies exist and are built into design?
2. Who is the technology intended for and what is assumed about them?
3. What skills are implicitly required for the use of technology?
4. What assumptions are revealed from marketing and the imagery used?
5. What assumptions are made about the context and use environment?
6. What supporting systems or infrastructure are assumed available?

Investigators will use a Grounded Theory approach for conducting this research [24]. In this method, data from various sources including media, observation, and interviews are collected and documented. This information is then coded and interpreted, and becomes the source of emergent patterns in an iterative process of theory building.

The next phases of this study will take place in the fall of 2012 at Mulago Hospital as investigators join the USTOP surgical team for several weeks. The data and insights gathered about assumptions from VGH will be validated in an alternate context at Mulago through observations and interviews with medical device users.

In addition to validating assumptions on design from VGH, new perspectives will be sought on the values and needs of users at Mulago through the use of cultural probes. This technique introduced by Gaver equips users with a reflection toolkit consisting of a journal, questionnaires, and a photo camera [25]. Users are instructed to collect photographs and reflections, and to answer specific questions that serve to inform designers about their life context. Currano demonstrates the value of 'reflection-out-of-action', which the cultural probes tools would afford by allowing users a self-guided reflection process without the pressure of a formal interview setting [26]. This method is expected to uncover important differences among this user group and their environment as compared to their Western counterparts, and will partially address Von Hippel's sticky information problem and the power dynamics involved.

After validating the design assumptions from VGH and gathering new insights at Mulago, these can then be prioritized to identify which attributes are of greatest concern in design, whether they be human, technology, or systemic in nature. Focus group discussions with medical users at Mulago will identify which results are of priority in the local context, placing each attribute on a spectrum from absolute to more flexible. This exercise will inform what trade-offs are acceptable and desired in a local context, which previously held assumptions would have hidden from view. The areas of most flexibility will provide for designers a rich set of opportunities for innovation.

Finally, users will be engaged in a creative thinking and imagination exercise in order to co-create locally appropriate solutions. Using the method of Outcome Driven Innovation (ODI), opportunity areas are mapped as a series of tasks, or jobs, that the user performs, each leading to an overall desired outcome [27]. Armed with insights about local priorities and acceptable trade-offs, users will be engaged to re-imagine how their desired outcomes could be achieved in innovative ways. Such innovations that reduce the need for inaccessible inputs or remove steps that don not fit the local context can radically change the face of technology-mediated surgical care in the developing world.

5 Expected Results

Background discussions with Canadian surgical staff involved in the USTOP program have revealed a series of valuable insights and serve to highlight preliminary areas of exploration for design requirements and potential design assumptions. These examples will be explored further in all phases of this study.

Vital signs monitoring: An example of a problem facing surgical staff in the developing world is the information gap within their practice, as compared to Western counterparts. Due to the lack of technology, especially for patient vital signs monitoring, surgeons and anesthetists are, in a sense, operating blindly to the status of the patient.

Patient medical history: Another information gap is in the lack of medical records for patients, both in terms of longitudinal patient history, past procedures, and potential reactions, but also lacking details of the interventions and test results from the current hospital stay. These unknowns may lead the surgeon to feel a heightened sense of risk, which affects the decisions that will be made during a procedure and the type of care a patient can receive.

Logistics and tracking: Similarly, a lack of logistics and tracking information for equipment inventory and sterile indicators for quality control may affect the confidence of practice and willingness to move forward with certain decisions. These unique differences in information availability, as well as the resulting risk tolerance that impacts decision-making, affect the way in which technologies will be used or not within a medical system. As such, they may have great implications for how design is to be approached in such a context.

Infrastructure and technology: The availability of various infrastructure and supporting systems for the practice of surgery is often quite different. Designers in traditional markets may take for granted the availability and consistency of power and water supply. Thus they may not take into consideration the immense voltage spikes and variability that cause nearly 30 % of donated device failures in developing world hospitals [4]. The lack of appropriate technology within the operating suite may also have implications for the design and use of co-dependent technologies. For long, the ability to repair long bone fractures using internal fixation was unattainable due to the unavailability of intra-operative fluoroscopic imaging. This supporting technology is an essential tool in the accurate placement of any modern day intramedullary nail, which is an internal supporting rod that keeps the broken bone in alignment during healing. Recently, designers of the SIGN Intramedullary Nail were able to overcome this challenge by creating a purely mechanical system that uses a jig for accurate placement of a nail without the need for fluoroscopy [28]. By stepping back to question the basic assumptions about long bone fixation procedures, they were able to turn constraints into an opportunity for innovation. Users could then reach the same health outcome but with a change in the steps and inputs of the process.

Time constants: Other examples of potentially embedded design assumptions include the time-constants assumed in a surgical setting, which are often not the same in international surgery due to resource gaps, inefficiencies, and differing priorities or values.

Sterilization: Sterility is a factor assumed critical and near-absolute in a Western surgical suite, but similar standards and reliability simply can not be met in a developing world hospital. Technologies then cannot be assumed to depend on such standards.

Human resources: The human resource capacity in a hospital is assumed to be above a certain standard. Even in the Western medical setting, designers often assume technical competence with information technology as a given, but many older nurses and doctors face difficulty using new generations of devices.

This human challenge is compounded in a developing world context where other factors such as literacy, education level, culture, motivation, and confidence in practice can come into surprise designers.

Visualization: Finally, certain characteristics of a procedure are assumed. A tourniquet is one of the most basic pieces of equipment in a trauma department, used to contain blood loss in a limb during surgery. The result is that surgeons typically operate in a bloodless field with a high degree of visibility of the tissue. Technology designed for use in such working conditions may not take into account the visualization issues in a time-critical and stressful surgery where blood cannot be controlled due to the lack of a tourniquet.

These are a sampling of assumptions built into the design of medical technology, and part of the reason why technology developed in the West stands little chance of sustainable use in a developing world hospital. Each of these has implications for how designers must proceed in their work, and will be explored in further detail throughout this study, along with new assumptions that surface.

It is expected that this study will result in insights that help ground in reality the design of medical devices intended for use in the developing world. Assumptions will be explored with users in order to prioritize and better understand where trade-offs could pave the way for novel approaches that lead to potential innovations. Design workshops using Outcome Driven Innovation techniques will generate alternative solutions for achieving acceptable surgical outcomes in the field of orthopedic trauma surgery.

6 Conclusion

The field of international surgery is greatly lacking in technological capacity, with Western-designed medical technology so far failing to improve this outcome. As surgery is a highly technology-dependent field, it is critical that designers become familiar with innovating products for this context if both social and economic benefits are to be realized.

This study proposes that the challenges faced in achieving success are twofold. First in the ability to understand the problem space, and second in the biased approach that Western designers bring to the solution space.

Through a process based on reflection and user feedback, the authors propose that these two problems can be addressed and a step forward taken in the design of medical technology for international surgery. Assumptions and biases can be surfaced in Western medical settings and validated within a developing world context in order to enable a more appropriate approach to design. Uncovering and then challenging the attributes assumed important in a design space can allow for prioritization and trade-offs to be made in order to achieve an acceptable outcome with limited resources.

This approach allows designers to account for the constraints in an unfamiliar system, while surfacing insights, which may lead to disruptive new health technologies.

Acknowledgments The authors would like to thank the Engineers in Scrubs program, as well as the Branch for International Surgery at the University of British Columbia for their generous support of this study.

References

1. Mock CN, Jurkovich GJ, nii-Amon-Kotei D et al (1998) Trauma mortality patterns in three nations at different economic levels: implications for global trauma system development. J Trauma 44(5):804–814
2. World Health Organization (2004) The global burden of disease: 2004 update
3. Mathers CD, Loncar D (2006) Projections of global mortality and burden of disease from 2002 to 2030. PLoS Med 3(11):e442
4. Malkin RA (2007) Design of health care technologies for the developing world. Annu Rev Biomed Eng 9:567–87
5. World Health Organization (2010) Medical devices: managing the mismatch
6. Prahalad CK (2003) The fortune at the bottom of the pyramid: eradicating poverty through profit. Wharton School Publishing, Upper Saddle River
7. Holtzman Y (2012) The U.S. medical device industry in 2012: challenges at home and abroad. Med Device Diagn Ind 17, http://www.mddionline.com
8. Das R (2012) Asia pacific healthcare outlook 2012–2015. Frost & Sullivan, USA
9. CIA, CIA World Factbook (2012) http://www.cia.gov
10. GE Healthymagination (2010) 2010 Annual report, http://www.healthymagination.com
11. Johnson & Johnson (2011) 2011 Annual report, http://www.jnj.com
12. Covidien (2012) Covidien opens US$45 million R&D facility in China, http://investor.covidien.com
13. Deloitte (2012) Securing the next level of growth: second tier emerging markets, http://www.deloitte.com
14. Duflo E, Banerjee AV (2011) Poor economics: a radical rethinking of the way to fight global poverty. Public Affairs, New York
15. Zenios S, Makower J, Yock P (2009) Biodesign: the process of innovating medical technologies. Cambridge University Press, Cambridge
16. Pietzsch JB (2009) Stage-gate process for the development of medical devices. J Med Devices 3:021004
17. Von Hippel E (2005) Democratizing innovation. MIT Press, Massachusetts
18. Suri JF (2005) Thoughtless acts?. Chronicle Books, San Francisco
19. Brown DS, Motte S (1998) Device design methodology for trauma applications. Proc Comput Hum Inter (CHI), pp 590–594
20. Dudley E (1993) The critical villager: beyond community participation. Routledge, London
21. Adams JL (2001) Conceptual blockbusting: a guide to better ideas. Perseus Publishing, Cambridge
22. Stefik M, Stefik B (2005) The prepared mind versus the beginner's mind. Design Management Review, Winter, pp 10–16
23. Sehgal V, Dehoff K, Panneer G (2010) The importance of frugal engineering. Strategy + Business 59
24. Glaser BG, Strauss AL (1967) The discovery of grounded theory: strategies for qualitative research. Transaction Publishers, New Jersey

25. Gaver B, Dunne T, Pacenti E (1999) Design: cultural probes. Interactions 6(1):21–29
26. Currano RM, Steinert M, Leifer L (2011) Characterizing reflective practice in design: what about those ideas you get in the shower. Int Conf Eng Des (ICED11)
27. Ulwick AW (2002) Turn customer input into innovation. Harvard Business Rev 80(1):91–97
28. Sekimpi P, Okike K, Zirkle L, Jawa A (2011) Femoral fracture fixation in developing countries: an evaluation of the SIGN intramedullary nail. J Bone Joint Surg 93(19):1811–1818

Co-Web: A Tool for Collaborative Web Searching for Pre-Teens and Teens

Arnab Chakravarty and Samiksha Kothari

Abstract This paper presents a design case of a Rich Internet Application Co-Web: a collaborative work tool for pre-teens and teens to help collect, collaborate, organize and format information from the web for their school projects more holistically by enhancing their in-search and post-search experience. A user-centered design methodology was followed to help identify how teens and pre-teens use search engines and other technology tools in their daily life to collaboratively work on school projects and recognize the key real-world interactions, which help support this activity. This design solution proposes that integrating collaboration with family, friends and visualizing search keeps the user group interested and helps them retain and use the information they seek more cohesively within the existing search paradigms. This paper describes the design methodology, findings from co-design with participants and reflects on designing new web search interfaces that provide tools for collaborating.

Keywords Web search · Collaboration · Teenager · Computer-supported cooperative work

A. Chakravarty (✉) · S. Kothari
Industrial Design Centre, IIT Bombay, Adi Shankaracharya Marg,
Ramabai Nagar, Vikhroli West, Mumbai, MH 400706, India
e-mail: chakravarty.arnab@gmail.com

S. Kothari
e-mail: kothari.samiksha@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_55,

1 Introduction

Children and young adults are one of the biggest adopters of computers and Internet in India and across the world [1, 2]. The primary use of Internet by secondary and high school children in India is for education and entertainment purposes [3]. Due to increase in exposure to these technologies in schools and classrooms, more and more children are using the Internet and computer based media as primary sources of information for academic related activities [3]. Search engines and online libraries require proper articulation of query, analysis of results to find out the most important result or involve an understanding of abstract concepts which are beyond a child's still- developing skills [4–6] especially in India, where English is not the first language. Searching for information on the web is usually seen as a solitary activity, which often results in incomplete searches, unsatisfactory results and discouraged users [7]. There exists a big need to understand the real-world interactions that children turn to for support in their information seeking activities and to develop applications to support the ecosystem. We conducted interviews with educators, parents and others who frequently observe how children in high schools use computers and Internet for their academic purpose to understand the extent of use and behaviors of the stakeholders. We followed this up with a contextual inquiry with 8 school students and observed them while they carried out a collaborative project in their regular environments. Based on these interviews and observations, we identified several limitations of current collaborative information gathering, search and collaboration practises. Informed by the findings of this formative study, we propose the design of Co-Web, a system for facilitating collaborative Web search among secondary school students working at different locations on a common topic. We provide a detailed overview of the Co-Web system, including a sample usage scenario. We also report some early experiences in co-designing and exploring the design space offered by Co-Web, highlighting on future possibilities. Finally we conclude by highlighting the need of integrating aspects of collaboration and teamwork to support users' desires to engage in active, small-group collaborative searching while finding information on the web.

2 Related Work

Co-Web is built upon several areas of research, including studies of people's information retrieval habits, systems that support synchronous/asynchronous web searching, 'passive' collaboration systems, and systems supporting multi-user searching.

Commercial search engines and Web browsers focus on single-user scenarios [8]. However, there are some systems that enable collaborative work around web searching but most of them focus around co-located collaboration on Web searching like Co-Search, which allows collaborative web search in a co-located setting, i.e., when several people are gathered around a single computer [8]. Teamsearch supports co-located search of digital photo collections by groups seated around an interactive tabletop display [9]. WebSplitter [10] generates personalized views of Web pages for multiple co-located users based on currently available devices with the users at a given point of time.

There has been some prior work which has explored in way to support remote Collaboration on Web tasks. GroupWeb is a browser that allows group members to visually share and navigate World Wide Web pages in real time using tele-pointers for enacting gestures [11]. Search Together enables groups of remote users to synchronously or asynchronously collaborate when searching the Web [12]. Search Together [12] focuses on supporting collaboration during the process of searching the Web, including formulating queries, exploring search results, and evaluating the information that has been found. S3 allows users to asynchronously share useful sites found during a Web search by representing search results in a persistent file format that can be sent to and augmented by several people [13].

In contrast to these systems, Co-Web's design is specifically contextual to secondary and high school students and it has been designed by keeping their unique needs in mind. It supports two or more synchronous or asynchronous searchers using a variety of Web-based search services, and provides integrated support for information collection, collaboration, assimilation and presentation.

3 Formative Studies

In order to verify the prevalence of collaborative web-based information projects and to understand the needs of the stakeholder, we conducted a series of semi-structured interviews with 10 people who work in settings where computers were used for projects in schools. We interviewed 3 teachers, 2 librarians, 3 mothers and 5 children. The teachers included a primary school teacher teaching in Dahanu, a town in Thane District, India, a primary school teacher teaching in a medium-income public school in Mumbai and a secondary school teacher teaching in Kandivali, a medium-income suburb in Mumbai, India. Of the 2 librarians, one worked in a school library in Mumbai and one worked in a small public library. Of the 2 mothers, one was computer-literate and could guide and assist her children at home, one was non computer-literate and had a computer at home and one was not computer-literate and had children who used it at school. In each interview, a set of open-ended questions were asked which were customized to each individual. The questions were designed to investigate about how high school children searched for information in schools, libraries for school projects, the frequency of collaborative search, participation of each collaborator, the within-group roles that emerge, the type of search tasks, the reservations against use by the parents/teachers, the motivations of searching collaboratively and the physical setup of resources needed.

4 User Study

We recruited 8 students and the children were observed in their natural settings to perform pre-defined search tasks on their computers. The studies were conducted in two phases:

In phase 1, Participants were asked to 'think aloud' during the task and tell the researchers about any issues or problems they faced. The participants were also encouraged to avail the help of other people in case of difficulties to observe how they traditionally completed tasks, which they could not do independently. Finally, we conducted semi-structured interviews with participants after they had completed the task.

In phase 2, the same 8 students were divided into 2 groups and were asked to do a project on 'Surface Tension', which was a topic from their curriculum but had not been covered by the teachers yet. The project was to be submitted within five days and the final deliverable was a MS Power-point presentation, which is the most common form of presenting content in most schools (as conveyed to us by the participants in formative study). The participants were all acquainted with each other. They all had previously used internet and computers for school projects but had not used online collaborative tools. Each group member had a computer connected to the Internet and they were free to use other standard software like the Microsoft Office suite as well as well as take notes.

During both phases, we observed the participants' search strategies, usage of tools, and creation of any electronic and non-electronic artifacts during the search. Also, we saved all the information found by participants during the task and the phase 1 individual searching was video recorded. This two-phase study design gave us a chance to observe information gathering not only during synchronous collaboration but also when collaboration was asynchronous. We analyzed the data using affinity mapping and looked for themes related to how group members understood the information (e.g., websites) found during the task as well as information related to division of labor, group members' task strategies, and task state.

5 Insights

The formative study revealed several themes regarding the challenges of finding information and collaborative Web search for students, teachers and the parents.

Prevalence of internet based information gathering: The librarians and parents both reported that students frequently perform online searching for their project purposes. Teachers pointed out that it is also mentioned in the teacher's curriculum to encourage students to find additional information on the internet after a lesson is taught in class to arouse their curiosity to know things and break beyond the information provided in textbooks. Librarians mentioned that due to lack of books in the library about specific topics taught in classroom, children often use the library computer which has access to internet and try finding relevant books and in turn ask the librarian to order these books for their school library. Students and teachers both mentioned that more and more classroom assignments related to exploring subjects and making presentations were expected to be done on the computer.

Participation and enthusiasm in group projects: Teachers also stated that collaborative activities in classroom prove to be very helpful for the students. Students also enjoy it as they like to work and play together. Parents and children also reported that the energy levels of the children would peak up during collaborative and group projects if they had selected the group themselves. Children would see it more as a fun activity compared to usual homework. Also, competing with other groups in the class would make them do little more than required at times, to prove themselves as the best group. There were reservations about the lack of visibility of individual contribution in group projects. If a member was not working, the entire group had to suffer. The intent of the project was clearly defined to the users as to try and explore the subject and gain more information apart from what is currently there in the textbook to get a better understanding of the subject, but it was observed that for some of participants, working on the project merely was a task completion activity and due to which the motivation and enthusiasm in other participants got affected. The initial division was soon forgotten and work was done on an on-need basis. The work kept shuffling between the members of the group as per need.

Locations of computer use: The librarians stated that they rarely saw students in her library using computers in isolation. Librarian also reported that students would use the computer lab for collaborative tasks during free periods, as that would require discussion, which would not be possible in a library atmosphere. Parents and students reported that although most of the first sessions would start with a physical meeting with all the teammates either in school or some collaborators house, most of the other coordination would happen over telephonic conversations. While students preferred working in a co-location setting, day-to-day logistics issues prevented them from physically meeting teammates and do group project.

Resolution of breakdowns: The librarians stated that students of secondary school often come with problems that they are unable to find information of particular topics on the Internet and need guidance on how to frame the query to get relevant information. One parent reported that her son's online searches are mediated either by his father or elder brother as he generally needs help as he is unable to find information by himself. The help provided is typically guiding the search by making query suggestions (verbally) or navigation suggestions (by pointing). In the individual task, 6 out of the 8 users gave up when they could not locate the desired information. Students reported that they gave up more easily when they were working alone on a project. They had to either wait to ask a family member or request help from a class-mate. In collaborative tasks, it was easier as everyone was working on the same project so they did not face any hesitation.

Minimal Sense-making: During collaborative Web searches, the interviewees reported that students would divide the projects in multiple tasks and choose these tasks as per their skill sets and facilities available with each one of them. There would be students who would be good at making presentations and finally after all the other collaborators have gathered information, one student would compile all of it into a beautiful looking presentation. In some cases, the presentation would be divided into stages and each one would contribute some slides.

Lack of Awareness of Search Engines and Boolean searches: The problem seen with students searching for information on the web was that Children are poor at representing their needs in form of a query. Most of the children found it difficult to articulate what they were looking for. On the other hand, search engines are poor at responding to vague queries. They were not aware of the various techniques and tricks available to articulate their query in a search engine friendly manner for the best results.

Minimal Awareness: In the collaborative task, there were communication problems observed among the users as they were not at the same pace. Most of the things were communicated over telephonic conversations. There were misunderstandings among the team mates as they couldn't see each other's screen and visualizing what exactly is being viewed by the teammate became difficult.

Plethora of programs: Users generally coordinated and worked using a multitude of different programs/websites for different tasks. e.g.: MS-Word for editing content, Skype, Instant Messengers for co-ordination with other team mates, PowerPoint for formatting and presenting content etc. The users kept switching between multiple applications which were pointed out by users as being irritating and distracting. Most of the files were shared over email or instant messenger file transfers which added to their confusion and a lot of time was spent on keeping track of different files spread over different locations on the computer. A lack of version control also ensured that mismatches in data crept up especially when the data was being assimilated for presentation.

Video as a distraction: Users generally got distracted while using video chat of instant messengers. Due to poor broadband speeds, video generally did not stream well and much time was spent in trying to fix it.

Parental Control: Parents often enforced a time-limit of anywhere between 45 min to 2 h for a single session. Parents often could not identify whether the computer was being used for casual purposes or for project work.

6 Design Goals

It was quite clear from the user studies and interviews that collaboration on projects remotely was quite prevalent. Also, students collaborating on finding information together had the potential to improve search experiences and outcomes even within the existing search paradigm. Since these activities are not supported by current paradigms, people were employing workarounds and multiple applications to communicate and coordinate. It was postulated that systems and tools were designed to support such user behavior will benefit students and help them. With the above considerations in mind, the envisioned design goals of Co-Web were as follows:

- To create a collaborative environment to reduce redundancy and repetition in search queries thereby increasing productivity.
- To provide tools to save/search results and create new visualizations of search results to elicit more user involvement in the information search rather than it just being a mechanical activity.
- To provide a sense of comfort and reinforce user confidence in completing a search by turning it into a group activity yet not a competitive one.
- To help users articulate their queries better by incorporating advanced search techniques in a visual manner.
- To ensure that users complete their search activities with higher confidence/correctness by involving family, friends and teachers in the search activity.

7 Co-Web

Based on our investigations of students' collaborative search practises and needs, Co-Web is designed to enable either synchronous or asynchronous remote collaboration between students. The application is a RIA (rich internet application), which ensures that the reach of the internet can be leveraged with a compelling user interface. In the next section, we shall illustrate the experience of using Co-Web by describing its features. In the most basic Co-Search usage scenario, a group of students can login to the application and run an instance of co-web on their individual computers. They can collaboratively search information and collect relevant pieces of information in the shared space. Each user is represented by a unique color and icon. Every piece of collected information displays the identity of the person who created it. Audio and text chat functionality is in-built so that participants can collaborate. Special search categories like Encyclopedia and summary search are integrated so that participants can find relevant information quickly. Related search and Boolean operations are also included. Basic text editing tools are also integrated so that basic formatting and presentation can be done in the application itself. The application has a separate interface for the teachers where they can have an overview of the project.

7.1 Features

The first screen is sectioned into three main sections:

- Start individual search (Fig. 1a)
- Start collaborative search (Fig. 1b)
- Continue an ongoing project (Fig. 1c)

Clicking Collaborative search on (Fig. 1b) takes the user to the screen (Fig. 2) where he/she can choose to either browse through previous projects (Fig. 2a) or start a new project (Fig. 2b). The user can choose to invite friends, family and other people from his contacts to join the session, merely by dragging and dropping the contacts (Fig. 2c) on the project book (Fig. 2b). (In case of a group project, the friends added to the project become the collaborators).

Dynamic Cloud and Booleans: A tag cloud (Fig. 3a) displays a network of words related to the inputted query word. On clicking a related search terms from the interactive cloud, a Boolean operator 'AND (+)' (Fig. 3b) is added along with the initial query term to narrow down search and get more accurate results to help ease the problem of articulating search queries for the best results.

Encyclopedia and Project Search categories: Two new categories of 'Encyclopedia' (Fig. 4) and 'Project search' (Fig. 4d) have been created especially considering the search requirements of the user group: 'Encyclopedia' category returns results of the search term from a set of pre-selected online encyclopedias. It was noticed during the user studies that people were not using other encyclopedias for content and defaulting to Wikipedia since it was the only encyclopedia they had used regularly and were aware of. However, there was a latent aspiration to use information from other resources. 'Project' category summarizes different categories (Fig. 4a, b, c) of information traditionally related to an academic project (namely encyclopedia, experiments, diagrams, videos, definition, images) on a

Fig. 1 First screen

Fig. 2 Project view

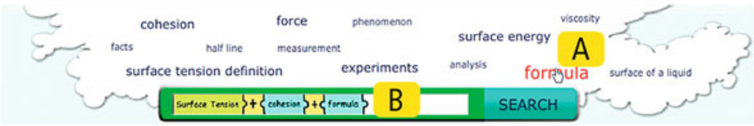


Fig. 3 Related query terms

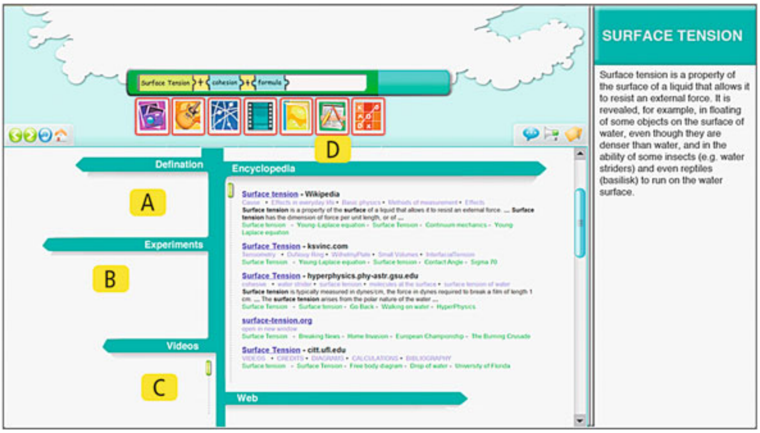


Fig. 4 Project search category visualization

single screen. Clicking the button (Fig. 4d) fires multiple queries to get all project related information at one go and it's visualized in a common space. Users don't have to keep swapping between different categories every time while searching for information and can access it from a common screen.

Fig. 5 Project tools for documentation

Shared Space: (Figure 5d) The application provides a shared space for all the team members to keep dumping all data collected by them. This data can be viewed by all the collaborators and anyone who has been invited to join the session. The icon (Fig. 5c) of members who dumped the data is shown to avoid confusion and for further referencing. Also, the application gives the users an indication when the collaborators join/leave (Fig. 5b) the session by showing their icon in the shared space.

Collapsible and flexible space: The shared space is a flexible space, which can be adjusted to any size to avoid using too much space while searching. During the search activity the shared space can be collapsed and while editing the content it can be expanded into full screen. This provides a common ground between the users to carry out discussions, view, share and comment (Fig. 5d) on the data being accumulated by team members. Users can collectively take a decision on what can be finally chosen for the final presentation. Changes made by the group members are reflected in real time. Discussion and expressing view-point leaves a scope for reflection—a vital component of learning.

Timeline: The timeline option in the project tools (Fig. 5c) shows a replay of how the shared document has been edited from the start. This is a valuable aid to view the chronological progression of the actions of all group members in editing the information gathered during the entire search session. This can be valuable aid to recognizing dead-ends, reorganizing and adopting a different search strategy also prevents redundancy.

Integrated chat: (Figure 5a) The application helps the team to communicate by integrating a text and audio chat feature in the application. This is to ensure that searching and discussing information can happen simultaneously. A combination of a singular shared space and audio/text chat helps a lot in preventing miscommunication.

Fig. 6 Project tools for documentation

Project Tools: (Figure 5c) The application provides basic editing tools in the shared space, so that a rich documentation of the project can be completed in the application itself. The final edited summary can also be exported into different file formats.

The application has a separate interface (Fig. 6) for the teachers (to make sure they are not directly involved) where they can view, comment, suggest corrections and reward (Fig. 6b) the projects to encourage the team.

8 Co-Designing and Experiencing Co-Web

A high-fidelity prototype created in Action script and deployed as an AIR application was used to evoke the participation of multiple students working on finding information for a common project. A group of students and teachers were asked to try out the sketch and then discuss the possibilities that opened up during the sketch. The students believed that the overall idea of carrying out informational searches in a common space was helpful but stressed the need of more ways to simplify articulation search queries. Features visualizing search (timeline, shared space, dynamic tag cloud) were among the most highly rated aspects of the prototype. Users expressed a desire to directly print the edited summaries and use it in their project scrapbooks. This suggests that providing rich documentation/post searching experiences is an important aspect of supporting collaborative Web search and is something that the users enjoy and cherish. Teachers expressed the view that it would not be comfortable for them to add any person to the project (esp. family members of students) and also wondered if there was enough sense-making of the data that was would be collected by the students using this application. One student expressed that she could use this to even do collaborative searches with her siblings and use it to teach her mom who did not know how to use internet search. Thereby in addition to evaluating the specific features of the sketch, the process facilitated a move forward in co-articulating what it means to design and use digital technology to facilitate collaborative information searching in everyday life.

9 Future Work and Possibilities

Technologically, the first step would be to develop a completely working application which is tested with a bunch of students on a real project. This will be taken to the homes and schools of users to discuss the design space of possibilities. Future efforts should be taken in the direction of increasing sense-making of the information collected collaboratively by the participants. It may also be interesting to expand the formation of search queries through different Boolean operators apart from 'AND' and also visualizing other advances search techniques in an intuitive and usable manner. Therefore, future research plans include not only further evaluation of Co-Web interface, but further development of the interface to support various collaborative scenarios, increasing leaning and ensuring better search articulation.

10 Future Work and Possibilities

In the above sections, we detailed how the design space offered by collaboration in online searches and information retrieval in secondary school students was explored. We further detailed the interviews and user studies carried out to flesh out this design space and how Co-Web emerged out of the pain-points and opportunities presented by the design space. We finally conclude by reflecting on the contributions of the paper: firstly, providing a high-fidelity prototype in the form of Co-Web and secondly this initial exploration opening up and adding to the emerging design space of collaborative web searches and information gathering online for children.

As described above, the design of Co-Web evolved from user studies and interviews to early software manifestation in a co-design setting where the students and teachers evaluated the ideas and specific features as the process moved forward. Adding to this, the process was set in the actual site of their individual homes of the students, thereby brining forward more direct and relevant evaluation of the concept. We end by discussing the future directions and the possibilities that emerge out of this exploration and the direction further research can take for creating unique collaborative interfaces used by children for better information retrieval.

References

1. The "Internet Habits of High School Children". http://kraran.com/internet-habits-of-high-school-children/
2. "UNICEF-India- Statistics". http://www.unicef.org/infobycountry/india_sta tistics.html
3. PricewaterhouseCoopers (2010) Information and communication technology for education in India and South Asia
4. Moore P, St. George A (1991) Children as information seekers: the cognitive demands of books and library systems. Sch Libr Media Q 19:161–168
5. Druin et al. (2001) Designing a digital library for young children: an intergenerational partnership. In: Proceedings of ACM/IEEE joint conference on digital libraries
6. Walter VA, Borgman CL, Hirsh SG (1996) The science library catalog: a springboard for information literacy. Sch Libr Media Q 24:105–112
7. Gayo-Avello D, Brenes DJ (2009) Making the road by searching—a search engine based on swarm information foraging CoRR abs/0911.3979
8. Amershi S, Morris MR (2008) Co-search: a system for co-located collaborative web search. CHI 2008, pp 1647–1656
9. Morris MR, Paepcke A, Winograd T (2006) Team-search: comparing techniques for co-present collaborative search of digital media. IEEE Tabletop, pp 97–104
10. Han R, Perrett V, Naghshineh M (2000) WebSplitter: a unified xml framework for mutli-device collaborative web browsing. CSCW 2000, pp 221–230
11. Greenberg S, Roseman M (1996) GroupWeb: a WWW browser as real time groupware. CHI 1996 conference companion
12. Morris MR, Horvitz E (2008) SearchTogether: an interface for collaborative web search. In: Proceedings UIST 2008, pp 3–12
13. Morris MR, Horvitz E (2007) S3: storable, shareable search. Interact 2007, in press

Part VII
Design Management, Knowledge Management and Product Life Cycle Management

Modeling and Analyzing Systems in Application

Maik Maurer and Sebastian Maisenbacher

Abstract Technical products and processes do not represent complex but complicated systems. Complexity gets implemented into such systems by including users and use cases. Hereby, technical systems can be interpreted as enablers, which fulfill functions for the user. We define the combination of users and enablers as a "system in application" and propose applying methods from structural complexity management for its modeling and analysis. Therefore, we introduce two structural characteristics and their interpretation. Based on modeling, analysis and interpretations we present procedures for system improvement and evaluation in terms of increased system usability. The practical application of the new approach on the check-in process for air travel shows achievable benefits from systematic improvement and evaluation strategies. Future work will cover the extension of applicable structure analyses and methods of multi-domain analyses.

Keywords Structural complexity · Enabler · User · Design structure matrix

1 Introduction

In a modern society, people often deal with networked and complex issues [1–3]. Today, new technologies and innovative products enable users to manage many of those issues, which were difficult to solve in the past. Therefore it is a prerequisite

M. Maurer (✉) · S. Maisenbacher
Product Development, Technische Universität München, Garching, Germany
e-mail: maik.maurer@pe.mw.tum.de

S. Maisenbacher
e-mail: maisenbacher.seidl@t-online.de

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_56, © Springer India 2013

that users are familiar with those supporting technologies and products. This can be illustrated in the context of mobile communication: Many people desire permanent internet connection and worldwide communication even while traveling. Linking their mobile devices to different networks asked for significant effort until a few years ago. Today, smartphones can establish connections to many different networks without any manual user interaction. Thus, permanent internet connection can be easily realized today. The precondition for this simplification is that the user knows how to interact with the smartphone.

"Complexity increases" is a common statement, which often focuses on technical products and processes (e.g. smartphones). In contrast to that we state that processes and products can be complicated but not complex. Application of products and processes requires the user to possess sufficient capabilities. These capabilities differ from one user to the other. A system can become complex when products or processes are linked with a user. In such a "system in application", complexity reduction means shifting complexity from the area of user interactions to the product or process and to simplify the interface between user and the product or process.

This contribution introduces a method for modeling, analyzing and interpreting a complex system as a combined view of the user context and the technical system. This can help adjusting products and processes to user capabilities and making products and processes more user-friendly.

In Sect. 2 we discuss the difference between complicated and complex system and define the terms, which are relevant for our approach. Then we describe the state of the art concerning inclusion of users into complex system consideration. In Sect. 3, we explain how to use possibilities of structural complexity management for modeling and analyzing systems in application. The application process then gets detailed in Sect. 4. Section 5 describes a case study of the mobile check-in process for air travel.

2 Definitions

The introduction of the new approach toward complex systems modeling requires some initial definitions. Based on these definitions we explain why products and processes can be complicated but not complex. And we introduce the "system in application", which allows including the subjectivity of users into complex system consideration.

2.1 Simple, Complicated and Complex Systems

Cotsftis [4] quotes that systems belong to one of the following three states: simple, complicated and complex. Simple systems consist of a small number and weakly coupled elements, which are acting according to well understood laws [5]. The behavior of simple systems is predictable.

Complicated systems consist of lots of elements and relations between them. These elements and relations are constant and the behavior of the system is deterministic [6]. According to [4] complicated systems can be decoupled and elements can be identified. The system elements are connected to external elements, which can influence the system. Complicated systems have a limited range of response to environmental changes [5]. A defect or change on critical parts brings the entire system to a halt. Complicated systems can easily generate complex dynamics, if they are influenced by external elements.

Complex systems comprise of a large number of elements, which are strongly interconnected [7]. Interconnection and interaction between the elements prevents the system from decomposition, it cannot be divided into subsystems [6]. Complex systems are also strongly connected to their environment, which results in a high amount of possible system conditions. Thus, complex systems possess internal dynamics [4] with changing system behavior [6]. The dynamics can arise from the system and from its environment (in contrast to that, dynamics in simple or complicated systems only arises from the environment). Cotsftis and Richardson [4, 6] define this as self-organization. This enables a complex system to respond to changes in the environment [5]. All aspects mentioned can be summarized in the following definitions for the three system states:

A simple system consists of a small number of weakly connected elements. The structure is easily manageable and different system states result from external sources only.

Complicated systems possess a hardly manageable structure with lots of elements and relations. As in simple systems, different system states can only result from external sources. A complicated system becomes static, if it gets isolated from its environment.

Complex systems possess a high number of elements and relations. The crucial characteristics are the existence of internal dynamics and self-organization, which make complex systems hardly predictable and uncertain.

2.2 Internal and External Complexity

Several authors distinguish internal and external complexity in an industry context (e.g. [8]). Internal complexity describes the variety and interdependencies of elements, which are required to realize the product portfolio offered by the company. External complexity results from the market, customers and competitors, who represent the (also interlinked) requirements, which have to be met by the product offer. Eppinger and Browning [9] mention that external complexity is the input from the environment to the system.

In the context of our approach, internal and external complexity means complexity inside or outside of the system borders (thus definitions are not limited to a company view). Consequently, only complex systems possess internal complexity (see definitions above). Complicated systems do not contain internal complexity, because they only show static behavior when separated from their environment.

2.3 System Classification of Products and Processes

Technical products and processes can be classified as complicated systems in the context of our definitions. A product consists of a specified number of components, which are partly interconnected. A process consists of a specified number of process steps, which are ordered in a sequence. Technical products and processes do not contain internal complexity. They can only adopt one static condition, if considered without input from their environment.

However, products and processes are influenced by the external environment, if they get applied. Such application can change the condition of products and processes by implementing external complexity to the system. For example, changing network connection of a smartphone can result in interruptions in communication; new downloads, updates or malware can lead to system improvement or deterioration and mistreatment by the user can cause malfunctions or destruction of the smartphone.

2.4 System in Application

The explanations on system classification suggest not limiting complexity analyses to technical system descriptions only, because external complexity needs to be considered as well. The inclusion of users and use cases into system models allows representing the application of technical systems and processes and therefore integrates external complexity into the system descriptions. We define a "system in application" as consisting of a subjective user, a technical product or process and different use cases (or environmental conditions). The technical system or process is also called enabler, as it fulfills functions for the user.

The subjective user represents the source of external complexity for the enabler. UML use case diagrams are often applied for modeling the connection between users or use cases and technical systems [10]. Such diagrams allow describing a specific (external) influence to a technical system. However, this influence does not get correlated to the internal structure of the technical system [11]. But the integrated consideration of an internal complicated product structure and the external complexity is required for analyzing the behavior of a system in application.

Design Structure Matrices (DSM) represent a powerful method for modeling technical products and processes [12], but aspects of external complexity are rarely integrated.

So far the combined consideration of enablers and users in a structural system model is not covered sufficiently. Investigations on system complexity require a comprehensive description, which also provides insights into the interfaces between users and products or processes.

3 Modeling and Analyzing a Systems in Application

In this chapter we present a model scheme, followed by analysis techniques for successfully manage systems in application. Interpretations of analysis results allow drawing conclusions on the system behavior, which then can be optimized by adequate measures. Such measures can be the redesign of the interface between users and enabler and the beneficial positioning of system complexity in the user or enabler area.

3.1 Modeling a System in Application

A system in application can be split up into two parts describing an enabler (technical product or process) and a user. The enabler permits the user to execute an intended task or to solve a problem. The structure of an enabler is formed by its elements (e.g. product components or process steps) and dependencies between them.

Users apply the enabler. Differences between users (subjectivity of users) can be important aspects of systems in application [13]. And this can increase systems' complexity. Also non-human, unpredictable or dynamic processes (e.g. weather conditions) can be modeled as system users. Elements (e.g. processes executed by the user) and their mutual dependencies form the structure of a user. As the system user and his connections to the enabler area can be complex, this system part can hardly be modeled completely. This is not a drawback of the new approach, because the intention is to build only a useful view of the real system [12].

Dependencies between user and enabler represent the mutual influence between both subsets and can implement complexity into the system. The example of an applied smartphone can clarify this: Users interact with their smartphone mainly by input devices like the keypad or touchpad. Input devices change over time, e.g. from keypads to voice recognition. User groups, e.g. elderly people, show the subjectivity of users, which influences the design of input devices. For example, larger keys and reduced menu navigation are offered for elderly people.

The structure of a system in application can be modeled using the Multiple-Domain Matrix (MDM) [12]. The general layout is shown in Figure 1. This matrix is applied in the method of structural complexity management [12]. This method includes approaches for information acquisition, definition of the objective as well as system boundaries and also provides analysis procedures for systems in application. User and enabler represent subsystems, which are modeled as DSM. The interface between both subsets is modeled by two Domain Mapping Matrices (DMM). One indicates inputs from the user to the enabler; the other DMM contains responses or outputs from the enabler to the user.

The general MDM layout from Fig. 1 needs to be further detailed for system representation. Therefore, relevant domains have to be defined for specifying users as well as the enabler. A domain means a set of similar system elements, e.g. components or process steps. The selection of appropriate domains requires basic system knowledge.

For all domains system elements and dependencies between them need to be collected. It is advisable not only to focus on acquiring elements and dependencies in the single subsets. Rather modelers should separate the acquisition of elements and dependencies from their subsequent assignment to users or enablers. When allocating elements to the user and enabler area the interfaces between both areas result automatically in the upper right and lower left sector of the matrix. Figure 2 shows the two steps by using a generalized example, which consists of three domains (persons, components and process steps).

3.2 Analysis Approach

Structural complexity management provides possibilities for identifying characteristics in system structures. This can also be used for analyzing structural models of systems in application. The analysis of the entire matrix (complete system in application including all four subsets) allows interpreting the overall system interdependencies. A graph representation of the system can be helpful, if an appropriate layout algorithm visually indicates structural characteristics like clusters or articulation nodes [12]. And metrics like the level of connectivity or the amount of clusters are useful for comparing two or more systems (e.g. variants or alternative designs) on a general level.

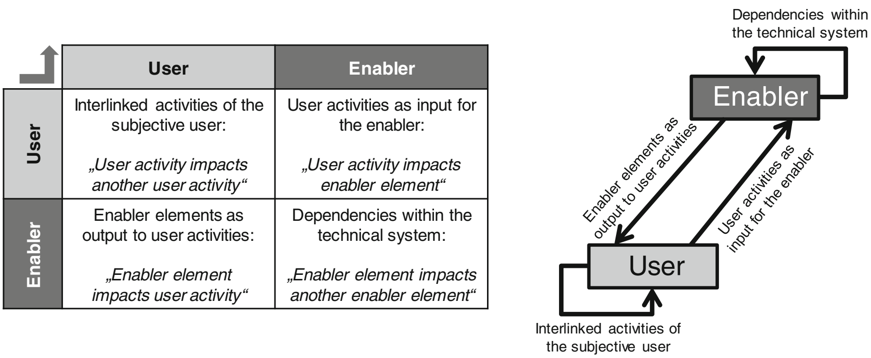


Fig. 1 System in application modeled as multiple-domain matrix (*left*) and graph (*right*)

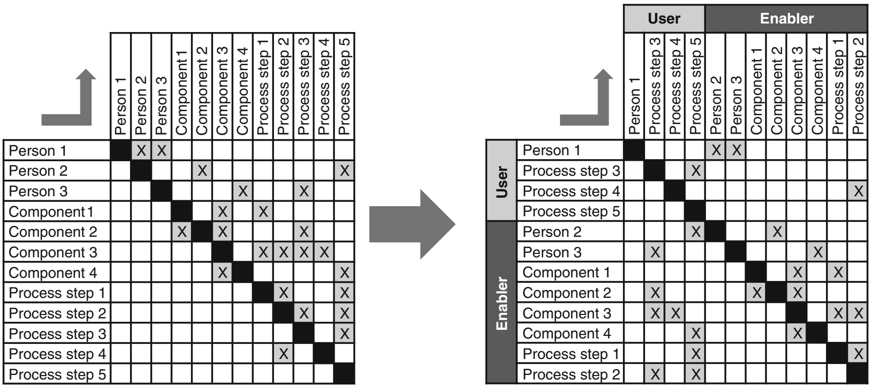


Fig. 2 Acquisition of elements and dependencies (*left*) and their classification (*right*)

Detailed structure analysis can be executed for all four subsets and cover different objectives. One has to consider that the two DSM (isolated views on the technical system and the user) partly allow other analyses than the two DMM (interfaces between users and technical system) [12]. E.g. feedback loops can only occur in DSM.

In the following paragraphs we will describe the application of two analysis methods taken from structural complexity management and explain their interpretation in the context of the four subsets of a system in application.

3.2.1 Clustering in Systems in Application

A cluster is a group of system elements, which possess many internal and only few external dependencies [12]. Clusters can exist in all four areas of the system model, as indicated by Fig. 3 (left). A cluster in the two DSM can be interpreted as strongly interrelated user activities (1) or technical components (2) suitable for being implemented as a module. Clusters in DMM combine elements of two domains and have to be interpreted differently. A cluster, which links user activities to enabler elements (3) describes a set of activities, which are all required as input for the same group of technical system components. In extreme cases one missing user input could make all other inputs obsolete and could block fulfillment by the enabler. The cluster indicated as (4) in Fig. 3 can be interpreted as a set of enabler elements which all provide output to a defined set of user activities. A missing output results in lacking information for all involved user activities.

When considering specific systems in application, beneficial analyses need to concretize cluster interpretations. However, the general identification of clusters without context specific interpretation allows drawing useful conclusions. For example, clusters of user inputs to enablers can indicate the existence of a systematically structured interface.

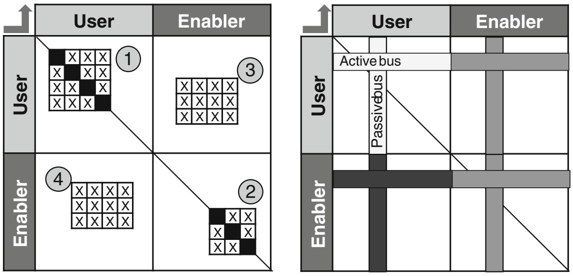


Fig. 3 Clusters and bus elements in a system in application

3.2.2 Bus Elements in Systems in Application

A bus element is characterized by many dependencies to other system elements. Busses can be active or passive. This means they influence the entire system or get influenced by the system [12]. In the model of a system in application a bus can appear in all four subsets (Fig. 3, right). The position of a bus element impacts its interpretation.

If located within the user domain (upper left area), an active bus means a user activity influencing many other activities, e.g. the starting of a phone call on the mobile phone. A passive bus then means a user reaction to several other decisions made before. Interpretations of bus elements within the enabler domain (lover right area) can be deduced similarly. Bus elements in the upper right and lower left area represent important interfaces, which connect users and enablers. Such interfaces contain many technical components or many user activities. The initiation of an internet connection via a smartphone was such an interface, as long as many manual inputs (user activities) were required for this enabler function. Moving bus elements from interface areas to internal areas of users or enablers can be advantageous for the system's usability and is described in Sect. 4.

3.2.3 Interpreting Further Structural Characteristics

The new approach models systems in application according to the methods of structural complexity management. More structural characteristics from this management approach should be transferable to systems in application. For example, consideration of feedback loops, hierarchies and articulation nodes seem to be beneficial for interpretation and optimization of systems in application. A systematic transfer and evaluation of structural characteristics from structural complexity management will be part of the future work.

4 Application Process

Analysis and interpretation of systems in application can serve two general objectives. Firstly, identification of possibilities for system improvement can be desired. Improvements mean reducing complexity for users when interacting with the enabler. This does not mean that products or processes need to be simplified. They can even be complicated (see definitions in Sect. 2), but their application should be as simple as possible. In the depiction of a system in application this implies the transfer of nodes and edges from the user area to the enabler area and the facilitation of interfaces between user and enabler.

Secondly, one could ask for evaluating the impacts of ongoing design activities to the system. Therefore, two states of the system structure need to be compared (delta analysis) and rated by appropriate indicators. Both objectives are indicated in Fig. 4 and explained in the following paragraphs.

4.1 Identification of Possible Improvements

From a user perspective, possibilities of improvement can be found in the user area and the two DMM, which connect users and enabler. The intention is to transfer complexity from user's responsibility to the technical system. In the matrix that means transferring system elements from the user to the enabler domain. This can be implemented, if those elements can also be executed by the technical system (enabler).

An example is the initiation of internet connections via mobile phones. Some years ago users were responsible for implementing all settings for connecting to the internet. If users were not familiar with technical vocabulary and network specifications, internet connections were hard to establish. Modern smartphones do not require any user specifications and provide an internet connection almost automatically. This shows that moving elements from the user to the enabler does also move interdependencies within the system. Whereas the manual internet

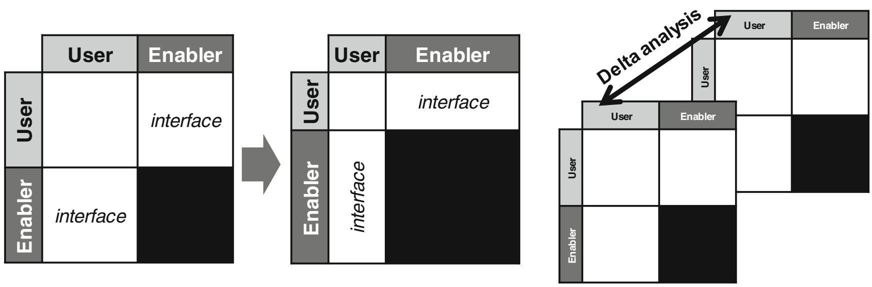


Fig. 4 Objectives for system interaction, system improvement and design evaluation

connection required an extensive interface between user and enabler, automatic internet connection simplified this interface. Such a measure does not change the overall system complexity. But elements and dependencies become aggregated in the technical system and user interactions are decreased (Fig. 4).

4.2 Evaluation of System Design Activities

It can be helpful comparing different versions of a system in application for evaluating the technical progress. For example, many user-involved service processes (e.g. check-in process for air-travel) have changed in the last few years by integrating mobile media devices. In this case, one could ask if the process has been improved for users.

When comparing two system versions, some indicators can be applied for evaluation: The amount of elements in both areas (users and enabler) allows estimating the degree of system automation. The amount of dependencies in the user DSM and the two DMM (interfaces) indicate if the degree of user interactions could be decreased. Such delta analyses between system states are also applicable for evaluating design measures concerning their effectiveness in terms of increased system usability. As well, design measures can be initiated by identifying system improvements according to Sect. 4.1.

5 Case Study: Check-in Process for Air Travel

Possibilities for passengers to check-in for air travel have changed over the last few years. In the past, the process was characterized by printed documents (receipt, ticket, boarding pass) and related user activities. Since some years the check-in can be executed by using a smart phone. Users do not have to interact with documents (e-tickets) and can directly proceed to the gate, when using the mobile check-in. The integration of new technologies should facilitate the entire process. However, many people do still not use the mobile check-in. They declare the new process to be more difficult than the prior one.

Figure 5 shows the model of the mobile check-in with two domains for the user and the enabler (element names start with "U_" and "E_"). The number of elements in the user domain decreased in comparison to the model of the prior (paper-based) check-in process (not shown here) from 35 to 25. In the enabler domain the number of elements increased from 12 to 17. The degree of connectivity in users' input interface (upper right subset) dropped from 6.7 to 5.2 %. These changes can be interpreted as simplification of users' need for interaction and their input interface.

Whereas the model indicates a system improvement, still many users refuse mobile check-in and describe it as being too difficult. In Fig. 5 one can see that

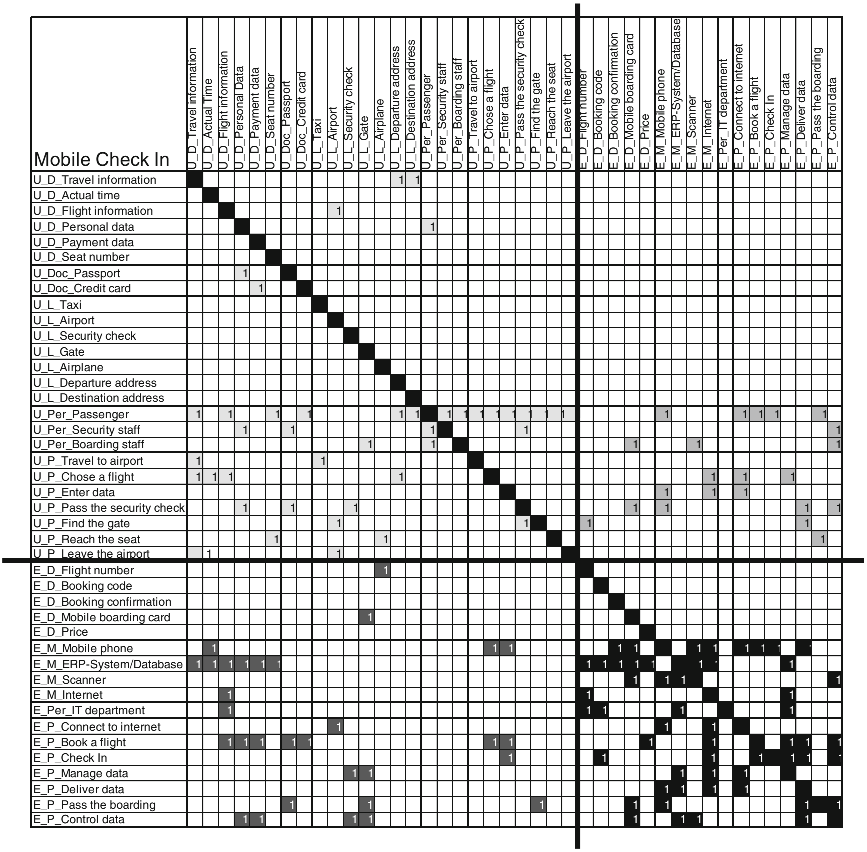


Fig. 5 System model of the mobile check-in process for air travel

passengers have to interact intensely with the smartphone and have to enter data. If users are not familiar with these tasks, mobile check-in can not be executed.

The model of the mobile check-in process provides possibilities of improved system usability. E.g. the process "U_P_Pass the security check" is an element of the user domain with an intensive interface to the enabler area. The interface would get simplified, if this step could be moved into the enabler domain in future check-in processes. In fact, the concept of "trusted passengers" is currently under consideration. Hereby, passengers would not have to pass security checks any more. In this concept the enabler executes background security checks of passengers. If successful, passengers obtain their status as "trusted passenger" and enter airport security zones without further checks.

6 Conclusion and Future Work

We argue that technical products and processes are not complex but complicated. Complexity arises when a system is formed by subjective users and use cases in combination with products or processes. Such a combination we call a "system in application". We propose applying methods from structural complexity management for modeling and analysis of such systems. This is the basis for system interpretation and implementation of optimization measures. We showed two structural characteristics and their interpretation in the context of user related and enabler related system elements. And we introduced procedures for system improvement and evaluation in terms of usability. Practical application on the check-in process for air-travel indicated suitability of the modeling approach and achievable benefits from systematic improvement and evaluation strategies.

So far, only few possibilities of analysis and interpretation have been adapted from structural complexity management. Several others could be helpful for better understanding and adapting systems in applications. In future work we will evaluate the applicability of structural characteristics like feedback loops, hierarchies and articulation nodes.

Systems in applications are formed by the user and enabler domain. And both domains typically contain further sub-domains (e.g. processes and components). If the entire system should be investigated, possibilities of multi-domain analyses are required—but not available so far. Therefore, we will also focus on expanding structure analysis to multi-domain contexts in future work.

References

1. Calvano C, John P (2004) Systems engineering in an age of complexity. J Syst Eng 7(1):25–34
2. Chung L, Cooper K (2004) Defining goals in a COTS-aware requirements engineering approach. J Syst Eng 7(1):61–83
3. Kohn A, Lindemann U (2009) Combination of algorithms and visualization techniques considering user requirements—a case study. 11th international design structure matrix conference
4. Cotsftis M (2009) What makes a system complex?—an approach to self organization and emergence. In: Aziz-Alaoui M et al (ed) From system complexity to emergent properties. Springer, Berlin, pp 49–99
5. Amaral L, Ottino J (2004) Complex networks. Eur Phys J B 38:147–162
6. Richardson K (2001) On the status of natural boundaries: a complex systems perspective. Systems in management 7th annual ANZSYS conference, pp 229–238
7. Anderson P (1999) Complexity theory and organization science. Organ Sci 10(3):216–232
8. Marti M (2007) Complexity management: optimizing product architecture of industrial products. Dissertation University St. Gallen
9. Eppinger SD, Browning TR (2012) Design structure matrix methods and applications. MIT Press, Cambridge

10. Von der Maßen T, Lichter H (2002) Modeling variability by UML use case diagrams. International workshop on requirements engineering for product lines, Essen
11. Koch N, Kraus A (2002) The expressive power of UML-based web engineering. Second international workshop on web oriented software technology CYTED, pp 105–119
12. Lindemann U, Maurer M, Braun T (2009) Structural complexity management. Springer, Berlin
13. Gulliksen J (1996) Designing for usability—domain specific Human-computer interfaces in working life. PhD thesis, University of Uppsala

A Categorization of Innovation Funnels of Companies as a Way to Better Make Conscious Agility and Permeability of Innovation Processes

Gwenola Bertoluci, Bernard Yannou, Danielle Attias and Emilie Vallet

Abstract It is common in the Management Science and Design Engineering communities to represent the processes contributing to innovation in companies as a funnel or similar variants. It is assumed it is possible to represent an analogy to the stages of planning and idea generation (the so-called fuzzy front-end), conception generation, as well as idea and concept selection to end up with the very few emerging developed and launched products and services on the market. First, this analogy may feature different innovation process layers, each of them independently as well as the entire set of these innovation process layers. After a review of literature on this funnel representation, we show that this analogy may be meaningful to globally represent and discuss about some properties of the innovation capability of a company at different locations: the R&D process as well as a given NPD process. We further describe a survey carried out within 28 large European technological companies through 48 detailed face-to-face interviews. Our questionnaire has allowed us to observe some characteristic patterns in the

G. Bertoluci · B. Yannou (✉) · D. Attias
Laboratoire Genie Industriel, Ecole Centrale Paris, Grande Voie des Vignes 92290 Chatenay-Malabry, France
e-mail: bernard.yannou@ecp.fr

G. Bertoluci
e-mail: gwenola.bertoluci@ecp.fr

D. Attias
e-mail: danielle.attias@ecp.fr

G. Bertoluci
AgroParisTech, 1 Avenue des Olympiades 91744 Massy, France

E. Vallet
Logica Business Consulting, Immeuble CB16, 17 Place des Reflets 92400 Courbevoie, France
e-mail: emilie.vallet@logica.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_57, © Springer India 2013

innovation funnels. We finally propose a model of five innovation funnels varying by their shape, permeability of emerging ideas and agility in terms of innovation management. We also hypothesize that these 5 funnels evolve in a sequential and cyclic way and that our cyclic model may be used as a questioning tool for the continuous improvement of the innovation management.

Keywords Innovation funnel · Development funnel · Product development · Design process · Innovation management

1 Introduction to Funnel Representations

Looking for ideas for an individual or group to document the resolution of a problem implements a cognitive process [1] of divergence and convergence. This is in this divergence part of ideation that creativity tools are solicited. This second convergence part is often represented as a synthesis funnel (see [2] and Fig. 1) in which ideas are selected, recombined or eliminated to result in the very few selected ideas that merit to be further detailed.

Design exploration process is an important part of design creativity and novelty [3]. The design activities in conceptual design are contained in two kinds of steps: divergent and convergent [4–6]. Cross [4] thought of the conceptual design process as mostly being convergent with the necessity to contain a deliberate divergence in the search for novel ideas (see Fig. 2).

Pugh's model [5] for conceptual design and the definition of the convergence and divergence activities can be represented as on Fig. 3. Pugh mentioned that it is essential to carry out concept generation and evaluation in a progressive and disciplined manner so as to generate better designs. This progressive and disciplined manner is illustrated as an iterative, repeated divergent and convergent process with the number of solutions gradually decreased (see [7]).

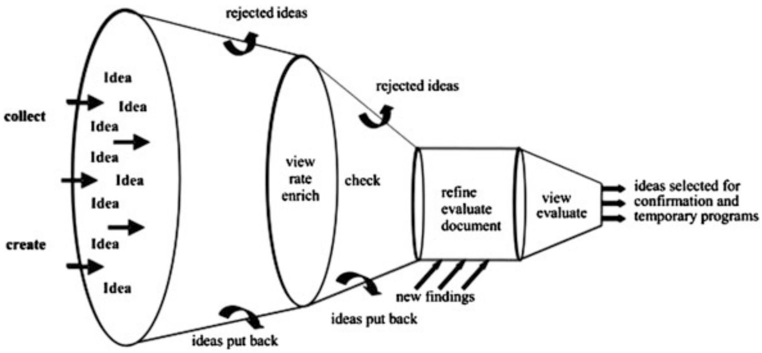


Fig. 1 Idea funnel [2]

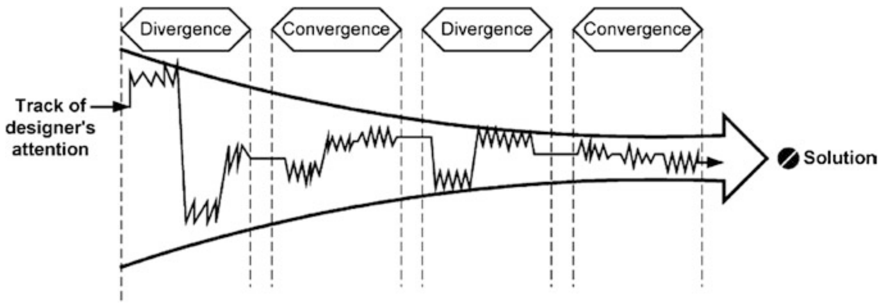


Fig. 2 The conceptual design process defined by cross [4]

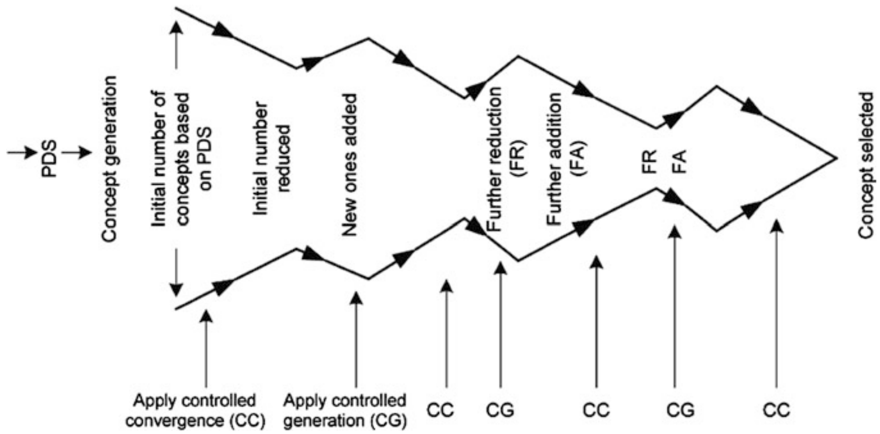


Fig. 3 Pugh's conceptual design process [5]

This representation of the progressive reduction of the possible design space has been extended by various authors [8, 9] to take into account the development of new technologies whenever a new technology is a key lever of innovation. Wheelwright et al. note that the companies that supply these funnels by R&D (Fig. 4a) on technologies, processes and products also extend the scope of the funnel to bottom-up uses (Fig. 4b) to identify and filter out new ideas from a strategic market analysis.

The two situations of convergent part of an ideation process (innovative process) and technology push or market pull representations (strategic innovation management) are very different. Whether one refers to very general models such as the Chain Linked of Kline and Rosenberg [10] and the Stage and Gates of Cooper [11], or more detailed and structuring processes proposed in design engineering [9, 12–15], this analogy of forward selection and progressive shrinking of the design space appears to be a highly interpretative task. However, it is very well illustrated by Wheelwright and Clark [9] who clearly associate it with the product planning stage preceding that of product development (Fig. 5).

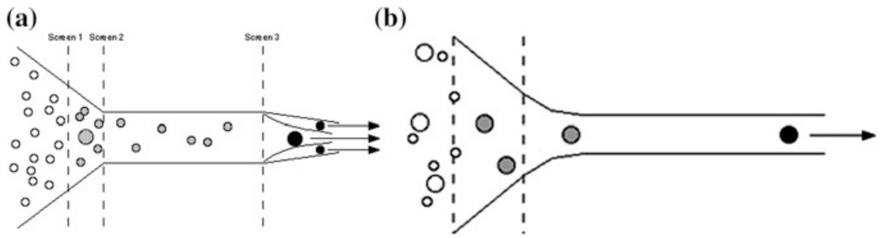


Fig. 4 Funnel representations of Wheelwright [9] **a** Funnel of technology push. **b** Funnel of market bottom up

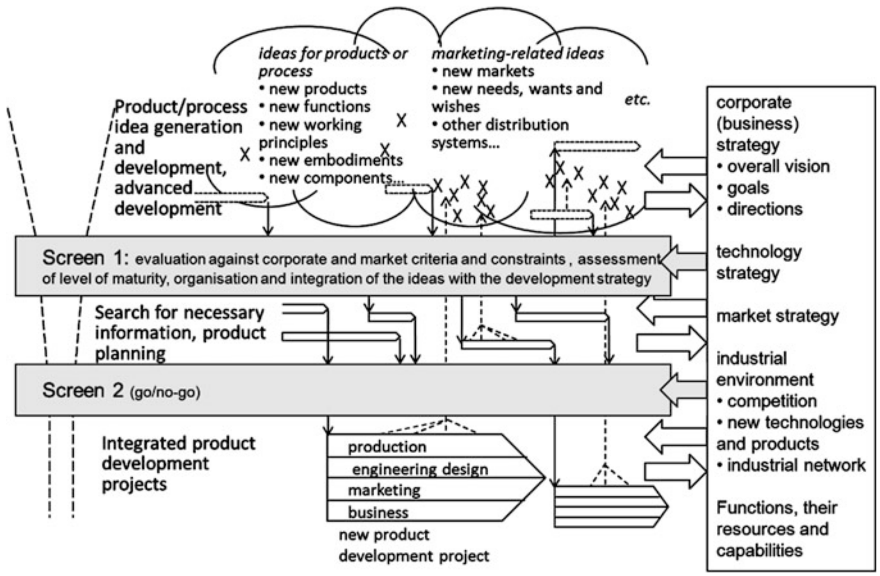


Fig. 5 The funnel development process of Motte et al. [19], adapted from Wheelwright and Clark [9]

These representations in funnels do not aim to facilitate the structuring of a process of innovation but to illustrate how an organization has the means to open and close its creative space and thus its products space. In this sense, to interrogate the businesses associated with the innovation process on how they actually process opens or closes to integration of new ideas and new opportunities, throughout a development process, is a way to identify how this funnel is actually generated. It is a question asked on the innovative organization behind that could lead to a continuous improvement of the innovation management. The objective of this paper is to propose a tool for the continuous improvement of the innovation management in companies based on a funnel categorization obtained after an innovation survey in 28 large companies.

2 Survey on Innovation in Large Companies and Lessons Learned

In a recent survey of 28 large European companies in the industry, we investigated the state of practice in innovation and innovative organizational models in large companies. This survey has provided qualitative and quantitative results which have been reported in a book [16]. We interviewed 48 R&D or innovation directors by asking them to self-diagnose their business practices according to the five management areas that contribute to value creation: strategy and business intelligence, organization of R&D, management of innovation processes, innovation culture and management of human resources and R&D, measurement of innovation performance. Our learning are numerous and sometimes surprising. We report hereafter just a few of them to contribute to this paper.

Two thirds of respondents reported having profoundly transformed or reorganized their R&D over the past three years. For reasons to support the international expansion, pooling and centralization of research upstream, location in the business unit of applied research and development or reorganization of the development process and resource allocation of R&D. These reorganizations are made in trial and error mode (no apparent method) and reflect a search for greater innovation performance. Indeed, companies face a real difficulty in measuring performance and the benefits of innovation, investment in research that results often lately by the market launch of innovative products and services. Management indicators of innovation or value creation are often of "rear-view mirror" type like the number of patents rather than of "looking ahead" type (able to monitor the value increasing).

Finally, the companies say that the upstream processes of ideas management are poorly organized. Indeed, 47 % of companies do not use a methodology for generating ideas. The methods used are the idea boxes and idea contests without, in most cases, budget for the exploitation of good ideas that emerge. Also appalling, the only methods of generating ideas and driving innovation that are sometimes referred by high-level managers are TRIZ and Design to Cost and Objectives.

The companies surveyed acknowledge the fact that the so-called "innovation process" of a company is actually a series of strata or four processes (see Fig. 6 which is our own representation) with interconnections but acting at different times, with specific strategies, roadmaps and different but interdependent budgets. These four processes are:

1. The process of ideas generating on products, technologies, processes or organization,
2. That of research or technology management
3. That of product lines or programs management or planning

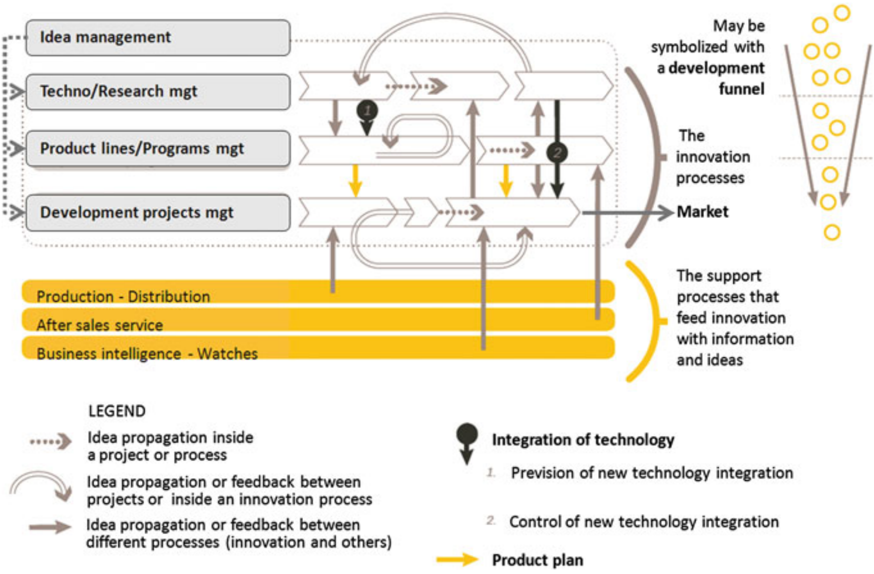


Fig. 6 Modeling innovation or value creation processes in companies

4. The very activity of project management of New Product Development (NPD), which supplies the market with new offers and contributes largely to the creation of business value.

It may be noted that a number of business support processes such as marketing, customer relations, after sales service, purchasing and competitive intelligence also contribute more indirectly to the increased degree of effective innovation of the company's products. Note also that according to the ideas (nature, size, maturity), process #1 of Ideas Management can feed processes #2, #3 and #4. All this must necessarily be organized within the company with the collection process of ideas and transfer of ideas within mature roadmap that invest and plan their development and their deployment in research, product lines or project development. However, these transfer processes are currently poorly organized and coordinated so that the process of generating and collecting ideas as we have seen. But there are organized and standardized processes within the company such as product development. These are step by step processes with intermediate outcomes expected, so-called "stage and gate". It turns out that these processes are as well necessary to ensure a minimum quality and coordinate development activity on a complex project, as sometimes too rigid and not very permeable to new ideas and opportunities that would upset too much a strategic positioning or that would appear during the project.

In our book [16] we have thus classified the 28 surveyed companies into 5 categories of innovation funnels (there are 6 companies per category in average), considering the characteristics of the whole 4-layer innovation process of Fig. 6

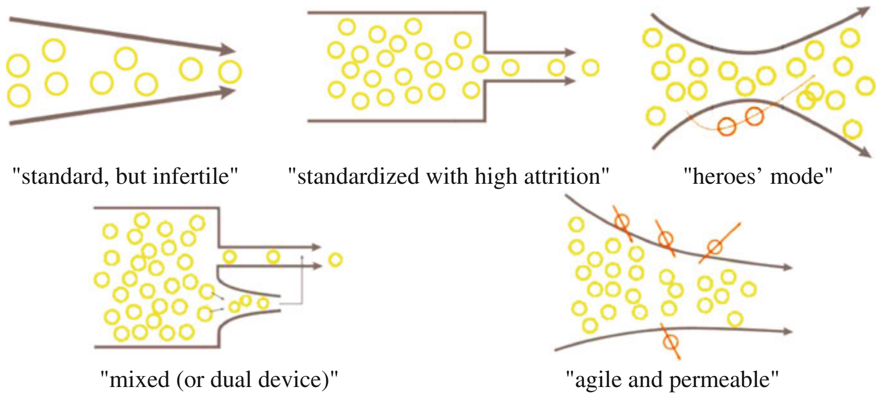


Fig. 7 Our model of five innovation funnels

after the three general properties of *shape*, *permeability* to emerging ideas along the process and process *agility*. This classification has been made by us, the 10 researchers having contributed to interview the company managers.

We have baptized them: the funnel "standard, but infertile", the funnel "standardized with high attrition", the "heroes' mode" funnel, the funnel "mixed (or dual device)", the funnel "agile and permeable". We have also graphically represented them in simple and expressive pictorials with small circles for ideas and contours for the shape (see Fig. 7).

3 Definition of 5-Funnel Model and Correlations with Company Features

3.1 The "Standard, but Infertile" Funnel

For this funnel, few ideas and innovative proposals are selected upstream. The process R&D is classical and relatively heavy. It usually results in a limited number of development projects that generally go until the completion; it is not very selective. This model is found in sectors such as aeronautics, submitted to severe constraints of technical reliability in operation and intense capital investments. It can also be found in the energy sector, a sector where a R&D Director said: *Today the results will kill creativity*; *R&D is today is a super design department*.

The main characteristic of firms adopting this funnel is to have a limited number of ideas in the sequence generation/collection. However, the steps of selection/maturation and launch/development are well standardized and instrumented (Stage and Gate, TRL-Technology Readiness Levels—project mode). Despite a cumbersome process, the dropout rate of development projects is low, once the concept validated and the decision to develop the product made.

These companies are mainly technology companies where the product renewal period is long (more than 10 years) and where the type of innovation is “product” dominant. However, some companies doing predominantly “product” innovation may refer to other funnel models.

The competitive intensity corresponds to relatively oligopolistic markets which, even if they evolve with new entrants, do not change they belong to the exclusive club of leaders in their field.

3.2 The “Standardized with High Attrition” Funnel

Here, the process Research and Development (TRL, Stage and Gate) is unique, classic and relatively heavy, with progressive selection and strong attrition of the proposals. In this model, it is difficult to stop the projects launched once they have passed the stage—gate—of product development. This funnel is found in sectors such as pharmacy or mass retailing where the selection of ideas for innovation is strong before starting the process of development itself.

In this model, many ideas are killed as they pass upstream phase (vision/selection/feasibility of innovation concepts), sometimes despite an abundance of leads and ideas for innovation in this phase. For the transition phase in product development phase, the company takes the minimum possible risk and projects that pass this stage are then under control. But as explained by a Director of Research, Technology and Innovation, *Risk reduction is the anti-innovation. The goal is not to reduce risks, but to manage them. The difficulty comes from people who want to reduce the risks.*

However, the development projects initiated are not arrested or very little even when they no longer meet the original expectations: *I have a project in mind. When I arrived ten years ago, people said It’s been ten years since we talk of it*, it’s still there!.

These companies face a double problem. First, how to reduce the number of tracks to explore and to evaluate in upstream stage—which has a cost—to focus on the most promising? Then, how to accept anyway to take risks, knowing that establishing sales forecasts of innovation on the market is both a delicate task and a choke point? In other words, how not to “sterilize” automatically waiving any idea if its business case is not solid in terms of apparent ROI, given that the expected revenue is often not accurate?

3.3 The "Heroes' Mode" Funnel

The "heroes' mode" funnel makes coexisting a standardized funnel with a heroic mode. It is a R&D process (Stage and Gate) classic that can turn out to be cumbersome with a progressive selection of ideas and difficulty to kill the projects once they started. It is characterized by a weak support to potential innovations proposed by the field and which have failed to take the step of selecting initial ideas. The innovations are defended by tenacious individuals with strong personalities that sometimes succeed to make their ideas acknowledged by others and to put them into an official project portfolio.

Companies in this scheme feed well the funnel in ideas in the upstream phase. But there may be two reasons for not ensuring a good transfer from upstream phase to downstream phase: (1) A R&D process too cumbersome, judged too bureaucratic and procedural or (2) conversely, a lack of a real ideas selection process.

Innovations that pass this barrier are supported for some literally "overreach" by the holders of ideas, which we called the "heroes" and who, with tenacity and by using their internal network, particularly among the bosses of business units, manage to insert their idea into the mainstream product development.

3.4 The "Mixed (or Dual Device)" Funnel

As its name suggests, this funnel combines two processes. On the one hand, a conventional process of Research and Development (TRL type, stage and gate) works, but it can be cumbersome. It is often keyed to the yearly budget. Once the candidate ideas issued, it works more in "top down" mode. Its main features are a progressive selection and difficulty to kill projects launched. On the other hand, the process is light, but institutionalized, organized and resourced to capture the ideas and proposals. It is "bottom up", which gives real resources to support potential innovations, giving the possibility to impact the official portfolio of research and development projects.

This funnel consists in putting another competing device in parallel of the standard R&D process (standardized funnel). This parallel process encourages the expression and development of ideas, if possible "out of the box". It is light, rather "bottom up", but well processed and sequenced. It is generally funded fairly "light".

Conditions to help ideas holders are implemented effectively, albeit on a modest scale in comparison with the official process. They can take different forms: a department dedicated to breakthrough projects and exploration of new growth territories, small committees with financial resources which support the evolution and development of the idea, fund dedicated to disruptive innovation. In the best case, an idea supported and emerging from this parallel device may reinstate the traditional process, or even take the place of a program or development project already in the portfolio.

These models are very new in the organizations we met. Some have produced tangible results, that is to say that ideas have been supported and reintegrated into the process of a traditional project. However, none has yet succeeded in bringing an innovation project standalone, ready to integrate the portfolio of projects issued from the official planning.

3.5 The "Agile and Permeable" Funnel

Here, the innovation process is instrumented and institutionalized to generate and capture ideas constantly. The whole organization—not only the functions dedicated to Research and Development—and its culture are adapted to support the ideas and give them means. The permeability of the funnel acts both for "input" and "output": stopping of the project, outsourcing of a part of the cycle, selling the idea and the first results obtained for continuing the development by a third party, etc. The engagement process of the projects is disconnected from the annual budget process for more flexibility while roughly maintaining the budgets allocated to them.

This funnel that one can qualify of "ideal" is pretty close to the previous. When the "dual device" opens a new avenue for innovation, this funnel seeks to open innovation to all disciplines (research, engineering, marketing, design, sociology, risk management, regulatory watch) and to external partners, from the upstream stage of the process (exploration of innovation fields).

4 Let us Hypothesize an Evolution Law in a 5-Funnel Cycle

4.1 An Evolution Law of Companies in a 5-Funnel Cycle

We have also observed that these different forms of funnel tend to be on a sequential series which is even cyclic. Indeed, the surveyed companies described their 3–5 years past and were entitled too to describe their idealized future in terms of innovation management. Therefore, we experimentally hypothesize that there is a natural law of evolution like it exists in TRIZ theory for technical systems [17, 18].

We define these five stages of evolution of a company in terms of innovation management maturity as:

- The start-up, spontaneously permeable and agile
- The growing company that tends to standardize processes

- The healthy reaction to the normalization: the heroes that defend innovations
- The awareness of the need to establish mechanisms that promote innovation "out of the box"
- The organization of agility

In more details, the 5 stages are:

1. **Stage 1**: At the beginning of a company, at the stage of start-up, the involvement of the founders, the small size of teams and the low volume of activities make that an oral culture is adequate. The whole company is spontaneously committed, led by leaders heavily involved at the operational level, to ensure the output of innovations. The funnel is naturally agile and permeable (or "ideal") without the need for formal processes.
2. **Stage 2**: The growing company creates specialized functions and provide them with dedicated resources. The implementation of processes, operating rules, management tools is needed to control the volume of activity and resource use. The company becomes "technocratic" and sometimes "bureaucratic". A standardized funnel is then implemented. Depending on the types of innovation practiced and sectors concerned, the standardized funnel can be "infertile" (number of ideas for innovation low, often linked to highly technical products and processes and to their renewal duration) or, on the contrary, can be of "high attrition".
3. **Stage 3**: To fight against the negative effects of this form of selection, heroes appear, which personally defend innovative ideas that have failed to pass the formal selection process and eventually turn into real success stories.
4. **Stage 4**: Companies capitalizing on these successes and eventually recognizing the value of one or more parallel channels to the formal and standardized selection process, finally put in place a dual system by putting them in competition and, at best, in making them cooperate and exploiting synergies.
5. **Stage 5**: At the ultimate stage, companies are able to merge all the channels of innovation in addressing innovation transversely to functions, approaching it from a multidisciplinary perspective, identifying and exploiting at best external sources of innovation or the value of their Research and Development. They manage to implement, on an industrial scale, an ideal, organized and equipped, agile and permeable funnel, returning to the virtues of roots. In practice, companies in our study [16] are almost all in stages 1–4; only a few have some characteristics of the ultimate stage 5. This clearly reveals how much progress still to implement a process for ideas and projects management that is not too rigid while being sufficiently organized. The challenge, in our opinion, for the company that wants to be fully innovative is to get to stage 5, at least for innovations that are not strictly incremental. To be truly innovative as it grows, the company must recover the dynamics and virtues of its beginning as illustrated by Fig. 8 of the evolutionary cycle of the five funnels.

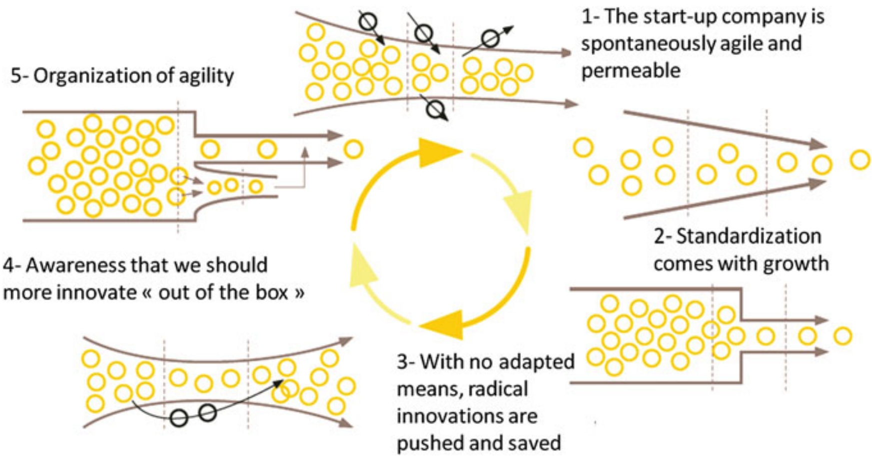


Fig. 8 The evolutionary cycle of the five funnels

4.2 *How to Find the Agility and Creativity of the Origins?*

It is not mandatory at all to evolve towards the next stage of innovation funnel for a company. But one believes that, like the TRIZ evolution laws of technical systems [17, 18], making people conscious of the innovation funnel their company is likely to be close to is already fruitful for them to visualize their company process and start discussions about what today contributes to the funnel *shape*, *permeability* and *agility*. Each people can also try to imagine how to personally interpret this innovation funnel.

In the case where the company is not satisfied with innovation management and performance, we propose to use the previous evolution law as a tool for continuous improvement. A creative workshop can be organized as follows:

– Gather a short-list of some players representing the ideas and projects management processes in the company (generation, selection, development, managers).
– Make them positioning their business on the 5-funnel cycle. Make them express the reasons to be at a given location and try to result in a consensus for the whole company.
– Then, lead a brainstorming session on how to move from the present company funnel to the next stage.
– Work to a strategic and operational roadmap.

5 Conclusion

It is common in the Management Science and Design Engineering communities to represent the processes contributing to innovation in companies as a funnel pictorial. We noticed that it could be used in several situations: representing the ideation process, as well as more strategic innovation processes. We propose to use the funnel representation as a holistic representation of the 4-layer processes that well model innovation or value creation processes in companies (see Fig. 6).

Our survey on innovation practices in 28 large companies [16] has led to the observation that the innovation funnels of these companies can be categorized into 5 funnel types differentiated by their shape, permeability to ideas and process agility, and that they could be easily sketched as meaningful pictorials (see Fig. 7). Our surveyed companies also learnt us that the past or the expected future of the companies let us think that the 5 funnel types follow a sequential and cyclic evolution law, as in TRIZ theory.

We finally propose to use the 5-funnel model as an inspiring tool for making people conscious of the innovation processes of their company and discussing of it. In addition, they can use it in a creativity workshop to imagine a strategic and operational roadmap for making their company evolving from one funnel stage to the next. These tools are being tested in companies and they truly appear insightful.

References

1. De Brabandere L, Mikolajczak A (2002) Le plaisir des idées. Libérer, gérer et entrainer la créativité au sein des organisations", Dunod, ISBN 210040847, Paris
2. Deschamps JP, Nayak PR (1995) Product juggernauts—how companies mobilize to generate a stream of market winners. Harvard Business School Press, Arthur D. Little, Inc., ISBN-10: 0875843417, Boston
3. Gero JS, Kazakov V (1996) An exploration based evolutionary model of a generative design process. Microcomput Civil Eng 11:209–216
4. Cross N (1994) Engineering design methods—strategies for product design. Wiley, Chichester
5. Pugh S (1990) Total design: integrated methods for successful product engineers. Addison Wesley, New York
6. Roozenburg NF, Eekels J (1995) Product design: fundamentals and methods. Wiley, Chichester
7. Liu YC, Chakrabarti A, Bligh T (2003) Towards and 'ideal' approach for concept generation. Des Stud 24(4):341–355
8. Brem A, Voigt K-I (2009) Integration of market pull and technology push in the corporate front end and innovation management—insights from German software industry. Technovation 29(5):351–367
9. Wheelwright SC, Clark KB (1992) Revolutionizing Product Development. Free Press, New York
10. Kline SJ, Rosenberg N (1986) An overview on innovation, in the positive sum strategy.In: Landau R, Rosenberg N (eds) National Academy Press, Washington, DC

11. Cooper RG (1990) Stage-gate system: a new tool for managing new products. Business Horizons, May–June, pp 44–55
12. Cooper RG (1983) A process model for industrial new product development. IEEE Trans Eng Manag 30:2–11
13. Cooper RG (1988) Predevelopment activities determine new product success. Ind Mark Manage 17:237–248
14. Pahl G, Beitz W (1984) Engineering design. The design council. Springer, London
15. Ulrich KT, Eppinger SD (1995) Product design and development. McGraw-Hill, New York
16. Cuisinier C, Vallet E, Bertoluci G, Attias D, Yannou B (2012) Un nouveau regard sur l'innovation—Un état des pratiques et des modèles organisationnels dans les grandes entreprises. Techniques de l'Ingénieur, ISBN 978-2-85059-130-3, Paris
17. Petrov V (2002) The laws of system evolutions. The TRIZ J, Mar 2002, paper #2, see http://www.triz-journal.com/archives/2002/03/b/index.htm.
18. Savransky SD (2000) Engineering of creativity—introduction to TRIZ methodology of inventive problem solving. CRC Press, Boca Raton
19. Motte D, Bjärnemo R, Yannou B (2011) On the interaction between the engineering design and development process models—Part I: elaborate elaborations on the generally accepted process models. In: Proceedings of ICoRD: 3rd international conference on research into design, Jan 10–12, Bangalore

A Methodology for Assessing Leanness in NPD Process

B. A. Patil, M. S. Kulkarni and P. V. M. Rao

Abstract Lean concepts are routinely used in manufacturing but are still relatively new to New Product Development (NPD) process. If manufacturing can be modeled as flow of material, an analogous model for NPD process would be flow of information. This paper addresses the issue of eliminating wastes in new product development process by bringing lean concepts through an assessment system. The paper first defines wastes in the context of NPD process. A large number of waste drivers which add to wastes in any NPD process are identified. Similarly lean enablers and lean tools which if implemented can reduce wastes are also identified. A model connecting wastes and lean enables is arrived which gives a holistic picture of relationship to address and assess wastes in any NPD process. In order to measure the effectiveness of NPD process five lean performance measures are used which include design cost overrun, product cost overrun, schedule overrun, knowledge capture and customer satisfaction. Industrial inputs are used to arrive at assessment system proposed in this work and a further feedback from industry is used to enrich the assessment system after it is developed. Though the proposed system is developed for machine tool development process, it is generic in nature and can be used to assess any new product development activity.

Keywords New product development · Lean product development · Leanness assessment

B. A. Patil · M. S. Kulkarni · P. V. M. Rao (✉)
Mechanical Engineering Department, IIT Delhi, New Delhi, India
e-mail: pvmrao@mech.iitd.ac.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_58,

1 Introduction

Greater competition and more demanding customers are forcing industries to continuously responds to their demands and develop new products. As a result of this organizations are bringing new products at frequent intervals to keep customers excited about their products. In other words to survive and succeed, industries should now be able to design new products as per customer requirements in a short period of time. Failure to do so can be very costly, not only in terms of lost market share, but also in terms of investment made to develop a new product.

New Product Development (NPD) consists of a set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product [1]. The major steps included in an NPD process are product planning, concept development, system level design, detail design, testing and refinement and production ramp-up. According to Cooper and Kleinschmidt [2], a new product or process is closely related to the stages of its development process the success of which depends on the manner in which these stages are executed, the way in which these stages complement one another, and the effectiveness with which persons responsible for these stages interact with each other. The communication among suppliers, customers, designers, shop-floor people are important and any miscommunication between these members severely affects the smooth execution of NPD process [3, 4]. One way to be effective in this process is by adopting lean practices.

The term lean which is synonymous with manufacturing was popularized by Womack et al. [5] to describe the concepts and philosophy behind Japanese auto manufacturers. Since then the concept of lean has spread to cover other industries, other parts of the world and other product life-cycle activities. Lean concepts are now integrated and practiced extensively in new product development process as well. Lean when implemented translates as less human effort, less resources, less time and even less space while simultaneously delivering products that customer really wants to pay for. In this way, it facilitates increasing value while decreasing wastes at the same time [6]. The underlying premise is that any feature or an activity, which does not add value to the product, is waste and customer is not willing to pay for it.

There have been many initiatives in the past to adopt lean practices in an NPD process. MIT's Lean Aerospace Initiative has pointed out that improvements in manufacturing alone with the help of lean principles will make only a marginal difference in ultimate system costs, because production and service of a quality product by manufacturing, usually seen as the delivered value, are not valuable if the product itself does not please the customer [7]. In other words, planned value by design process only ensures the delivered value satisfying the end user. In this manner product development (PD) has a great deal of leverage on both the creation of the right product, and the enabling of lean production through appropriate design [8].

It has been emphasized that lean NPD requires the right information at the right place at the right time [9], bringing focus to the value of information. Lean NPD helps companies to develop a seamlessly flowing PD value stream with minimal waste, defined and pulled by the customer [10]. According to Oehmen and Rebentisch [11] the lean product development focuses on defining and creating successful and profitable product value streams which facilitates global need to develop products and systems faster, cheaper and better. Though there have been efforts to adopt lean practices in an NPD process there are no significant efforts to measure the effectiveness of lean implementations. It is needless to state that in order to improve the performance of a process, it must be measured. In other words measurement of leanness in an NPD process can facilitate in effective adoption and implementation of lean practices. The present work proposes a methodology for the same which is termed as lean function deployment (LFD).

2 Previous Work

Though there have been some efforts to quantify leanness in the domain of manufacturing, the same is not true in the area of new product development. Following paragraphs discuss a few efforts made in this direction and some insights given by researchers to understand leanness.

McManus et al. [12] tried to differentiate between lean NPD process and lean manufacturing. Their effort to study application of five basic lean principles applied to two domains gives a good perspective as summarized in Table 1.

It is clear that an assessing system developed for manufacturing can not work or be extended to NPD process because the two are essentially different. In NPD process value is harder to see, and the definition of value-added is more complex in this case [9, 13]. Due to uncertainties or interdependencies, branching or iterative flows may be beneficial because designers learn from iterations that what is worked and what did not, which is not true in case of manufacturing. The iterations help to improve the tacit knowledge as well as the explicit knowledge of the designers. The flow in manufacturing is of material which is being processed whereas PD processes deals with the flow of information which is generated at each step of the process, and value of information is increasing at each step which helps to reduce the risk of not meeting the product performance. Pull in manufacturing is more related to the market demand and the capacity of the plant, whereas in PD process pull is more dependent on the timely requirements of the downstream processes from the upstream processes of design [14]. Finally, perfection is even harder to reach in case

Table 1 Lean manufacturing versus lean NPD [12]

Lean principles	Manufacturing	Product development
Value	Value at each step, defined goal	Harder to see, emergent goals
Value stream	Parts and material	Information and knowledge
Flow	Iterations are waste	Planned iterations are must
Pull	Driven by take time	Driven by needs of enterprise
Perfection	Process repeatable without errors	Process enables enterprise improvement

of product development as simply doing the process very fast and perfectly with minimal resource used is not the final goal. The goal is to ensure the efficiency of the design process (in terms of product output with resources consumed, ensuring right method of developing a product) as well as effectiveness of the PD process ensuring the development of the right product.

According to Murman et al. [15] lean concepts and approaches should be used to create and deliver value for all stakeholders, and not just end users. Hines et al. [16] have developed a framework for lean product development which is driven by use of lean tools by industries. Anand and Kodali [17], have proposed a framework to make existing NPD process leaner by classifying activities into value added and non value added.

While developing a framework for creation of value in PD process, Chase [13] has discovered that value is facilitated using four tools namely, right tasks, resources, environment, and management approach. For measurement of value addition by an activity, ten different attributes of value are considered. In yet another attempt, McManus and Team [14] used a questionnaire based approach to know the occurrence of flow and pull in PD process.

Stanke and Murman [18] developed a framework for achieving a lifecycle value consisting of three phases as value identification, value proposition, and value delivery. Six value creation attributes covering holistic perspective, organizational factors, requirements metrics, tools and methods, enterprise relationship and leadership management were used to assess effectiveness of PD process. In a survey carried out by Hoppman et al. [19], leanness assessment was done based on three supporting measures (goals defined, human resources for introduction to LPD process, use of value stream mapping). The goal of the survey was to investigate the process of introducing a lean PD system.

Some important observations can be drawn from the above studies. Most of the works assess leanness based on whether or not certain lean tools are in practice. They do not consider the inherent relationship between lean tools and waste drivers. These approaches miss identification of value and quantification of waste in PD process. Some of the methods end with assessment of leanness without proposing any remedial measures. As one of the goals of lean implementations is continuous improvement, the leanness systems proposed are not able to address this aspect. Lastly the goals of adopting lean concepts in an NPD process differ from one organization to another. The systems proposed are not able to address this aspect and assume a common goal for all lean implementations.

To overcome these limitations, a more effective and a holistic approach is proposed in the present work. Though the proposed work is developed for assessment of leanness in new machine tool development process, the framework is generic in nature and can be easily applicable to NPD process of other products and organizations as well. The term new in an NPD process can mean any of the following four cases:

1. An entirely new product based on new technology or new concept
2. A new product lines or family which allows entry into newer markets

3. Making additions to existing product lines
4. Improvements in existing product.

A preliminary study of machine tool industry, particularly that of Indian machine tool industry has shown that most of NPD activity belongs to improvement of an existing a product, product line or product family. Keeping this in mind, the present research focuses on classification of new products as defined under Sects. 2 and 3.

3 Lean Function Deployment

The methodology proposed in the present work called as *lean function deployment* (LFD) is both qualitative and quantitative in nature. It can be used to benchmark one organization with respect to another or can be used for assessing continuous improvement of any organization from one state to another. It not only identifies problem areas but also gives remedial measures to correct the same. The proposed methodology is based on constructing many houses of leanness each with a definite objective. The process has similarities with Quality Function Deployments (QFD) often used to capture customer requirements. The proposed methodology consists of following steps.

3.1 Identification of Performance Measures

Organizations which implement lean often do with certain specific objectives in mind. These are referred as *lean performance measures* in the present work. The reason for referring them as performance measures is that these measures should improve or reach an improved state at the end lean implementation. The performance measures identified include: Project cost overrun, schedule overrun, product cost overrun, customer satisfaction and knowledge capture. It is true that for any organization all these measures are important. However, organizations would like to concentrate on improving one or more from existing state to an improved state. For example an organization doing well in terms of project cost over run and customer satisfaction would like to implement lean to improve its delivery schedules. First step in the proposed methodology is to identify, prioritize and if necessary assign weights to these performance measures.

3.2 Identification of Wastes

Any activity or process which does not add value to the product and customer is not willing to pay for it can be called as waste. Identification of wastes is key to any lean activity. The eight wastes commonly defined in manufacturing domain can not be borrowed in the case of product development. Some are retained and some are newly defined for NPD process. The five wastes identified for NPD process in the present work are untapped human potential, waiting time, wasting time, overdesign and rework. As wastes are difficult to quantify, sub-wastes are defined which are specific manifestation of wastes and are somewhat quantifiable. For example lack of a system to address suggestions from team members is a sub-waste under the category of waste untapped human potential. Waste driver is even one level below which tries to find the root cause(s) because of which a particular waste or sub-waste happens. In this work five wastes are classified into 19 sub-wastes which are further sub divided into 49 waste drivers. In other words the probability and magnitude of presence of a type of a waste is evaluated by knowing the waste drives are extent to which it happens in any given organization.

3.3 Identification of Lean Enablers and Lean Tools

A systematic application of lean and its principles ensures the delivery of value to all stakeholders in a process. *Lean enablers* are the attributes/characteristics of NPD Process which enhance the lean component in the process and thus ensure the creation of value. Lean enablers are not only derived from the industry best practices but also are extracted from the core lean thinking principles. 21 lean enablers are identified in this work.

Lean tools are those which promote leanness in a system by strengthening lean enablers. The different lean tools identified and used for assessment include customer relationship management (CRM), quality function deployment (QFD), Design for X (DFX), Failure modes and effects analysis (FMEA), cross functional teams (CFT), set based concurrent engineering (SBCE), design structure matrix (DSM), theory of inventive problem solving (TRIZ), knowledge management, product life-cycle management (PLM) etc.

3.4 Relating Lean Performance Measures to Wastes

There exist a strong relation between lean performance measures and wastes. Establishing this relationship is vital for the assessment system. Given the performance measures which organization wants to improve, it is possible to know from this relationship what wastes or waste drivers need to be addressed for achieving the same. This relationship is in the form of a matrix or house of leanness where rows are lean performance measures and columns are waste drivers. The relative importance of performance measures is first established. This can be done by pair-wise comparison using tools such as AHP. This helps in addressing waste drivers which are more important than the others. This step not only considers presence of a specific waste in an organization but also considers magnitude and probability of its occurrence.

3.5 Relating Wastes to Lean Enablers

In this step wastes measured in terms of sub-wastes are related to lean enablers. This step is important as it gives an insight into what lean enablers influence which waste and vice versa. In other words it gives enough information to identify lean enablers to overcome certain wastes predominant in an organization being assessed. Together with step 4 it also quantifies the readiness of organization for implementing lean.

3.6 Relating Lean Tools to Lean Enablers

Previous five steps identify a set of lean enablers which need to be addressed to overcome weaknesses in an organization being assessed. Lean enablers can be strengthened by implementing lean tools as discuss previously. The relation between lean tools and lean enablers is not straightforward as one lean tool can influence many lean enablers and vice versa. One needs to know the relative influences of each lean tool on lean enablers. Building this relation is the sixth step in lean function deployment (LFD).

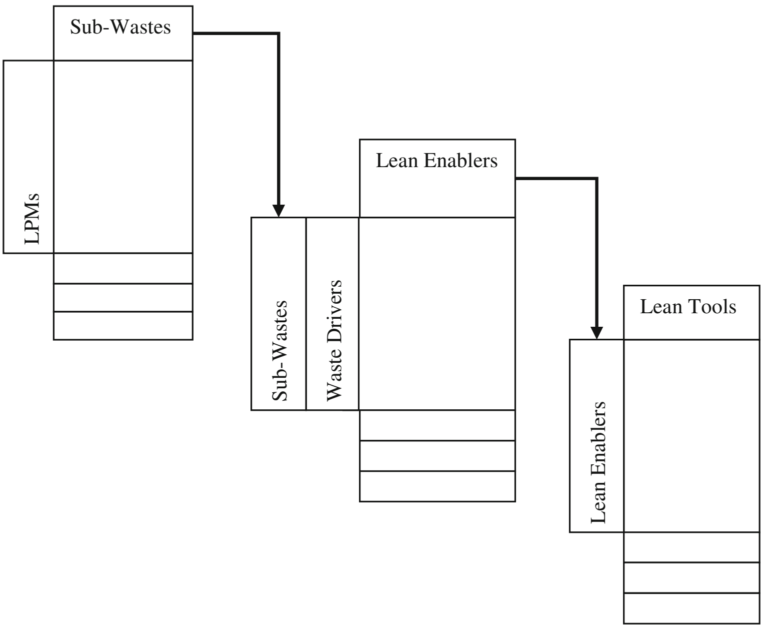


Fig. 1 Lean function deployment framework

Sub-wastes → **Lean Performance Measures**	People waiting for information	Overdesign	…….	Unutilized tacit knowledge
schedule overrun				
project cost overrun				
product cost overrun				
customer satisfaction				
knowledge capture				

Fig. 2 Relating lean performance measures with sub-wastes

Lean Enablers → **Waste Drivers**	Organization of Knowledge	Reuse of components	…….	Standardize work processes
Not allowing/motivating employees to put forward their ideas and views				
Unevenness in work distribution				
………….				
Over commitment of resources				

Fig. 3 Relating waste drivers to lean enablers

Lean Tools → **Lean Enablers**	QFD	DFX	…….	PLM
Organization of knowledge				
Reuse of components				
………….				
Standardize work processes				

Fig. 4 Relating lean enablers to lean tools

4 Implementation

Figure 1 gives pictorial representation of all six steps discussed above. Once all the relations have been built and validated, the proposed framework can be used in multiple ways to assess leanness as well as to identify tools necessary for continuous improvement. For example one can assess an organization by extent to which it uses lean tools. It is important to mention here that mere notional adoption of lean tool is not a true assessment. For effective results, these have to be assessed at various levels as is done in a typical capability maturity models (CMMs). As per the proposed framework, implementation of lean tools is effective if it finally improves the performance measures as desired.

Secondly one can start with performance measures to be improved and using the frame work, identify lean tools which need to be implemented or strengthened. At each stage of assessment, one can visualize both qualitative and quantitative information about performance measures, wastes and lean enablers. The detailed quantification measures are not discussed here and are a subject of another work.

Figure 2 shows how lean performance measures can be related to wastes. In this first level of assessment either all lean performance measures can be given equal weightage or they can be prioritized by assigning different weights. This would depend on what the organizations goals are in implementing lean programme. Figure 3 establishes relation between wastes and lean enablers. This is one of the larger matrices in the entire assessment system which requires industrial input and experience to structure it. Last stage of assessment as shown in Fig. 4 is optional. If one is interested in only assessing leanness in NPD, this stage can be avoided. However most of the organizations would be not only interested in knowing weakness but also to overcome them. In this context relating lean enablers with lean tools become an important task.

5 Conclusions and Future Work

The proposed framework has been arrived at after studying many of the exiting assessments system in practice and those proposed in the literature. Inputs from industrial experts have gone in coming up with proposed framework. This has been done by discussion with experts from multiple industries. A workshop of machine tool experts too has been organized to capture required inputs.

However, the proposed methodology is still a qualitative framework. It needs to be fully validated quantitatively in multiple industrial scenarios. The efforts are presently on in this direction the results of which will be communicated later.

Acknowledgments The authors acknowledge the financial support received from Department of Science & Technology (DST), International Division in carrying out this work.

References

1. Ulrich KT, Eppinger SD (2004) Product design and development. McGraw Hill, New York
2. Cooper RG, Kleinschmidt T (1986) An investigation into the new product process: steps, deficiencies, and impact. J Prod Innov Manage 3:71–85
3. Brown SL, Eisenhardt KM (1995) Product development: past research, present findings, and future directions. Acad Manag Rev 20(2):343–378

4. Olson E, Walker O, Ruerket R, Bonner J (2001) Patterns of cooperation during new product development among marketing, operations and R&D: implications for project performance. J Prod Innov 8:258–271
5. Womack J, Jones D, Roos D (1990) The machine that changed the world. Rawson Associates, New York
6. Womack JP, Jones D (1996) Lean thinking: banish waste and create wealth in your corporation. Simon and Schuster, London
7. Murman E, Thomas A, Bozdogan T, Cutcher-Gershenfeld J, McManus H, Nightingale D, Rebentisch E, Shields T, Stahl F, Walton M, Warmkessel J, Weiss S, Widnall S, (2002) Lean enterprise value: insights from MIT's lean aerospace initiative, Palgrave, New York
8. Mcmanus HL (2005) Product development value stream mapping (PDVSM) manual, lean aerospace initiative. MIT Cambridge, MA
9. Browning TR (2000) Value-based product development: refocusing lean. In: Proceedings of the 2000 IEEE, Engineering Management Society
10. McManus HL, Millard RL (2002) Value stream analysis and mapping for product development. Int Counc Aeronaut Sci 1–5
11. Oehmen J, Rebentisch E (2010) Waste in lean product development. LAI paper series lean product development for practitioners. Lean advancement initiative (LAI), Massachusetts Institute of Technology, July 2010
12. McManus H (2005) Lean engineering: doing the right thing right. In: Proceeding of the 1st international conference on innovation and integration in aerospace sciences. Queen's University Belfast, Northern Ireland,1–10 2005
13. Chase JP (2001) Value creation in the product development process. M.Sc. thesis, Massachusetts Institute of Technology
14. McManus HL, Team LP (2000) Flow and pull in PD. Working paper series, the lean aerospace initiative, Massachusetts Institute of Technology
15. Murman E, Stanke A (2005) Virtual assessment of lean user experience (VALUE) survey (v. 3.4.2), MIT
16. Hines P, Francis M, Found P (2006) Towards lean product lifecycle management: a framework for new product development. J Manuf Techno Manag 17(7):866–887
17. Anand G, Kodali R (2008) Development of a conceptual framework for lean new product development process. Int J Prod Dev 6(2):190–224
18. Stanke A, Murman E (2002) A framework for achieving lifecycle value in aerospace product development. International Council of Aeronautical Sciences Congress, 1–10 2002
19. Hoppmann J (2009) The lean innovation roadmap—a systematic approach to introducing lean in product development processes and establishing a learning organization. Diploma thesis, Institute of Automotive Management and Industrial Production, Technical University of Braunschweig, June 2009

PREMΛP: Exploring the Design and Materials Space for Gears

Nagesh Kulkarni, Pramod R. Zagade, B. P. Gautham, Jitesh H. Panchal, Janet K. Allen and Farrokh Mistree

Abstract Design of a gear that meets specified requirements is a challenging task. Competition from other power transmission components as well as increasing demands from industry such as increased power density, low noise etc., are forcing gear designers to design gears using novel methods (which are beyond the traditional standards based design methods). We, at Tata Consultancy Services, are developing a Platform for Realization of Engineered Materials and Products (PREMΛP), which helps a designer exploit the synergy between component design, material design and manufacturing. One of the key features of PREMΛP is its decision support capability, which we are demonstrating using design of spur gear as an example. The compromise Decision Support Problem (cDSP) construct

N. Kulkarni · P. R. Zagade · B. P. Gautham (✉)
Tata Consultancy Services, Pune 411013, India
e-mail: bp.gautham@tcs.com

N. Kulkarni
e-mail: nagesh.kulkarni@tcs.com

P. R. Zagade
e-mail: pramod.zagade@tcs.com

J. H. Panchal
School of Mechanical Engineering, Purdue University, West Lafayette, Indiana 47907, USA
e-mail: panchal@purdue.edu

J. K. Allen
School of Industrial and Systems Engineering, University of Oklahoma, Norman, Oklahoma 73019, USA
e-mail: janet.allen@ou.edu

F. Mistree
School of Aerospace and Mechanical Engineering, University of Oklahoma, Norman, Oklahoma 73019, USA
e-mail: farrokh.mistree@ou.edu

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_59, © Springer India 2013

is used to formulate the problem and the software DSIDES to solve it. Results obtained are well in agreement with existing knowledge of gear design. Ternary contour plots are created which show the compromise between various goals and associated standard deviation.

Keywords Gear design · Compromise decision support problem

1 Introduction

1.1 PREMΛP

PREMΛP—Platform for Realization of Engineered Materials and Products is conceived at Tata Consultancy Services. It is based on integrated computational materials engineering (ICME) [1] approach that is expected to (a) reduce the time and cost of discovery and development of materials and their manufacturing processes, and (b) enable faster development of products augmented with richer material information, is described in four parts:

- PREMΛP—A Platform for the Realization of Engineered Materials and Products [2],
- PREMΛP—Exploring the Design Space for Continuous Casting of Steel [3],
- PREMΛP—Exploring the Design and Materials Space for Gears (this paper),
- PREMΛP—Knowledge Driven Design of Materials and Engineering Processes, [4].

It hosts various tools for modeling and simulation supported by tools for informatics, knowledge engineering, robust design and decision support along with appropriate databases and knowledge bases. It is discussed in detail in Gautham et al. [2]. One of the key features of the platform is its decision support capability. In the second [3] and this, third paper of the series, application of compromise Decision Support Problem (cDSP) [5] to two problems, manufacturing process design and component design, are discussed. In the second paper [3] we discuss two features of PREMΛP, namely, robust design and the exploration of the design space through the use cDSP in the context of the manufacturing process, continuous casting of steel. In this the third paper, we illustrate a method for exploration of design space for the material and gear geometry simultaneously using the design of a gear as an example.

1.2 Designing a Gear—Challenges

Gears are extremely important components of transmission systems of many kinds and steel gears are the most widely used ones. According to the vision report of the gear industry [6], the global gear market exceeds US$45 billion per annum. Gears are mostly used in automobiles (which constitute nearly three forth of the entire gear market) along with industrial equipment, airplanes, helicopters, marine vessels and other applications. The vision document [6] lists various goals for the gear industry in areas such as profits and market share, gear performance, gear manufacturing techniques etc. It also lists key technological challenges and innovations required to achieve these goals. One of the challenges is innovative gear design and development.

Apart from the historical demand for high life and reliability, new demands have emerged such as low noise, high efficiency, low weight, high quality, etc., which are driven by demands from customers as well as by legislation. Traditionally gear design has been based on gear design standards from organizations such as the American Gear Manufacturers Association (AGMA), the International Organization for Standardization (ISO), and the German Institute for Standardization (DIN). These standards provide methods to select suitable materials and design the geometry of gears. They use different factors such as the overload factor, the load distribution factor, the geometry factor, and the size factor to correct for basic assumptions in analysis and to adjust for the uncertainties in load estimation, load distribution, stress concentration, etc. Similarly, a number of factors are considered such as the reliability factor and the safety factor to account for variability in material and manufacturing processes based on historical data and experimentation. The resulting design is safe but it may be bulky, hence the gear design process needs to be improved. It should take advantage of recent developments in numerical modeling of gears and materials and manufacturing processes, in order to make it amenable to competition and to survive. The new process should be such that it can take into account the effects of material and manufacturing processes such as residual stresses, detailed distribution of properties and microstructure, etc. [2, 7]. Defects introduced during steel mill production gives rise to problems during further manufacturing process of these mill products. For example, segregation influences distortion during forging of gear blanks; the fatigue life is impacted by the residual inclusion content during the continuous casting stage. This leads to the complex problem of making design decisions across multiple domains—mechanical design, materials processing and manufacturing. The integrated computational platform PREMΛP described in Gautham et al. [2] is envisaged to provide means for such development.

The decisions on selection of gear geometry, material and manufacturing parameters are riddled with compromises among performance, weight and cost, for example, high reliability design in general is costly. The cDSP is one of the possible constructs for decision support for such situations. In this work, we present cDSP for gear geometric design and material selection, a subset of the larger problem described earlier, to explore the compromises one has to make between the compactness, cost and reliability of gears. We use DSIDES[1] for solving the cDSP. The present work is seen as a first stage high throughput

[1] Mistree F., "DSIDES-Decision Support in the Design of Engineering Systems", User manual.

screening using AGMA standards and will be extended through the incorporation of a detailed analysis of gear performance and manufacturing processes in an integrated computational framework in the future.

2 Gear Design in PREMΛP Using the cDSP Construct

2.1 PREMΛP Based Gear Design

An integrated design of a gear envisages concurrent design of geometry, material selection and manufacturing process design starting from a round bar of steel sourced from a steel supplier. This needs a preliminary gear design using AGMA standards for setting the initial design space, followed by detailed analysis of gear performance utilizing the material information from the manufacturing process simulation. This in turn requires detailed simulation of manufacturing processes that provide the material property evolution as well as estimates of manufacturing costs. Armed with this information, the designer can arrive at an acceptable solution that meets the targets on cost, performance and constraints. In Sect. 4.2 of Ref. [2] the authors discuss such aspects in detail. Further to an integrated design, evolving specifications of mill products or developing new alloys starting from the chemistry requires further integration with upstream processes of the steel mill. For example, the inclusion content that remains at the casting stage influences final fatigue properties. Designing the continuous casting process parameters under cDSP construct is discussed in Ref. [3]. The integrated design is envisaged to be carried out on the ICME platform PREMΛP being developed at Tata Consultancy Services [2]. In this paper we deal only a small part of the chain—AGMA based geometric design and material selection—in a cDSP framework. This initial geometry and material is taken as initial guess and appropriate design space is built around it for integrated design discussed in Ref. [2].

2.2 The Compromise Decision Support Problem

The cDSP differs from standard optimization formulations in that it is a hybrid formulation based on mathematical programming and goal programming. It enables the construction of different practical scenarios in a multi-objective formulation by giving appropriate weightage to different goals and exploring the compromise among them. It works by minimizing the difference between the desired (the target G_i) and the achieved ($A_i(x)$) value of a goal. The difference between these values is the deviation value, d_i^+ and d_i^-, which represents overachievement and under-achievement of each goal respectively. A cDSP is constructed such that constraints and deviations are always positive and no simultaneous over or under achievement is allowed. The details of cDSP can be found in Refs. [8, 9].

2.3 The cDSP for Gear Design

In traditional gear design based on AGMA, the designers make use of guidelines and procedures given by AGMA to make decisions on the design variables such as module, number of teeth, etc. At this stage, the designer has a number of choices and would eventually pick one of them that satisfies the constraints and one or more of targets. This design process can be put in a formal optimization loop to search a design which satisfies the constraints and provides the best possible value of the objective function. On the contrary, robust design using cDSP involves exploring the design space for flat regions while trying to satisfy the constraints. The additional information given by cDSP allows the designer to add/modify constraints and goals systematically to achieve better designs.

2.3.1 Problem Statement

The current problem deals with design of a pinion for the first gear reduction for a compact sized automobile. The problem statement is as follows

> Design a gear set (pinion and gear) to transfer maximum torque of 113 Nm @ 4,500 rpm with a speed reduction ratio of 3.5. The gear set has standard full depth teeth 20° pressure angle. The teeth are generated with a rack cutter. Design compact, light weight, cost effective and reliable spur precision (AGMA quality no 8) gearing (moderate shock in driving engine, moderate shock in driven machinery). A minimum reliability of 99.99 % is expected. The minimum expected fatigue life is 10^{9} cycles. The maximum allowable center distance is 300 mm. Materials for the gear are available in the range of 800 to 1,600 MPa. Space available for gear and pinion is 600 mm. Standard gear geometry as per AGMA standard is desired.

2.3.2 Formulation

Following the example in Ref. [8], the cDSP for the design of a gear is formulated as given below.

Given

It is required to design a pinion of a commercial spur gear system of AGMA precision no. 8 for torque of 113 Nm @ 4,500 rpm with speed reduction of 3.5 ($G = 3.5$) having a minimum of 99.99 % reliability (though helical gear are preferred for such applications, we restrict this study to spur gears for easier illustration). The pressure angle of gear teeth is given to be 20° and cut using rack cutter. The gear pair is to be designed to have fatigue life of 10^9 cycles.

The materials for gear are available in the range of tensile strength of 800–1,600 MPa. Space available for gear and pinion is 600 mm.

Design variables: The standard gear geometry is expressed using AGMA standards [10] in terms of: module (m) in mm, number of teeth (N), and face width (b) in mm. We use these geometry variables along with material strength (UTS) in MPa and reliability (R) as design variables. Reliability is considered part of design variable, as the design space will be explored with different levels of reliability.

Bounds on design and deviation variables

- B1: $4 \leq m \leq 8$ (mm)
- B2: $18 \leq N \leq 40$
- B3: $40 \leq b \leq 80$ (mm)
- B4: $800 \leq UTS \leq 1{,}600$ (MPa)
- B5: $0.95 \leq R \leq 0.9999$, though reliability of 99.99 % is required, we are exploring this range of reliability to study its influence in a wider range.
- B6 to B8: restriction on deviation variables, defined in Sect. 2.2, $d_i^+ \cdot d_i^- = 0$ for $i = 1\ldots3$ and $d_i^+, d_i^- \geq 0$ for $i = 1\ldots3$

Design constraints

- C1: Minimum face-width*: $$b \geq 3m \quad (1)$$
- C2: Maximum face-width*: $$b \leq 5m \quad (2)$$
- C3: Maximum limit on center distance#: $$d = m(1+G)N/2 \leq 300 \text{ mm} \quad (3)$$
- C4: Bending stress induced *#: $$\sigma_{allowable}^{bending} - \sigma_{induced}^{bending} \geq 0 \quad (4)$$
- C5: Contact stress induced*#: $$\sigma_{allowable}^{contact} - \sigma_{induced}^{contact} \geq 0 \quad (5)$$
- C6: Minimum contact ratio*: $$R_c \geq 1.4 \quad (6)$$
- C7: Maximum contact ratio*: $$R_c \leq 1.8 \quad (7)$$
- C8: Number of teeth are integer value†: $$(N - INT(N)) \leq 0.01 \quad (8)$$

** as per AGMA guidelines* [10, 11],
 # as per problem statement,
† cDSP requires all variables to be of type real, N is also treated as real variable and an additional constraint is added to make it an integer.

Goals:

- G1: Maximize reliability R

  In AGMA based design, the influence of reliability is brought in through a correction factor (Y_z) in the allowable stresses during gear design through constraints C4 and C5.

- G2: Minimize center distance d (make the design compact)
- G3: Minimize cost C

  Total cost consists of material cost and manufacturing cost and calculated as

$$C = W\left(a_0 + b_0\left(1 + \left(\frac{S_{ut} - (S_{ut})_{\min}}{(S_{ut})_{\max} - (S_{ut})_{\min}}\right)^{1.5}\right)\right) \tag{9}$$

where, W is weight of component, a_0 is the manufacturing cost (taken as INR. 5/Kg), b_0 is the material cost (taken as INR. 40/Kg for 800 MPa UTS steel). The increase in material cost with UTS is as per the form given in Eq. (9). The above equation for cost is valid from $(S_{ut})_{\max}$ and $(S_{ut})_{\min}$, which are maximum and minimum tensile strengths.

These system constraints and goals are normalized as suggested in Mistree et al. [9]. The deviation function is constructed as shown below

$$Z = \{(d_1^- + d_1^+), (d_2^- + d_2^+), (d_3^- + d_3^+)\} \tag{10}$$

As we are minimizing for multiple goals [maximization of reliability (R) is considered as minimization of ($1-R$)], the negative deviation is always 0 and Eq. 10 simplifies as

$$Z = \{d_1^+ + d_2^+ + d_3^+\} \tag{11}$$

Archimedean formulation [9] is used to construct the deviation function and it is solved using the software DSIDES.

$$\begin{gathered} Z(d^-, d^+) = \sum W_i^+ d_i^+ \quad i = 1\ldots3 \\ \sum_{i=1}^{3} W_i = 1 \ \text{ and } \ W_i \geq 0 \ \text{ for all } i \end{gathered} \tag{12}$$

Table 1 Gear design scenarios

Scenario No	Goal	Requirements	Conflicts
1	Maximum reliability design	Larger gear geometry and high strength material	Compact design, minimum cost design
2	Compact design	Smaller *m* and *N*, and high strength material	High reliability design, possible weak conflict with cost
3	Minimum cost design	Smaller gear geometry and low cost material	High reliability design

2.3.3 Gear Design Scenarios

A designer often encounters conflicting demands while designing a gear, such as a reliable design and compact design, or reliable design and minimum cost design. In this gear design problem, we have 3 goals as described earlier. In Table 1 we list the requirements and conflicts of a given goal with other goals.

We explore the above three goals with different weights using the Archimedean approach as discussed earlier. Figure 1 represents different practical scenarios explored.

3 Results and Discussion

DSIDES has many control options, namely, adaptation to control exploration of the design space, specification of maximum number of iterations and criteria for convergence of design and deviation variables. We set the maximum number of iterations to 100, stationarity of design and deviation variables to 2 %.

3.1 Validation

We obtained various designs for different scenarios using DSIDES and few representative gear designs obtained are selected for validation. As DSIDES uses adaptive linear programming, which linearizes constraints and goals during exploration, there could be a scope for error creeping in. In order to verify this, we have plugged in *m*, *N*, *R* and *UTS* (obtained from gear design by the DSIDES) in the AGMA gear design formulae and computed the face width for selected five cases. The face width computed using AGMA and that given by the DSIDES are given in Table 2.

From Table 2, we can see that the results obtained using DSIDES are well in agreement with that of AGMA. The difference in the value of face width observed is due to the existence of active constraint, i.e., allowable contact stress, which has

Table 2 Validation of results obtained using DSIDES

	Design 1	Design 2	Design 3	Design 4	Design 5
b (mm) using AGMA	77.81	67.72	39.23	72.85	58.40
b (mm) using DSIDES	78.73	57.32	40.00	68.57	61.34
% Error	1.18	−15.36	1.96	−5.88	5.03

been violated within acceptable limits. In the worst case, i.e., Design 2, we observe that the actual factor of safety in contact is 1.3, violating the specified factor of safety of 1.4 used in AGMA calculations (and this is acceptable situation as far as factor of safety is concerned).

3.2 Results and Discussion

The seven different scenarios (S1 through S7) illustrated in Fig. 1 are analyzed in detail using DSIDES and discussed in Sect. 2.3.3. While analyzing results of different scenarios we made the following observations. In scenarios such as compact design (S1) and high reliability design (S3) there are oscillations in convergence behavior of the design variables and deviation variables. In Fig. 2a we show the convergence behavior of design variables for scenario S1. We see that the variables that define compact design (i.e., minimum *m* and minimum *N*) converge within the first few iterations. The other three design variables oscillate between three possible states (contact stress constraint is active and violated within acceptable limit for these three designs). This is expected as a single S1 goal leads to an under constrained system as it does not put any constraint on face width, reliability and tensile strength and these three parameters can take theoretically infinite feasible combinations. A similar trend is observed for other scenarios like S3 where same reliability can be achieved through different combinations of geometry and material. For the scenario S6, which is a combination of scenarios

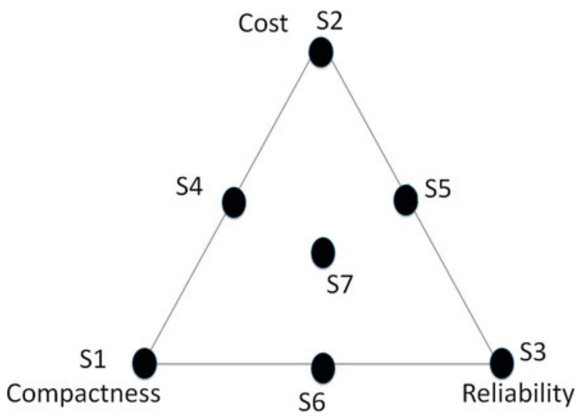


Fig. 1 Design exploration scenarios

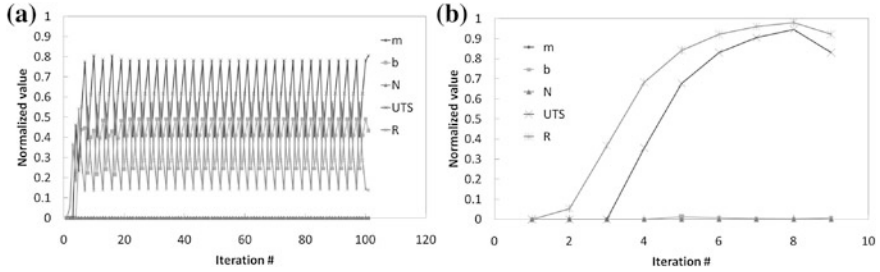


Fig. 2 Convergence behavior of design variables for **a** compact design (S1), **b** minimum cost design (S2)

S1 and S3, oscillation is observed in *UTS* and *b* in initial few iterations and finally a converged solution is obtained.

On the contrary, no oscillations are observed (Fig. 2b) in the convergence behavior of design variables for scenarios S2, S4, S5 and S7 (where cost goal is involved) as estimation of cost involves all the design variables and hence is well-constrained.

In Table 3 we list the best design and respective goals achieved for each scenario. In Fig. 3 we show the comparison of normalized goals achieved for different scenarios. These results are in line with known aspects of gear design such as:

- when compact design is required, the material strength needs to be high, and
- high reliability requirement needs increase in the size of gear as well as strength of the material.

We observe from the results that the minimum cost design is simultaneously a compact design and a minimum face width design. Compact design is not necessarily a minimum cost design (as it is a design with larger face width compared to the minimum cost design). The requirement for high reliability conflicts with compactness or cost as can be expected. Scenarios S5 and S7 involve a compromise between various goals. In order to observe the achievability of goals visually, we have collated all feasible designs obtained during the analysis and made ternary plots of average values of goals and their standard deviation as shown in Fig. 4.

Table 3 Results: design variables and goals for different scenarios

	m (mm)	b (mm)	N	UTS (MPa)	R (%)	d (mm)	C (INR)
S1	4.00	57.32	18	1,444	99.30	162.00	134.55
S2	4.00	40.26	18	1,464	95.40	162.00	96.14
S3	6.59	67.29	18	1,221	99.99	266.94	349.48
S4	4.00	40.26	18	1,464	95.40	162.00	96.14
S5	5.69	57.59	18	1,550	99.99	230.53	300.96
S6	4.99	76.72	18	1,550	99.99	201.95	307.71
S7	4.99	76.70	18	1,550	99.99	210.96	307.67

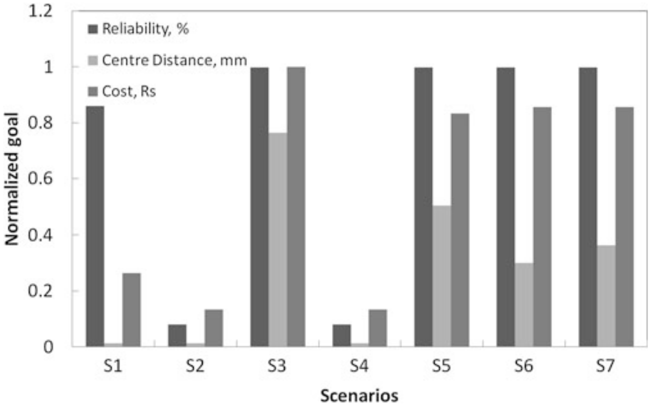


Fig. 3 Comparison of goals for different scenarios

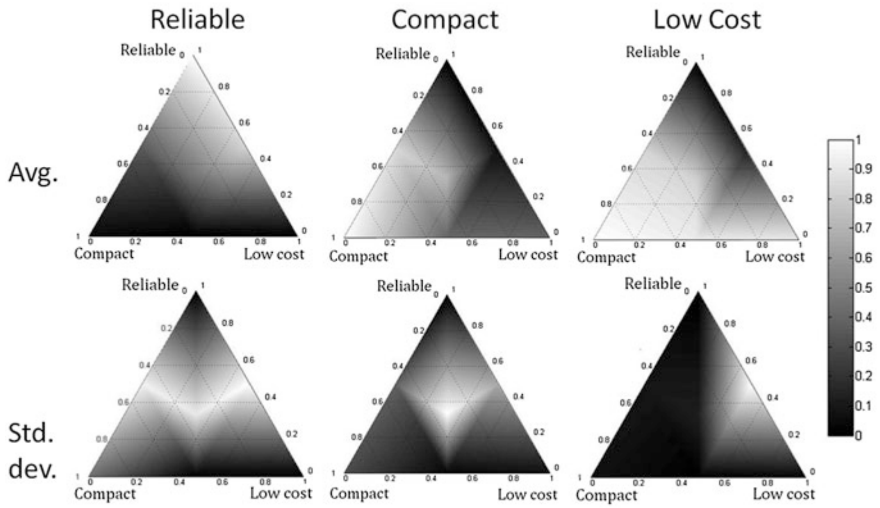


Fig. 4 Visual representation of average and standard deviation of achieved goals with different weights

As can be expected, when a specific goal has highest weight, it achieves the desired target fully. Highly reliable designs have least admissible space (large dark areas), as this requires larger gears and materials with high strength. Low cost gears can be achieved if we compromise on reliability. We further observe that the center region provides compromise between various goals. However, the center region also shows higher standard deviation. The center region represents the design space where equal weightage is given to all the goals. High standard deviation in this region represents same level of achievement in goals as a weighted sum can be obtained through different combinations of individual goals (diverse design choices are available). In such a situation one can formulate preemptive cDSP and explore the compromise in a narrowed down region; see Ref. [9]. This ternary plot (Fig. 4) can be used to make initial decision on the weights to be given so as to exploit the compromise between reliable, compact and low cost design. This is illustrated through the following example. For automotive gears, reliability and compactness are important considerations. It is very likely that the designer may settle for equal weight, i.e., 0.5 to these two goals. However, Fig. 4 suggests that the region corresponding to equal weightage to each of above goals is region of high variability, which may not be the ideal choice. In order to get a less sensitive design, one may select weights for compactness and reliability as 0.4 and 0.6 respectively.

4 Closing Remarks

Designing a gear that meets specified functional, non-functional as well as performance requirements is a challenging task. PREMΛP provides integrated systems engineering framework to design such complex components. In this work, we illustrate a method for exploration of the design and the material space simultaneously using the cDSP and through the design of a gear as an example. Various practical gear design scenarios such as compactness, reliability, cost and compromise among them are considered. DSIDES is used to solve the cDSP and results obtained are validated against AGMA standards. Results (geometry and material strength requirement) obtained are well in agreement with existing knowledge regarding gear design and the methods used provide means for systematic exploration of the design space.

We have collated all feasible designs obtained during the analysis and made ternary plots of average values of goals and their standard deviation. These charts show the regions of compromise. These charts can act as guideline, which should be helpful to the gear designer in making an informed choice among the various design objectives. This work also demonstrates two of key features of PREMΛP, viz., the robust design and exploration of geometric design and material space (through UTS) using cDSP for design of gears as an example.

Acknowledgments Authors acknowledge the support provided by management of TCS in pursuing this research. Janet Allen gratefully acknowledges financial support from the John and Mary Moore Chair at the University of Oklahoma. Farrokh Mistree gratefully acknowledges financial support from the L.A. Comp Chair at the University of Oklahoma.

References

1. Pollock TM, Allison J (2008) Integrated computational materials engineering: a transformational discipline for improved competitiveness and national security. The National Academies Press, Washington
2. Gautham BP, Singh AK, Ghaisas SS, Reddy SS, Mistree F (2013) PREMΛP: a platform for the realization of engineered materials and products. In: Proceedings of the 4th international conference on research into design, IIT Madras, Chennai, India, Paper Number: 63
3. Kumar P, Goyal S, Singh AK, Allen JK, Panchal JH, Mistree F (2013) PREMΛP: exploring the design space for continuous casting of steel. In: Proceedings of the 4th international conference on research into design, IIT Madras, Chennai, India, Paper Number: 65
4. Bhat M, Das P, Kumar P, Kulkarni N, Ghaisas SS, Reddy SS (2013) PREMΛP: knowledge driven design of materials and engineering processes. In: Proceedings of the 4th international conference on research into design, IIT Madras, Chennai, India, Paper Number: 66
5. Allen JK, Seepersad C, Choi H-J, Mistree F (2006) Robust design for multiscale and multidisciplinary applications. J Mech Des 128:832–843
6. Gear industry vision: a vision for the gear industry in 2025 (2004) Developed by the gear community, (http://agma.server294.com/images/uploads/gearvision.pdf: as on 27 May 2012)
7. Cavallaro GP (1995) Fatigue properties of carburized gear steels, Ph D Thesis, Gartrell School of Mining, Metallurgy and Applied Geology, University of South Australia, Adelaide
8. Rolander N, Rambo J, Joshi Y, Allen JK, Mistree F (2006) An approach to Robust design of turbulent convective systems. J Mech Des 128:844–855
9. Mistree F, Hughes OF, Bras BA (1993) The compromise decision support problem and adaptive linear programming algorithm. In: Kamat MP (ed) Structural optimization: status and promise, AIAA, pp 247–286
10. Design guide for vehicle spur and helical gears, ANSI/AGMA 6002-B93
11. Fundamental rating factors and calculation methods for involute spur and helical gear teeth, ANSI/AGMA 2001-D04

PREMΛP: Exploring the Design Space for Continuous Casting of Steel

Prabhash Kumar, Sharad Goyal, Amarendra K. Singh, Janet K. Allen, Jitesh H. Panchal and Farrokh Mistree

Abstract Continuous casting is a crucial step in the production of a variety of steel products. Its performance is measured in terms of productivity, yield, quality and production costs, which are conflicting. In this paper an integrated design framework has been developed based on metamodels and the compromise Decision Support Problem (cDSP) for determining a robust solution. Further, the design space for continuous casting has been explored to determine robust solutions for different requirements. Moreover, the utility of the framework has been illustrated for providing decision support when an existing configuration for continuous casting is unable to meet the requirements. This approach can be easily instantiated for other unit operations involved in steel manufacturing and then can be used to

P. Kumar · S. Goyal · A. K. Singh (✉)
Tata Consultancy Services, Pune 411013, India
e-mail: amarendra.singh@tcs.com

P. Kumar
e-mail: kumar.prabhash@tcs.com

S. Goyal
e-mail: sharad.goyal@tcs.com

J. K. Allen
School of Industrial and Systems Engineering, University of Oklahoma, Norman, OK 73019, USA
e-mail: janet.allen@ou.edu

J. H. Panchal
School of Mechanical Engineering, Purdue University, West Lafayette, IN 47907, USA
e-mail: panchal@wsu.edu

F. Mistree
School of Aerospace and Mechanical Engineering, University of Oklahoma, Norman, OK 73019, USA
e-mail: farrokh.mistree@ou.edu

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_60,

integrate the host of operations for the development of materials with specific properties and the combined design of products and materials. This enables an integrated simulation based design framework, PREMΛP, and will lead to a paradigm shift in the manufacturing industry.

Keywords Robust design · Compromise Decision Support Problem · Continuous casting of steel · Metamodels

1 Introduction

Global market trends are leading to continuously increasing demand for high quality and cost effective steel in order to meet the requirements and challenges posed by other advanced materials and increasingly demanding industries such as the automobile manufacturing industry. To remain competitive and to survive, steel manufacturers need to address the challenges of increasing productivity and quality as well as reducing production cost. This requires careful control of individual process parameters as well as improvement in the whole steel making process route [1].

In order to address such complex problems, efforts are going on at Tata Consultancy Services to develop a platform, "PREMΛP-Platform for the Realization of Engineered Materials and Products", based on an integrated systems engineering approach. It is expected to: (a) reduce the time and cost of discovery and development of materials and their manufacturing processes and (b) enable faster development of products augmented with richer material information. Detailed discussion on the development, platform architecture and components of PREMΛP is presented in Refs. [2] and [3].The efficacy of using the cDSP is illustrated using two foundational problems: (a) development of steel mill products and (b) integrated design of steel gears. Details of integrated design of steel gear are discussed in Ref. [4] and in this paper we discuss on development of steel mill products with a focus on illustrating two features of PREMΛP, namely, robust design [5] and the exploration of the design space using the cDSP for continuous casting of steel. The cDSP has been shown to be an effective construct for robust design [6–8].

Steel manufacturing involves a host of complex processing steps such as secondary steel making, continuous casting, rolling, heat treatment, etc. Among these, the continuous casting operation is a crucial step involved in production of a variety of steel products from liquid steel, for example slabs and billets, which are subsequently used for sheet and gear manufacturing respectively. The performance of the slab casting process is generally assessed using parameters such as productivity, yield, quality of slab and cost of production. All of these parameters need to satisfy very stringent requirement norms. But, achieving this is very difficult as these requirements are often conflicting. For example, if design variables are selected so as to maximize the productivity, then quality goes down and vice versa. Thus, we need to determine the design variables that balance these conflicting requirements. In principle, one could explore the effects of design variables through experiments and plant trials. However, the slab quality is governed by complex physics of heat transfer, fluid flow, mass transfer, stress evolution, etc. and the highly non-linear nature of these interacting phenomena. Hence obtaining these parameters through experimentation is very costly, time consuming and nearly impossible. It is quite common to sacrifice productivity to meet the quality specifications and run the process sub-optimally.

Considering its importance, continuous casting of slab has been widely studied and the latest edition of "Making, Shaping and Treating of Steel" [9] provides the current advances in technologies as well as present understating of various phenomena governing this process. There have been numerous studies on mathematical modeling of various phenomena related to continuous casting of steel and these are aimed at understanding the complex nature of the process. Very few studies, e.g., Ref. [10], use this information to get better control of the design variables by optimization. Even then, the solutions thus obtained are of limited scope owing to the fact that these constructs seek optimum rather than robust solutions. Due to the unsteady nature of the process, optimum solutions can become unsatisfactory with small changes in the inputs. Hence, there is a need to designing robust solutions.

In this paper, we describe how we explore the design space for this important intermediate operation of slab casting. Comprehensive mathematical models of continuous casting operations have been used to develop metamodels which are used to predict shell thickness, segregation index, temperature at critical locations, oscillation mark depth, etc., as a function of different design variables. These metamodels are then integrated with the cDSP to develop an integrated design framework. This formulation uses performance and robustness related goals in terms of productivity and quality and explores the design space bounded by constraints and limits for a set of design variables such as superheat, casting speed, mold oscillation frequency, cooling conditions in different segments of strand, etc.

Our aim is to demonstrate the potential of mathematical modeling and a multi-objective robust formulation in an integrated design framework supported by PREMΛP. We discuss the potential of the developed integrated design framework to provide insight and answer some of the key questions with respect to the casting process, such as: (a) What values of design variables should be used for a casting process to meet quality and productivity requirements, (b) Can meet these requirements with the existing configuration? If not, what configuration changes are required?

The significance of the above work is that it can be easily instantiated for other unit operations involved in steel manufacturing and can be used to integrate the host of unit operations, supported by PREMΛP.

2 Problem Description and Solution Strategy

2.1 Overview of Continuous Casting Process

A schematic diagram of continuous casting process is shown in Fig. 1 [9]. The process is briefly described here. As hot melt from tundish enters the continuous casting mold through the submerged entry nozzle,it gets cooled by the heat extracted through the mold (primary cooling) and starts to solidify at the metal-mold interface. The mold oscillates in order to avoid sticking (as shown in the inset (a) of Fig. 1 [9]). As superheat of the melt from tundish varies with time, the casting speed is dynamically adjusted. The thickness of solidified layer (shell thickness) keeps on increasing as it moves down the mold. Typically, the mold height is of the order of 1 m and the shell thickness at mold exit should be such that it can withstand the ferrostatic head of the liquid metal. Beyond the mold exit, the movement of the slab is guided and supported by rollers and it is cooled by water with the help of spray nozzles. There are several segments of rollers, varying in roll pitch and diameter. In this paper, we have considered only four segments of rolls, which are clearly depicted in Fig. 1, where the spray cooling by water, the secondary cooling, is done. In this area, a small amount of cooling also takes place by air (natural convection) and support rolls (conduction).As the slab moves further, solidification progresses only due to natural convection and roll

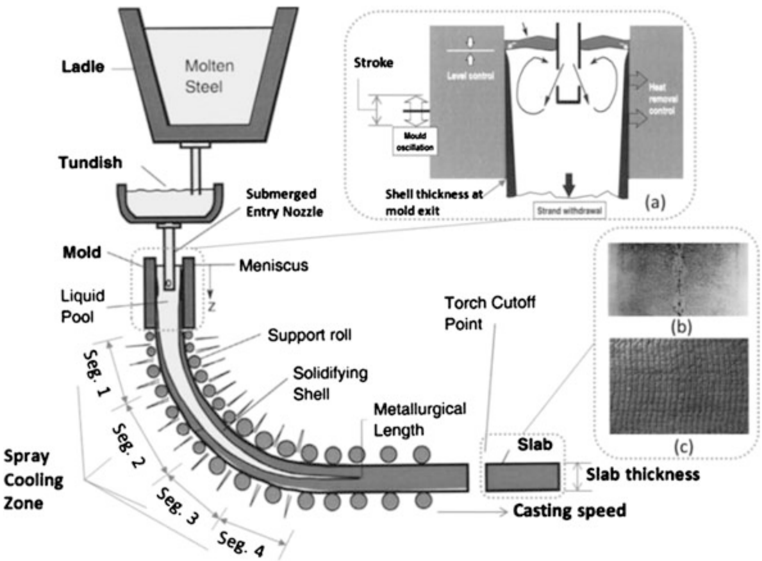


Fig. 1 Schematic diagram of continuous casting process with inset (a) mold oscillation, (b) segregation and (c) oscillation mark [9]

conduction. At the end of the process, the solidified steel is cut to predefined lengths into slabs. Details of the process are reported in Ref. [9].

As mentioned earlier, the performance of the caster is generally assessed in terms of productivity and quality. The productivity of the caster is dependent on casting speed and width and thickness of the slab. Casting speed, in turn, is dependent on the superheat of the melt received from tundish and the required grade of steel. The overall quality of the slab depends on both qualitative and quantitative parameters. In order to define slab quality in a way which can be incorporated in a mathematical framework, we have focused on estimating key quantitative parameters such as segregation index and oscillation mark depth. These parameters are shown in inset (b) and (c) of Fig. 1. Some of the qualitative aspects of quality have been incorporated as constraints and bounds. These are obtained by experience and from the literature [10]. For example, a constraint on shell thickness at the mold exit ensures that there are no breakouts or excessive bulging, which, in turn, ensures better surface and internal properties of the slab.

2.2 Problem Statement

Our objective is to obtain a robust set of design variables, namely, superheat, casting speed, slab width, cooling conditions off our consecutive segments in the spray cooling zone (as shown in Fig. 1) and the mold oscillation frequency for slab casting, to meet the conflicting requirement of maximizing both productivity and quality. Minimum productivity and quality required are 3,000 t/day and 0.6 respectively (refer to Eqs. 18 and 19 presented later). In addition to this, some other constraints also must be satisfied such as segregation index should be less than 2.5, the metallurgical length should be less than 18.84 m, the shell thickness at mold should be greater than 10 mm, reheating (refer to Fig. 3) in each segment should be less than 100 °C, temperature at the unbending point should avoid the ductility trough, oscillation mark depth should be less than 0.25 mm and cooling condition in successive segments of the strand should be in decreasing order.

2.3 Solution Strategy

In this context, where we need productivity and quality and simultaneously minimize their variation for robust solution while satisfying a set of constraints, a mathematical construct capable of handling multiple objectives and constraints is required. For this purpose, the cDSP construct is used. The steps of the solution strategy are given in Fig. 2. Detailed simulation models have been developed for various problems and sets of requirements. Based on these models, Response Surface Models (RSM) have been developed. These response surface models have been integrated with the cDSP to develop an integrated design framework. Later

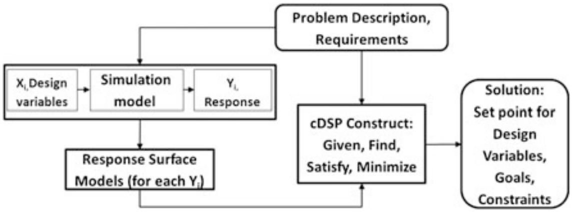


Fig. 2 Flow diagram showing the solution strategy

these are used to explore the design space for continuous casting and arrive at design variables to meet the conflicting requirements of both productivity and quality while satisfying the constraints.

3 Models

3.1 *Mathematical Model for Heat Transfer*

Mathematical models have been used to model the underlying physical phenomena and identify several additional parameters apart from process and design parameters that play an important role in quality control of the slab. A transient, 2-D finite-difference based heat transfer model has been developed to get the temperature evolution profile, shell thickness at mold exit and segregation index. The formulation is based on the fundamental heat transport equation [9] and modified Scheil's equation [11]. It is assumed that heat flow by conduction in the axial direction is low compared to the heat flow by bulk movement of slab in the axial direction. This reduces the problem to 2-D. Also, due to symmetry, only a quarter of the full cross-section of the slab has been modeled. Appropriate boundary conditions have been used in each zone. The trends observed in results are in good agreement with the data published in literature [10]. A typical temperature profile on surface of slab along the casting direction is shown in Fig. 3.

3.2 *Meta Models*

Ideally comprehensive and detailed mathematical models should be used for design to get high levels of accuracy. But, this may require intensively high computational power and time for analysis. Compared to these, metamodel approximations are significantly cheaper to run and can be easily linked to optimization algorithms for fast design exploration. Although, by doing this, some information is lost and accuracy decreases, metamodels can be used in the preliminary stages of design to reduce the design search space and later more comprehensive and detailed mathematical models can be used in the reduced design space to obtain accurate results.

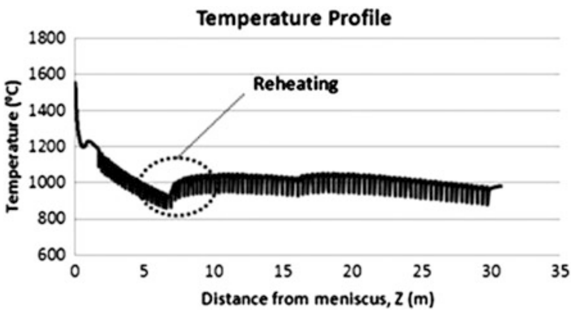


Fig. 3 Typical temperature profile on surface of slab along casting direction

Polynomial response surfaces are the most widely used approximating functions for constructing metamodels. We use a second-order polynomial function as shown in Eq. 1 for the response surface models for all the responses generated from the heat transfer model. The constants in the Eq. 1 are calculated using least square regression analysis of the data generated using the design of experiments. Some of the constant terms in a response surface model have been neglected because they are small as compared to other constant terms. The details of constructing response surface models and the design of experiments are described in Ref. [12]. The ranges of design variables for which these metamodels are developed are shown in Table 1. A summary of all the response surface models is presented in Table 2. The responses studied include segregation index (SI), shell thickness at mold exit (ST_{ME}), metallurgical length (ML), i.e., distance from meniscus to the point of complete solidification (see Fig. 1), temperature at unbending point (T_{UP}), reheating in segment 1 ($T_{R,1}$), reheating in segment 2 ($T_{R,2}$), reheating in segment 3 ($T_{R,3}$) and reheating in segment 4 ($T_{R,4}$). All the design variables are used in normalized form from 0 to 1 in the response surface models. For this example, a low carbon steel with composition (wt%) of C-0.055, S-0.005, P-0.011, Si-0.012, Mn-0.45 and Al-0.053 has been considered.

$$f(x_i) = a_0 + \sum_{i=1}^{n} a_i x_i + \sum_{i}^{n} a_{ii} x_i^2 + \sum_{i=1}^{n} \sum_{j>i}^{n} a_{ij} x_i x_j \qquad (1)$$

Table 1 Range of design variables

Sr.No.	Design variables	Symbol	Range
1	Super heat	X_1	10–45 °C
2	Casting speed	X_2	0.8–2.5 m/min
3	Slab width	X_3	1,000–1,550 mm
4	Cooling condition in segment 1	X_4	236–720 W/m^2 K
5	Cooling condition in segment 2	X_5	333–450 W/m^2 K
6	Cooling condition in segment 3	X_6	331–420 W/m^2 K
7	Cooling condition in segment 4	X_7	172–235 W/m^2 K
8	Mold oscillation frequency	X_8	95–250 cycles/min

Table 2 List of response surface models

Response surface models	
SI (R^2 = 0.89)	=(0.01142 + 0.00098 X_1 + 0.00129 X_2 − 0.00077 X_3 + 0.00094 X_4 − 0.00046 X_1^2 − 0.00091 X_2^2 + 0.00026 X_3^2 − 0.00018 X_4^2 − 0.00026 X_1X_2 + 0.00019 X_1X_4 − 0.00048 X_2X_4 + 0.00024 X_2X_5 + 0.0001 X_2X_6)/0.005
ST_{ME} (R^2 = 0.99)	=(0.02241 − 0.00436 X_1 − 0.01641 X_2 + 0.00558 X_2^2 + 0.0024 X_1X_2)
ML (R^2 = 0.99)	=(9.775 + 0.613 X_1 + 18.412 X_2 − 1.132 X_4 − 0.4 X_5 + 4.663 X_2^2 + 0.248 X_4^2 + 1.474 X_1X_2 − 0.767 X_2X_4 − 0.629 X_2X_5 − 0.66 X_2X_6 − 0.651 X_2X_7)
T_{UP} (R^2 = 0.99)	=(886.68 + 13.55 X_1 + 502.79 X_2 − 29.29 X_4 − 27.74 X_7 − 261.82 X_2^2 + 14.62 X_2X_4)
$T_{R,1}$ (R^2 = 0.98)	=(163.42 + 3.5 X_1 − 14.5 X_2 − 190 X_4 + 0.61 X_1^2 + 43.58 X_2^2 + 81.3 X_4^2 + 0.19 X_1X_2 − 2.50 X_1X_4 − 36.18 X_2X_4)
$T_{R,2}$ (R^2 = 0.99)	=(104.44 + 2.11 X_1 − 84.66 X_2 + 60.32 X_4 − 30.35 X_5 + 2.42 X_1^2 + 30.93 X_2^2 + 18.9 X_4^2 + 6.3 X_5^2 − 0.85 X_1X_2 − 4.44 X_1X_4 + 5.93 X_2X_4 + 6.17 X_2X_5 − 24.7 X_4X_5)
$T_{R,3}$ (R^2 = 0.87)	=(0.7557 − 0.10625 X_1 − 1.0887 X_2 + 0.15201 X_4 + 8.93837 X_5 − 12.372 X_6 + 1.1766 X_1^2 + 0.63 X_2^2 − 0.1175 X_4^2 + 9.2787 X_5^2 + 6.9296 X_6^2 + 0.01658 X_1X_2 − 1.9403 X_1X_5 − 0.08636 X_2X_4 − 1.637 X_2X_5 + 3.0596 X_2X_6 + 6.2287 X_4X_5 − 17.5402 X_5X_6)
$T_{R,4}$ (R^2 = 0.97)	=(125.82 + 2.39 X_1 − 32.51 X_2 − 3.82 X_4 + 0.324 X_5 + 27.87 X_6 − 46.64 X_7 +2.196 X_2^2 + 0.166 X_4^2 − 1.119 X_5^2 + 0.4 X_6^2 + 8.219 X_7^2 − 3.841 X_1X_2 + 8.499 X_2X_4 + 4.68 X_2X_5 + 7.993 X_2X_6 + 1.185 X_4X_5 + 1.958 X_5X_6 − 5.848 X_6X_7)

In addition to the response surface models, an empirical equation for oscillation mark depth (d) has been utilized, which is shown in Eqs. 2 and 3 [13]. Here, t_N, v_{cast}, f, S stand for negative strip time (s), casting speed (m/min), mold oscillation frequency (cycles/min) and mold stroke (mm) respectively. The oscillation mark depth has a significant effect on surface quality as it can act as a nucleation site for surface cracking and transverse cracks.

$$d = 0.065 \times 1.145^s \times (200 \times 0.9^s)^{t_N} \quad (2)$$

$$t_N = \frac{60}{\pi f} \cos^{-1} \frac{1{,}000\, v_{cast}}{\pi f s} \quad (3)$$

4 The cDSP for Exploration of Design Space of Continuous Casting of Slab

The detailed mathematical formulation of the cDSP for the problem discussed is given in Table 3. Some of the variables such as slab thickness, downtime for casting, density of steel (ρ), mold stroke and variance (σ^2) for all the eight design variables

Table 3 The cDSP for continuous casting of slab

Given:

Fixed parameters: Slab thickness = 210 mm, $\rho = 7.8$ g/cc, mold stroke = 6 mm, caster downtime = 1 h., $\sigma_{X_1}^2 = 0.04$, $\sigma_{X_2}^2 = 0.01$, $\sigma_{X_3}^2 = 0.03$, $\sigma_{X_4}^2 = \sigma_{X_5}^2 = \sigma_{X_6}^2 = \sigma_{X_7}^2 = 0.01$ and $\sigma_{X_8}^2 = 0.002$

Response surface models (Table 2) and equations (Eq. 2, 4, 18, 19)

Maximum and minimum value of each goal (calculated based on range of design variables), P_{max} = 8,800 t/day, P_{min} = 1,800 t/day, $\sigma_{P,max}^2$ = 650,000 (t/day)^2, $\sigma_{P,min}^2$ = 170,000 (t/day)^2, $Q_{max} = 1$, $Q_{min} = 0.08$, $\sigma_{Q,max}^2 = 0.7$, $\sigma_{Q,min}^2 = 0$

Target for each goal (normalized based on maximum and minimum value, 0–1): $P_{Target} = Q_{Target} = 1$ (maximize), $\sigma_{P,Target}^2 = \sigma_{Q,Target}^2 = 0$ (minimize)

Number of design variables = 8, Goals = 4, Constraints = 14

Find:

The value of design variables: X_i, i = 1,….,8

The value of deviation variables d_i^+, d_i^-, i = 1,….,4

Satisfy:

Constraints:

Shell thickness (m): $ST_{ME} - 0.01 \geq 0 \quad (4)$

Oscillation mark depth (mm): $d - 0.25 \leq 0 \quad (5)$

Metallurgical length (m): $ML - 18.84 \leq 0 \quad (6)$

Temperature at unbending (°C): $(T_{UP} - 800) \times (T_{UP} - 1{,}000) \geq 0 \quad (7)$

Reheating (°C): $T_R - 100 \leq 0, \quad \textit{for all four segments} \quad (8)$

Segregation index: $(SI - 2.0) \times (SI - 2.5) \leq 0 \quad (9)$

Cooling condition (W/m^{2}K): $(X_i - X_{i+1}) \geq 1, \quad \textit{for } i = 4, 5, 6 \quad (10)$

Productivity (tons/day): $(P - 3{,}000) \geq 0 \quad (11)$

Quality: $(Q - 0.6) \geq 0 \quad (12)$

Goals:

$$[P(x_i) - P_{min}]/[P_{max} - P_{min}] + d_1^- - d_1^+ = 1 \quad (13)$$

$$\left[\sum_i \left[\left(\frac{\partial P(x_i)}{\partial x_i}\right)^2 \times \sigma_{x_i}^2\right] - \sigma_{P_{min}}^2\right] / \left[\sigma_{P,max}^2 - \sigma_{P,min}^2\right] + d_2^- - d_2^+ = 0 \quad (14)$$

$$[Q(x_i) - Q_{min}]/[Q_{max} - Q_{min}] + d_3^- - d_3^+ = 1 \quad (15)$$

$$\left[\sum_i \left[\left(\frac{\partial Q(x_i)}{\partial x_i}\right)^2 \times \sigma_{x_i}^2\right] - \sigma_{Q_{min}}^2\right] / \left[\sigma_{Q,max}^2 - \sigma_{Q,min}^2\right] + d_4^- - d_4^+ = 0 \quad (16)$$

Bounds:

$0 \leq X_i \leq 1$, i=1,….,8 (Table 1)

$d_i^- . d_i^+ = 0$, $d_i^+, d_i^- \geq 0$, i = 1,….,4

Minimize:

The deviation function (Z): Archimedean formulation

$$Z = \sum_{i=1}^{m} W_i(d_i^-, d_i^+); \sum_{i=1}^{4} W_i = 1, \; W_i \geq 0 \quad \textit{for } i = 1, \ldots, 4 \quad (17)$$

have been fixed. The values for these have been determined based on literature review and experience. The metamodels have been used to formulate the constraints and goals. As discussed in Sect. 2.1, we have considered only two important performance goals, namely, productivity and quality for casting operation. Now, we discuss the mathematical formulation of these goals. Productivity [$P(x_i)$, tons/day] has been defined in terms of casting speed, thickness and width of slab, density of steel and caster downtime as shown in Eq. 18.

$$P(x_i) = x_2 \times x_3 \times \rho \times slab\,thickness \times (24 - caster\,down\,time) \times \frac{60}{10^6} \quad (18)$$

The Quality ($Q(x_i)$) of the slab has been formulated in terms of the normalized segregation index and oscillation mark depth from 0 to 1 as shown in Eq. 19. The weights for each of these parameters (W_{SI} and W_d) can be determined based on the application of the slab, i.e., if slab is being produced for an application which is highly sensitive to the segregation index, then a greater weight can be assigned to it. Further, other suitable quality indicator parameters such as the crack index can also be incorporated in this formulation, as appropriate. In this illustration, equal weights ($W_{SI} = W_d = 0.5$) have been given to both the segregation index and oscillation mark depth.

$$Q(x_i) = 1 - (W_{SI} \times SI(x_i) + W_d \times d(x_i)),\ \sum W_j = 1 \quad (19)$$

For the robustness of the solution, two other goals, variance in productivity (σ_P^2, Eq. 14) and variance in quality (σ_Q^2, Eq. 16) have also been incorporated and must be minimized. For all four goals, maximum and minimum limits have been calculated based on the range of design variables and these have been used to normalize the goals from 0 to 1.

The constraints are mainly metallurgical constraints (Eqs. 4–8). The details of these metallurgical constraints are reported in Ref. [10]. Considering economic aspects, plant practices and other requirements, some additional constraints are added (Eqs. 9–12). All the constraints must be satisfied to obtain a feasible solution.

Depending on the requirements for productivity, quality and robustness, different scenarios can be addressed by varying the weights given to each goal. Table 4 shows the different scenarios and the form of the corresponding deviation function (Z). Next we discuss the physical significance of these scenarios.

Scenario 1 represents a case where only productivity and quality goals are important. The process is controlled, so that there is very little variation in the design variables, and there is no concern for robustness. An equal trade-off between productivity and quality has been considered with constraints on them (Eqs. 11 and 12).

Table 4 Design scenarios for continuous casting of slab

Scenario no.	Scenario description	Deviation function
1	Overall, without robustness	$Z = (d_1^- + d_3^-)/2$
2	Productivity and its robustness	$Z = (d_1^- + d_2^+)/2$
3	Quality and its robustness	$Z = (d_3^- + d_4^+)/2$
4	Overall, with robustness	$Z = (d_1^- + d_2^+ + d_3^- + d_4^+)/4$
5	Ladle changeover	$Z = (d_3^- + d_4^+)/2$

Scenario 2 represents a case where there is an equal importance of productivity and its variance. Quality and its variance are either not needed or they are already in an acceptable range. For this, a constraint has been added on quality (Eq. 12).

In Scenario 3 quality and its variance are equally weighted. Productivity and its variance are not considered, but a constraint on productivity (Eq. 11) has been added to maintain a critical level of production.

Scenario 4 represents an equal trade-off among all goals. Productivity and quality has been constrained in order to satisfy minimum requirements (Eqs. 11 and 12).

Scenario 5 deals with ladle changeover during the casting operation where an empty ladle is being replaced by a filled ladle. During ladle changeover, maintaining the quality of slab is important. For this, an equal trade-off between quality and its variance have been considered with a constraint on quality (Eq. 12). It should be noted that this scenario is different from Scenario 3 because the bounds on the design variables have changed. Casting speed is lowered (0.8–1.31 m/min) to ensure proper transition and the superheat also decreases (10–35 °C).

5 Results and Discussion

The values of design variables and goals achieved are shown in Table 5. These are in close agreement with existing plant practices. Moreover, we observe a different solution in terms of design variables as well as goals, for all the five scenarios discussed earlier. This shows the importance of goals and helps in understanding the trade-offs among them. It is clear that slab casting process performed using design variables which are in agreement with the requirements, i.e., design variables should be fixed for operation depending on the requirements of productivity and quality.

In Fig. 4a and b, we show the convergence in the values of deviation variables and goals achieved respectively with successive iterations for Scenario 1. Similar trends are observed for other scenarios also. As expected, in Scenario 1, we see a decrease in value of the deviation function and increase in the value of goals (productivity and quality) achieved with successive iterations. It is important to note that as desired goals for productivity and quality are being maximized, their variances are also increasing. This means that even though the productivity and quality is high, the solution obtained is not robust because the variance is also high. In order to obtain robust solution greater weights must be given to the variance in productivity and variance in quality. This is explored in Scenarios 2, 3 and 4. On comparing the results of Scenario 1 with that of Scenario 4, we see more robust solution in Scenario 4 where variance is less but productivity and quality decreases, again this is as expected. Thus it is important to assign appropriate weights to each goal as per the requirements.

In Scenario 5 where ladle changeover has been considered, we observe that the quality reduced from 0.82 (Scenario 3) to 0.74. This indicates that with the existing

Table 5 Design exploration results for continuous casting of slab

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Design variables					
X_1 (^{0}C)	10	10	10	10	26
X_2 (m/min)	1.68	1.75	1.34	1.62	1.31
X_3(mm)	1,550	1,000	1,550	1,270	1,550
X_4 (W/m^{2}K)	420	694	411	418	419
X_5 (W/m^{2}K)	419	450	350	333	361
X_6 (W/m^{2}K)	417	412	331	331	331
X_7 (W/m^{2}K)	235	235	195	235	196
X_8 (cycles/min)	95	95	250	250	250
Goals					
Productivity (tons/day)	5,897	3,960	4,705	4,637	4,590
Standard deviation in productivity (tons/day)	700	540	662	600	659
Quality	0.84	0.64	0.82	0.77	0.74
Quality variance	0.1574	0.1678	0.0029	0.0029	0.0013
Deviation function (*Z*)	0.2955	0.4707	0.0972	0.3119	0.1448

plant configuration, it is not possible to meet higher quality (more than 0.74) requirements during ladle changeover. Even to maintain a low quality, the set point for superheat goes up from 10 °C (Scenario 3) to 26 °C, with other parameters remaining more or less the same, which is economically not suitable. To understand the modifications in the plant configuration needed to meet the quality requirements, we looked at the constraint values. We observed that constraints on reheating and temperature at the unbending point are just satisfied. These all indicate that to maintain the same level of quality during ladle changeover as in normal operating condition (Scenario 3), the bounds for cooling conditions (X_4 to X_7) need to be decreased. Alternatively this can also be achieved

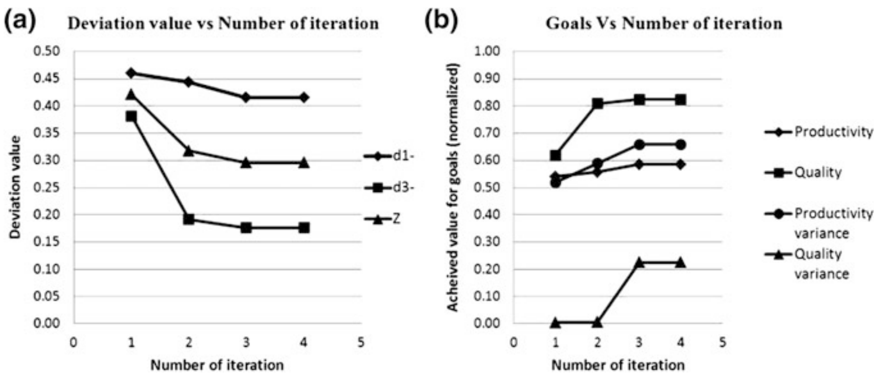


Fig. 4 Results of scenario 1 for variation in **a** deviation value and **b** goals with iterations

by incorporating some heating arrangements in the tundish to increase superheat. This leads to a guided change in existing plant configuration for meeting the requirements.

Further, it is important to observe that the superheat in all the cases (except Scenario 5) is close to its lower bound which is consistent with the basics. From a fundamental perspective, superheat should be as low as possible since higher superheat promotes segregation which affects the quality adversely. Also, high superheat limits the casting speed which adversely affects productivity. This has been observed in Scenario 2 where quality has not been considered yet superheat is low because it allows casting at a higher casting speed which increases productivity (goal for Scenario 2). Thus, it can be concluded that superheat should be low irrespective of the requirements.

In this paper, we have only dealt with a part of the process chain for the development of steel mill products [2]. Same approach can be used for other processes in the process chain and these can be used to integrate the processes for the development of materials with specific properties and the combined design of product and material. In future we will explore these issues. Along with these, we will also extend the present work to billet casting operation in order to address the challenges in gear manufacturing [2, 4].

6 Closing Remarks

An integrated design framework comprising of metamodels and a heuristic based cDSP has been developed. It requires various components such as simulation models, knowledge bases, optimization schemes etc., which are supported by PREMΛP. The design framework has been successfully employed to explore the design space of continuous casting of slab. The trade-offs between competing requirements has been clearly demonstrated. Using the framework, different scenarios based on different requirements have been analyzed and set points for design variables have been obtained. It is clear that the continuous casting operation for slab should have different sets of design variables for different set of requirements although superheat should be maintained at a lower value in each case. During ladle changeover, in order to maintain quality similar to that during normal operations, either the cooling pattern of the existing set up or configuration of tundish must go under a guided change. The cDSP can be further improved by improving upon models used and imposing more accurate constraints. More importantly, PREMΛP can be augmented for exploring the design space and determining the robust design of other unit operations involved in steel making.

Acknowledgments The authors thank TRDDC, Tata consultancy services, Pune for supporting this work. Janet Allen gratefully acknowledges financial support from the John and Mary Moore Chair at the University of Oklahoma. Farrokh Mistree gratefully acknowledges financial support from the L.A. Comp Chair at the University of Oklahoma.

References

1. Singh AK, Pardeshi R, Goyal S (2011) Integrated modeling of tundish and continuous caster to meet quality requirements of cast steels. In: 1st world congress on integrated computational materials engineering, vol 1, pp 81–85
2. Gautham BP, Singh AK, Ghaisas SS, Reddy SS, Mistree F (2013) PREMΛP—a platform for the realization of engineered materials and products. In: Proceedings of the 4th international conference on research into design, IIT Madras, Chennai, India. Paper no.: 63
3. Bhat M, Shah S, Das P, Kumar P, Kulkarni N, Ghaisas SS, Reddy SS (2013) PREMΛP—knowledge driven design of materials and engineering processes. In: Proceedings of the 4th international conference on research into design, IIT Madras, Chennai, India, Paper no: 66
4. Kulkarni N, Zagade PR, Gautham BP, Panchal JH, Allen JK, Mistree F (2013) PREMΛP—exploring the design and materials space for gears. In: Proceedings of the 4th international conference on research into design, IIT Madras, Chennai, India. Paper no.: 64
5. Allen JK, Seepersad CC, Mistree F (2006) A survey of robust design with applications to multidisciplinary and multiscale systems. J Mech Des 128(4):832–843
6. Mistree F, Hughes OF, Bras BA (1993) The compromise decision support problem and the adaptive linear programming algorithm. In: Kamat MP (ed) Structural optimization: status and promise, Washington, D.C., AIAA, pp 247–286
7. Simpson TW, Chen W, Allen JK, Mistree F (1999) Use of the robust concept exploration method to facilitate the design of a family of products. In: Roy U, Usher JM, Parsaei HR (eds) Simultaneous engineering: methodologies and applications. Chapman-Hall, New York, pp 247–278
8. Choi H-J, McDowell DL, Rosen D, Allen JK, Mistree F (2008) An inductive design exploration method for robust multiscale materials design. J Mech Des 130(3):031402-1/13
9. Cramb AW (2010) The making, shaping and treating of steel-casting volume, 11th edn, AIST
10. Santos CA, Cheung N, Garcia A, Spim JA (2005) Application of solidification mathematical model and a genetic algorithm in the optimization of strand thermal profile along the continuous casting of steel. Mater Manuf Proces 20:1–14
11. Ghosh A (1990) Principles of secondary processing and casting of liquid steel. Oxford and IBH publishing Co. Pvt. Ltd
12. Myers RH, Montgomery DC, Anderson-Cook CM (2009) Response surface methodology: process and product optimization using designed experiments. Wiley, New York (Wiley series in probability and statistics)
13. http://www.ewp.rpi.edu/hartford/users/papers/engr/ernesto/lankep/THESIS/Supplemental/CC_UserGuide.pdf

Requirements for Computer-Aided Product-Service Systems Modeling and Simulation

Gokula Vasantha, Romana Hussain, Rajkumar Roy and Jonathan Corney

Abstract The design of product-service systems (PSS) is a co-production process which involves the manufacturer, customer and suppliers as well as any other stakeholders. This multi-organizational, collaborative environment along with the unique tangible and intangible characteristics of PSS demands a novel computer-based design platform. To identify the requirements for modeling and simulating PSS, existing academic software for PSS, namely, Service CAD integrated with a life cycle simulator (ISCL), Service Explorer and the commercially available system modeling software OPCAT^{TM} are analyzed using a truck provider PSS problem. These platforms are used to represent PSS, model the factors and simulate the system in order to appreciate and compare the impact of different PSS designs. The evaluation reveals the scope of these platforms and proposes overall requirements for modeling and simulating PSS.

Keywords Product-service system · Modeling · Simulation

G. Vasantha · J. Corney
Design Manufacture and Engineering Management, University of Strathclyde, Glasgow, UK
e-mail: gokula.annamalai-vasantha@strath.ac.uk

J. Corney
e-mail: jonathan.corney@strath.ac.uk

R. Hussain · R. Roy (✉)
Manufacturing and Materials Department, Cranfield University, Bedfordshire, UK
e-mail: r.roy@cranfield.ac.uk

R. Hussain
e-mail: r.s.hussain@cranfield.ac.uk

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_61,

1 Introduction

Product-Service Systems (PSS) is defined as an integrated product and service offering that delivers value in use [1]. Goedkoop et al. [2] define a product-service system as—a system of products, services, networks of players and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models. A commonly sighted PSS example is the CorporateCare™ offering from Rolls-Royce Plc, UK [3]. CorporateCare™ is a comprehensive *cost-per-flight-hour* service, designed to deliver a highly competitive engine maintenance program to corporate customers. The key merits to the customers of this offering are low risk, predictable maintenance costs, increased aircraft availability and 24 h per day/365 days per year service support. However, Neely's [4] findings from the analysis of a large industrial database were that designing, implementing and managing this kind of offering is a huge challenge to the manufacturer as there is a distinct possibility of economic. However, in this challenging, globalized economy, PSS can help manufacturers to lock the customer into a long-term relationship, inhibit any replication of the customized offering by competitors, provide greater insights into how products are used and ultimately, if suitably delivered, also increase revenue. However, currently in industry, PSS conceptual design, in practice, is ad-hoc and it lacks a systematic approach. In order to support industry and designers in designing PSS, there has been an increasing interest with regards to developing theories, methodologies, tools and techniques.

A review of current PSS literature [5] reveals that the theories and methodologies to aid the design of PSS are still in their initial stages of development and substantial research is required to develop a practical PSS design methodology along with supporting tools. The interaction of the stakeholders in the design process and the unique characteristics of products, services, networks of players as well as the supporting infrastructure which is involved in the design of PSS, all demand a novel computer-aided modeling and simulation platform.

In this paper, we aim to enumerate the requirements for computer-aided conceptual modeling and the simulation of PSS designs. In order to identify the requirements for modeling and simulating PSS, existing academic software for PSS namely Service CAD integrated with a life cycle simulator (ISCL) [6], Service Explorer [7] and the commercially available system modeling software, OPCAT™ [8], are analyzed using a truck provider's PSS issue. ISCL and Service Explorer are greatly referred to within the PSS literature and OPCAT™ is an academic based system modeling platform which is based on the robust Object-Process Methodology (OPM). These platforms are used to represent PSS, model the factors and simulate the system in order to understand and compare the impact of different PSS designs. The evaluation reveals the scope of these platforms and proposes the overall requirements for modeling and simulating PSS.

2 PSS Design and Modeling Techniques

In the PSS literature, PSS design is not yet fully defined or commonly accepted. The research question 'what constitutes PSS design?' is yet to be answered and agreed upon by the PSS community. It is our opinion that PSS design can be defined as a process to synthesize and create sustained functional behavior through tangible products and intangible services [9]. Sustained functional behavior represents the degree to which a system can continuously achieve its purpose. PSS design involves the design of business models, the design of products and services, the design of processes and the interactions of all of the elements involved within the system. The primary motivation in PSS modeling is to co-create conceptual models that can be systematically shared and commonly interpreted by stakeholders.

Komoto and Tomiyama [6] have proposed that in PSS design processes, designers define an activity to meet a specified goal and quality and also define the environment as being the circumstance within which that activity is realized. We also argue that activity based mapping is an efficient representation for describing PSS design. By extending Komoto's and Tomiyama's PSS design process, we propose a representation for PSS design to be the mapping of each activity into inputs, outcomes, resources, competences, responsibilities, environmental variables and customer needs. These parameters are based upon the approach of capability-based PSS design [9]. A capability can be defined as the continuing ability to generate a desired operational outcome. Capabilities should be mapped depicting activities, outcomes and the reasons for deficiency. The core principles of this approach are:

- Fulfilling the customer's goal more closely by adjusting the customer's system to decrease system deficiencies [10].
- Understanding the capability shift between tangible and intangible elements and also between stakeholders.

Figure 1 details the activity based representation of PSS design. The sequence of activities is linked based on the satisfaction of preceding activity's outcomes. This representation highlights the necessary PSS parameters and the interactions amongst them.

To map and represent the parameters depicted in Fig. 1, a wide variety of representational techniques have been proposed in the literature. Representational techniques have been used in PSS design methodologies to define different processes involving products and services [11, 12]. They include Unified Modeling Language (UML), Structured Analysis and Design Technique (SADT), Functional Analysis, Service Blueprinting, Business Process Model and Notation (BPMN), Integrated DEFinition method of modeling functionality and information modeling (IDEF0), Data Flow Diagrams (DFD), Graphes à Résultats et Activités Interreliés (GRAI), Functional Flow Block Diagrams (FFBD), N2 charts, Behavior Diagrams, Design Structure Matrix (DSM) and Systems Modeling Language (SysML).

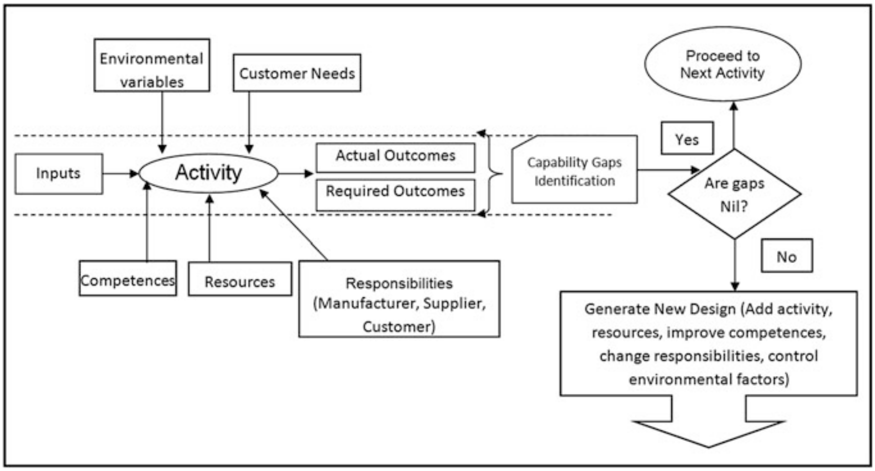


Fig. 1 Activity based representation of PSS Design

Detailed research studies are required to analyze and identify the suitability of these representational techniques in mapping the various parameters to define and present PSS design. Detailed elaboration and assessment of these techniques are out of the scope for this paper. In this paper, we aim to assess the representation used in three software platforms which could be potentially used for designing PSS: Service CAD integrated with a life cycle simulator (ISCL), Service Explorer, and OPCAT^{TM}. Along with these representational techniques, the assessment also aims to highlight the features required for designing and simulating PSS designs.

3 Truck Industry PSS Problem

In this competitive environment, Reliability, Availability, Maintainability and Safety (RAMS) are the four key performance indicators for the business-to-business activity for most large technical system manufacturers. The major goal of the truck company in question is to satisfy their customer's needs which are primarily based upon increasing truck uptime and lowering life cycle operational costs. Although the truck manufacturer has a large market share, they would like to become market leaders which they could attain by providing value-adding PSS offerings to their customers. An analysis of the existing capability gaps that their customers have and the identification of the issues with the trucks such as frequently occurring defects and the frequency and cost of maintenance (by analyzing historical maintenance data of the trucks) reveals that:

Table 1 PSS design solution for the truck problem

PSS design 1	PSS design 2	PSS design 3
Customer owns truck	Customer leases truck	Manufacturer owns truck
Guaranteed truck uptime and MOT pass with constant pricing throughout contract duration	Various services such as MOT and maintenance record management are provided in 'pay-as-you-go' mode	Customer pays for the amount of mileage they incur on the monthly basis

- The driver's skills (to drive correctly, that is, not commit too many driving faults such as harsh braking that could damage the truck) greatly influence truck performance, and hence services and life cycle cost.
- There is a requirement for an efficient IT system for maintaining truck records dealing with concerns such as inspection, maintenance periods and first time MOT pass.
- There is a lack of skills in performing regular maintenance checks and preliminary maintenance tasks.
- The cost of maintenance for frequent defects is very low, but the downtime due to frequent defects is very high.
- Different systems and components in trucks fail at different times creating difficulties in scheduling maintenance activities.
- If a preventive maintenance schedule is implemented focused primarily around the few critical systems, it could also lead to the replacement of several other components before they adversely affect the truck.
- There is difficulty in building relationships between how the vehicle is driven and the repairs that are incurred.

In order to add value to their offering to customers by eliminating or reducing these issues, various PSS designs have been generated. Three PSS designs have been chosen here to assess the aforementioned software are detailed in Table 1. Along with these designs, the parameters mentioned in Fig. 1 are used to describe software in the next section.

4 Illustrations of Chosen Platforms

4.1 Service CAD Integrated with a Life Cycle Simulator

ISCL [6] is a Python based computer-aided tool primarily developed to support the design of PSS. Its process modeling is based on service modeling and the simulation of process models with discrete event simulation are the main features of ISCL. ISCL consists of elements classified into Entity (which represents products and stakeholders), Attribute (which defines the state of entities), Activity (which represents any type of process), Scene (used to classify entity instances), and

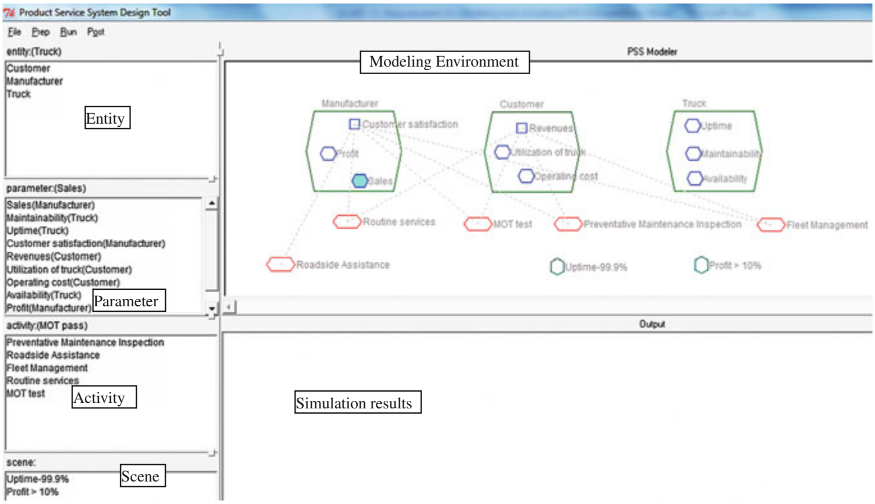


Fig. 2 The modeling environment of service CAD integrated with a life cycle simulator

Specification (which defines the requirements). Furthermore, ISCL structures the relations between these model elements. The elements and relationships are based on the concept that within PSS design, designers define the activity to meet a specified goal and quality and also define environment as being the circumstance within which that activity is realized. The "grammar" for modeling PSS design is programed into this platform and assists the designer in modeling and reasoning about the relationships between the elements.

Designers can create these elements on the canvas of ISCL and also move, inspect, and delete these elements on the canvas. Conditions and consequences are detailed for each activity to aid structure during discrete event simulation. Also activities can be sequenced to specify the simulation configuration. Activities treat scenes as the execution conditions and change the value of attributes and realize specifications. Simulation results are plotted in two-dimensional plots. Also, all simulation results can be downloaded in an excel sheet format (.csv). This software is currently in the public domain, downloadable and is actively supported by the developers. Figure 2 details the application of ISCL to the truck problem.

4.2 Service Explorer

Service explorer [7] was firstly developed for service engineering. Service explorer is a computer-aided tool which can be used to evaluate existing services and to design new services by allowing the visualization of the relationships from the customer requirements to the service delivery process. The elements of service are defined by the provider, receiver, contents and channel. A 'service' is defined as "an activity that a provider causes a receiver, usually with consideration, to change from an existing state to a new state that the receiver desires, where both contents and a channel are means to realize the service" [13]. It is based on the notion that service contents are provided by a service provider and delivered through a service channel. Depending on the business model, physical products are either the service contents or the service channel. The parameters are the Receiver State Parameter (RSP—this expresses the receiver's state), the Contents Parameter (CoP–is directly associated with the contents and factors in the RSP change), and the Channel Parameter (ChP—indirectly contributes to the RSP change with an action through the channel).

Service explorer structures a service model which consists of four sub-models: the 'flow' model (the "*who*"—the chain of agents who take roles of service providing and receiving), the 'scope' model (the "*what*"—the intended area of a service), the 'scenario' model (the "*why"*—the reasons for value)' and the 'view' model (the "*how*"—the functional structure for an RSP). An extended blueprint with Business Process Model and Notation (BPMN) is used to represent the view model. The design process is structured in the following steps: define the service target, represent the service target, describe the realization structures, evaluate a service, modify a service and create a service. Service explorer supports the development of the service case base, the design rule base and supports the reasoning for designers to construct service models. It also supports various techniques such as Quality Function Development (QFD), Analytical Hierarchy Process (AHP), DEMATEL, Activity Based Costing (ABC) and the Petri Net based technique (external simulator) for customer requirements and solution analysis as well as simulating the designed service process. As Service Explorer contains many features, the overall conceptual scheme underlying Service Explorer is detailed in Fig. 3.

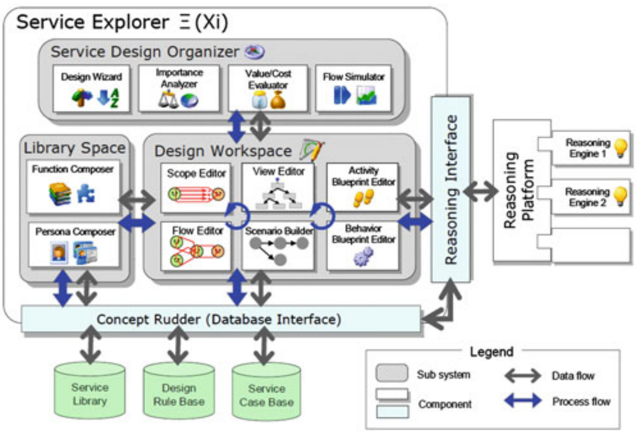


Fig. 3 The conceptual scheme underlying service explorer [2]

4.3 OPCAT™

The Object-Process Methodology (OPM) [8] is an underlying language and modeling approach for OPCAT software. OPM is a holistic approach for the conceptual modeling of complex systems. OPM is a modeling language based on a paradigm that views processes and objects as being equally important in the system model. OPM is modeled through three different types of entities: objects (things in the system that exist), processes (the things in the system that transform objects), and states. These elements are connected through structural (static time-independent relations) or procedural links (to describe the behavior of a system). The System Diagram (SD) is the topmost diagram in a model. It presents the most abstract view of the system, typically showing a single process as the main function of the system, along with the most significant objects that enable it (preconditions) and the ones that are transformed by it (results/effect/value). For each process the preconditions and the post-conditions of that process are described.

Features of in-zooming, unfolding and state expressing are used to show the various levels of detail which are represented of the system. These features aid scalability to system modeling and increase the information processing ability of designers. Also, different system views (a view is an assembly of system elements which specifies a certain aspect of the system) could be generated to explain the system to different stakeholders. The abstraction-refinement mechanism ensures that the context of a thing at any level of detail is never lost and the "big picture" is maintained at all times. The key benefit is that the OPM model integrates the functional, structural, and behavioral aspects of a system into a single, unified view, expressed bi-modally in equivalent graphics and text with a built-in refinement-abstraction mechanism. The OPM syntax specifies consistent ways by which entities can be connected via structural and procedural links, such that each legal entity-link entity combination bears specific, unambiguous semantics. Importantly it provides options for adding user text to define unidirectional and bidirectional between objects or processes. The OPCAT platform supports model repository, reuse engineering, simulation and validation of the model, and automatic document generation and management. Figure 4 illustrates application of the OPCAT in this truck industry problem.

5 A Comparison of PSS Modeling Environments

Table 2 compares the three platforms detailed in the previous section. This comparison indicates that operand, operator and the relationship definitions vary largely within the PSS domain itself. In order to avoid these problems with semantics it could be more fitting to use simple and precise terminologies as used in OPCAT™ or to develop PSS ontology which should be commonly accepted

Table 2 Comparison of three platforms under consideration

Aspects	ISCL	Service explorer	OPCAT^{TM}
Operand	Specification and entities	Receiver state, content, channel parameters	Object and state
Operator	Activity	Service channel	Process
Relationship	Conditions and consequences	Four sub-models	Arrows—structural and procedural links
Representation	No formal visualization	BPML, blueprint	OPM
Application domains	PSS	PSS	System description/Simulation
Evaluation tool	Discrete event simulation	QFD, AHP, dematel, petri nets	Life span graph, time limits, GUI presentation with animation

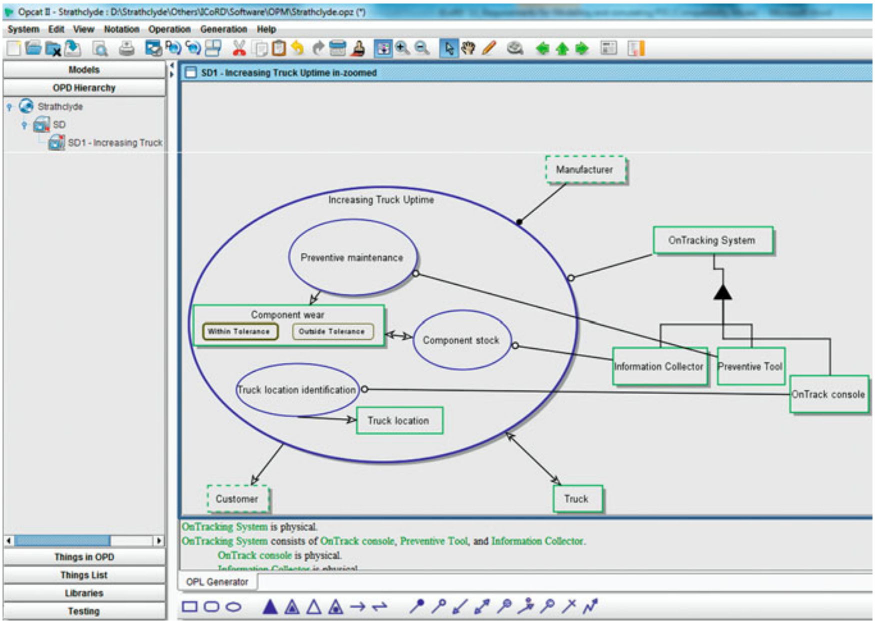


Fig. 4 The modeling environment of the OPCAT^{TM} platform

within academics and practitioners. Even though all three platforms provide a rigid structure for defining the elements within a system, OPCAT^{TM} facilitates users to define relationships between objects or processes. Information cognition loading for designers is suitably handled in the OPCAT^{TM} platform which is facilitated by in-zooming, unfolding and state expressing features which aid to limit defining 3–6 processes in each SD. Also, the system representation which is expressed bi-modally in equivalent graphics and text facilitates comprehension and

Table 3 Requirements for computer-aided PSS modeling and simulation

Modeling requirements	ISCL	Service explorer	OPCAT™
Multiple views of the PSS design	Available with only single view point	Available with only single view point	Multiple views which specify different aspects of the system
Illustration of the 'need behind the need' of the customer	Links between the goals are not described	State change of the customer is described with RSP	Illustrated through overall functional need
Responsibility sharing and Preferences of the stakeholders	Could be mapped through conditions specification	Scope model aids these descriptions	Procedural links could define these parameters
Several PSS designs configurations	Each configuration should be individually modeled	Each configuration should be individually modeled	Each configuration should be individually modeled
Mapping of PSS design functions and processes	Goals, activities, parameters and scenes are structured	RSP, CoP, ChP, activities are mapped	Objects, processes and states are structured
Co-production process	Single user platform	Single user platform	Single user platform
Assistance to designer to generate PSS design	Assist in syntax checking	Service case base could be used	Assist in syntax checking
Activity precedence and sequences (sequential, concurrent, coupled or conditional)	Issues with sequential, and coupled representation	BPMN supports these processes	Issues with sequential, and coupled representation
Consistent notation and common interpretation	Common interpretation could be an issue	Common interpretation could be an issue	Graphics and text based support common interpretation
Representation of differences between the current and the designed system	Need to be compared separately	Need to be compared separately	Supports comparison through multiple frames
Simple, flexible and easy to maintain	Becomes complex with more elements	Becomes complex with more elements	Handles complexity with in-zooming
Redundancy and inefficiency identification	Not supported	Not supported	Provides checking mechanism
Predictability of PSS design outcomes	Predictability not guaranteed	Predictability not guaranteed	Predictability not guaranteed
Change impact analysis and risk analysis	Simulates through discrete event simulation	Simulates through Petri Nets	Simulates through life span graph

(continued)

Table 3 (continued)

Modeling requirements	ISCL	Service explorer	OPCAT™
Iteration loop for PSS design optimization	Not supported	Not supported	Not supported
Integrated quantitative and qualitative analysis	Qualitative need to be supported	Qualitative need to be supported	Qualitative need to be supported
Product and service improvements	Not supported	Not supported	Not supported

interpretation between the stakeholders. With regards to ISCL, this provides a very useful feature in linking discrete event simulation to evaluate each PSS design.

A detailed list of requirements for computer-aided PSS modeling and simulation is enumerated based on the application of a truck industry problem to the three software platforms, our understanding of PSS design methodology [9], the proposed representation structure (Fig. 1) and a thorough review of PSS literature. Table 3 reveals that the computer-aided platforms, to assist designers in developing PSS, could be improved with the following features: multiple views of the PSS design, PSS design configurations, the co-production process, activity precedence and sequences, gap analysis, complexity management, redundancy and inefficiency identification, predictability of PSS design outcomes, an iterative loop for PSS design optimization, support for qualitative analysis.

6 Conclusion

The analysis of three software platforms (ISCL, Service Explorer and OPCAT™) by their application to a truck industry issue has revealed the scope of these platforms; these findings are used as the basis for the overall requirements which have been proposed for a software platform which aids the modeling and simulation of PSS. A list of the improvements which are required has been analyzed and presented. Although this list could be added to by other researchers in the field, even in this initial form, it still provides a current benchmark against which future PSS software platforms can be evaluated. Furthermore, PSS design configurations and the predictability of PSS design outcomes are issues which require particular attention.

Acknowledgments The authors would like to express their gratitude to Professor Dov Dori, Professor Yoshiki Shimomura and Dr. Hitoshi Komoto for providing access to the software referenced within this paper.

References

1. Meier H, Roy R, Seliger G (2010) Industrial product–service systems–IPS2. CIRP Ann Manuf Technol 59(2):607–627
2. Goedkoop M et al (1999) Product service-systems, ecological and economic basics. Report for Dutch Ministries of environment (VROM) and economic affairs (EZ)
3. http://www.rolls-royce.com/civil/services/corporatecare/. Accessed on 17 July 2012
4. Neely A (2008) Exploring the financial consequences of the servitization of manufacturing. Oper Manage Res 1:103–118
5. Annamalai GV et al (2011) A review of product–service systems design methodologies. J Eng Des. doi:10.1080/09544828.2011.639712
6. Komoto H, Tomiyama T (2008) Integration of a service CAD and a life cycle simulator. CIRP Ann Manuf Technol 57(1):9–12
7. Sakao T et al (2009) Modeling design objects in CAD system for service/product engineering. Comput Aided Des 41:197–213
8. Dori D et al (2008) From conceptual models to schemata: an object-process-based data warehouse construction method. Inf Syst 33(6):567–593
9. Vasantha A, Vijaykumar G et al (2011) A framework for designing product-service systems. International conference on engineering design '11, Denmark
10. Hussain R et al (2012) A framework to inform PSS conceptual design by using system-in-use data. Comput Ind 63:319–327
11. Durugbo C, Tiwari A, Alcock JR (2010) A review of information flow diagrammatic models for product–service systems. Int J Adv Manuf Technol 52(9–12):1193–1208
12. Becker J et al (2010) The challenge of conceptual modeling for product–service systems: status-quo and perspectives for reference models and modeling languages. IseB 8(1):33–66
13. Tomiyama T (2001) Service engineering to intensify service contents in product life cycles. Second international symposium on environmentally conscious design and inverse manufacturing. IEEE Computer Society, Tokyo, pp 613–618

Designers' Perception on Information Processes

Gokula Annamalai Vasantha and Amaresh Chakrabarti

Abstract Understanding information needs and managing organizational information resources are vital to face competitive globalized industrial environment. Support development to aid these processes is often failed in real-time environments due to lack of in-depth awareness about organizational interactions. In this paper a systematic approach to understand the information processes and information sources available in an aerospace organization was studied through a questionnaire survey. The analysis reveals that designers perceive that they get the right information at the right time in only 4 or more out of 10 for most of the times. Also they are unable to differentiate among the types of interactions they perform during their daily activities, due to which the information processes occurring within the interactions are not perceptible to them. This perception illustrates there is substantial need for the development of support to create awareness and satisfy the information needs of designers.

Keywords Information processes · Resources · Questionnaire

1 Introduction

Presently organizations are heavily pressurized to develop products which should be novel and useful in order to meet customers' demands and wishes. There are various barriers which influence the companies from achieving these targets,

G. A. Vasantha (✉)
Design Manufacture and Engineering Management, University of Strathclyde, Glasgow, UK
e-mail: gokula.annamalai-vasantha@strath.ac.uk

A. Chakrabarti
Center for Product Design and Manufacturing, Indian Institute of Science, Bangalore, India
e-mail: ac123@cpdm.iisc.ernet.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_62,

notably the increasing attrition rate of employees and the increasing amount of time spent by employees in information acquisition and dissemination. In this globalizing era, information has been seen as the foremost resource in an organization. It has been argued that in order to maximize business-specific working information, all sources and forms of organizational information have to come into play [1]. Information will be potentially utilized, if it is properly managed. Managing information will potentially retain the competence held by the organization if information generated across its projects and units is captured, structured and reused. It is noted that capture, storage, transfer and exploitation of information play a critical role throughout the information cycle and the cost of not retrieving information is indeed high [2].

Besides retaining competence of an organization, information capture and reuse practises will be substantially helpful in communication between agents, in understanding design, in training novices and in avoiding repetition. It could also help satisfy information requirements of designers at the right time and in the right format. Various tools are proposed in the literature to support information needs of the designers but the acceptance rate is low. These may be due to 'technology push' from vendors without adequate understanding of the unique nature of the information processes that each organization possesses. These issues, especially those related to understanding of the information processes of organizations are need to be understand in the industrial context.

Since studies involving organizational environment are time- and effort-consuming activity and also its outcomes substantially impact the information management strategy of the organization and technology to be developed to support information processes, it is necessary to define precisely and clearly the objectives of the study. There is little practical guidance on defining the scope of this study considering the complexity and scale of the undertaking, and how to tailor it to individual circumstances and goals [3]. In this paper, a systematic approach for conducting informational study in an aerospace organization is detailed through a questionnaire survey along with earlier results obtained through personal observation method.

2 Related Literature

In their pioneering work on identifying information needs, Kuffner and Ullman [4] define design history as a representation of the evolution of a product from its initial specifications. They argue that in order to develop a usable design history, it is necessary to determine the types of information needed by designers when they attempt to understand a design. The two most significant findings from this work are: 51 % of the questions and conjectures were about old topics, and a high percentage of questions and conjectures were about the construction of features and components. Khadilkar and Stauffer [5] have shown that, for generating new product concepts using information from previous design effort, the designers used both conceptual and detail level information almost in equal proportions. Also, the number of queries about product construction and description accounted for almost half of the total queries, and the subject-class 'component level' received 43 % of the queries.

Information requirements of designers as found from existing literature [4, 6] are summarized as follows: test or analysis data, explanation of structure and function information, feature, location, operation of components, purpose of assemblies of components, customer preferences, cost, projected sales, projected manufacturing runs, maintenance constraints, materials, processes, tools, standards, patents, cultural trends, competition details, terminology, values, contacts and market information. Aurisicchio [7] investigates the nature of requests formed by designers during design processes and their associated searches. The categories found in the information 'request' group are: *objective, subject, response process, response type, directions of reasoning, and behavior type*. The main findings are the following: in the total number of requests recorded, in the group of *response process* the percentage of *retrieval-recognition* (finding and returning information) (50 %) is higher than *reasoning* (making an inference) (30 %) and *deliberation* (following paths of inference and weighing arguments) (20 %); and 70 % of the requests were sourced through interactions with colleagues.

Marsh [8] observes that the majority of the information is obtained from personal contacts rather than formal sources. Also he noted that designers spend on average 24 % of their time in information acquisition and dissemination. Crabtree et al. [9] point out that project delays are mainly due to time spent in information acquisition and information access. The associated delays range from a single day to a year. MacGregor et al. [10] observe that engineers use company systems and colleagues in the same office to get information, and engineers perceive that 34 % of their time is taken in sourcing and locating relevant information. The amount of time spent for these processes is substantially high, and need to be reduced. Capture and retrieval could play a significant role in reducing designers' time spent in information acquisition and dissemination.

Even though many results have been produced in the literature, the approaches used, number of subjects studied, subjects' background, organizational context, projects involved and its design stages and location lead to prevent developing a unified methodology for informational study and transferring results from an organization to another. Also, the number of research papers published in informational study (from engineering design context) from India is almost none. To fill this gap, this paper aims to study the nature of information processes and resources in an aerospace organization in India.

3 Research Questions and Approach

This study was conducted in a research and development organization focused primarily on design and development of special purpose aircraft. It is a thirty years old company with around 240 employees in a centre studied in this work. The designation of these employees is noted with scientist grades from ‘A’–‘H’ (highest grade) and early starters with ‘Research Fellow’. In order to understand the information processes and sources, personal observation method was initially planned. Framing and using research methods in an organization set-up is challenging and time consuming. Even though personal observation method provides in-depth information in real-time situations for this research, it has been heavily restricted by the organization concerned, and obtained little cooperation from its designers. The study has been limited to seven designers instead of the 18 designers originally planned. In order to understand the perspectives of other designers and to further validate the results obtained from the personal observations of seven designers, a questionnaire has been developed. The detailed results obtained from personal observation are presented in [11]. This questionnaire survey was carried out in the organization to validate the results obtained from the seven designers who were observed through the personal observation method. The questionnaire is developed in order to understand the perception, of a broader group of designers, about the following:

- The types, processes and characteristics of information handled by the designers,
- Types of documents and their characteristics handled by the designers and
- Interactions carried out by the designers leading to information activities and their characteristics.

The questionnaire also provides insights into some of the issues such as importance and satisfaction of purpose of the interactions, reasons for not using the documents, and usage and usability of the software, which cannot be observed from the personal observations. Since the usage of the term ‘knowledge’ annoyed the designers in the organization, we used the term ‘information’ throughout the questionnaire. Since this questionnaire is a successor to the observations made in the organization for one and half years, the types of information for this questionnaire were chosen based on the observation results and also the subjects are given the option to fill in any other information which they felt is missing in the questionnaire. The designers taking part in the actual survey were informed that the questionnaire takes about 30 min to complete.

Out of the 39 circulated, 21 filled questionnaires were returned. The response rate is 54 %. The response rate is high due to continuous push from the researcher and due to the adoption of various methods to improve response rate, such as sitting with the subjects, filling the response by the researcher while asking the questions to the subjects, as well as allowing subjects to fill the questionnaire alone. In this survey, the subjects left the columns unfilled if they thought these were inapplicable to their work. The number of years of experience of the subjects participated range from 1 to 23 years. The average number of years of experience is 12. The subjects are widely involved in original, adaptive and variant designs. Also, the subjects together cover various stages in the product development starting from conceptual to testing phases. In the analysis, the unfilled columns are separated in the name of ‘not answered’. Subsequent sections elaborate results and analyzes obtained from the data collected through the questionnaire, and comparison of these results with the results obtained through personal observations.

4 Results

The results from analyzing the returned questionnaires are discussed in this section.

4.1 Types of Information Versus Information Processes

Figures 1, 2 show that the subjects agree about the importance of capturing and reusing all types of information. For capture, the least perceived importance are for cost of the product, and for installation, maintenance and service data. Frequency analysis reveals that information about behavior/operation, requirements, dimensions and performance of the product are the most frequently captured, while that for function, structure, materials, cost, assembly and, installation, maintenance and service data are the least frequently captured. Personal observations had revealed that property, component, feature, value and method were considerably needed by the designers. These results clearly show that there is mismatch between the information required and information captured by the designers.

The correlation coefficient between what is important for capture and reuse is moderate (0.58, $p < 0.01$). Some of the least preferred information for reuse are behavior/operation and cost of the product. Information about function/purpose, structure, components, assembly and performance of the product lead in the frequency of reuse. The correlation between the frequency of capture and reuse is very poor (0.19). Substantial support needs to be given in order to increase this

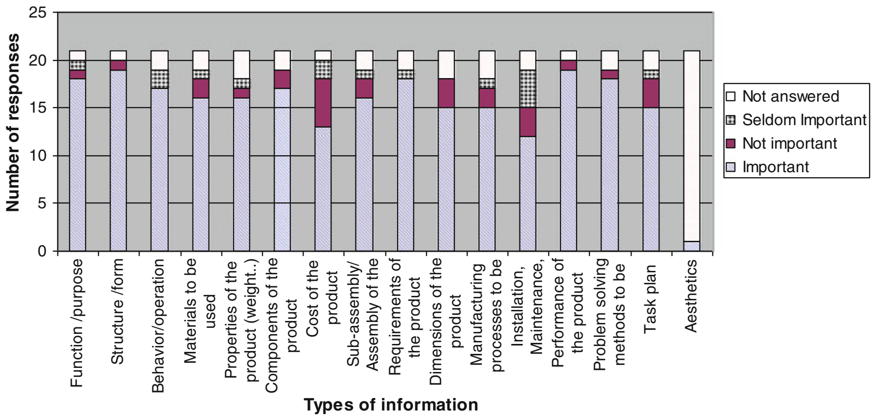


Fig. 1 Importance of capturing various types of information

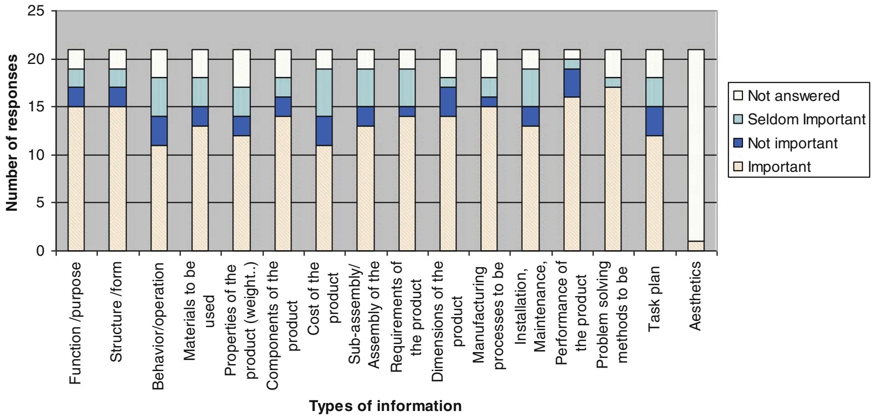


Fig. 2 Importance of reusing various types of information

coefficient of correlation; for instance, the designers' perception towards capture and reuse of information has to be changed. This is in line with the personal observations where on average only 10 % of the questions asked by designers are answered in the documents. Compared to the variation observed in personal observations for information needs, the replies in the questionnaire reveals that the designers perceive all types of information as important.

4.2 Interactions Versus Information Processes

The subjects perceived it important to interact with people having scientist grades for generating and sharing information. Even interactions with research fellows and contract employee are highly rated. Frequency of interaction with scientist grade equal to 'D' or below is highly rated for both generation and sharing of information. Communication mechanism is mostly mixed (verbal and written), for Scientists having above or below grade 'D' designation, within their project as well as outside the project. In contrast, interactions with research fellows and contract employees are mostly verbal. The written communications are very few in number for information generation and sharing, in all the designations. The frequency of written communication is higher with other directorates and communications outside the organization. Even though designers perceived that oral and written communications are mixed equally in the interactions, the personal observations reveal that oral communication dominates in various interactions among designers with all designations.

The subjects rated interactions within their group and directorate as important and frequent for both their project and for other projects, for generating and sharing information in the organization. This result is in line with the personal observations where most interactions occurred within the group and directorate.

4.3 Types of Interactions Versus Information Processes

Figures 3, 4 and 5 show that subjects rated all types of interactions except a few as important and frequent for information generation and sharing. The interaction 'One + Computer + Document' should be read as: 'designers interacting with computer and document'. The few interactions excluded are online chat, documents through post and video conferencing. The correlation between the importance and frequency of interactions for generating information is high (0.9, $p < 0.01$). The correlation between the importance and frequency of interactions for sharing information is very high (0.97, $p < 0.01$). These results are contradictory to the personal observations in which only interactions 'designer working with computer' and 'two designers working with a computer' frequently occurred. This possibly indicates that designers are unable to differentiate among the types of interactions they perform during their daily activities, due to which the information processes occurring within the interactions are not perceptible to them.

4.4 Time Consumed Versus Types of Interaction

The main interactions in which designers spend more than one hour in each day for generating information are 'alone', 'designer with a document', 'designer with a computer', and 'designer with a computer and document'. This result is in line with the personal observations, where 'designer working with computer' and 'two designers working with a computer' occupied most of the time during designing. The major interactions in which less than an hour is spent for sharing information are: 'designer interacting with another', 'designer interacting with another and notebook or documents', 'designer interacting with another in front of computer and/or document', and, meetings. This result is also in line with the personal observations, in which 'designer interacting with another' and 'designer interacting with another in front of computer' occupied most of the time for sharing

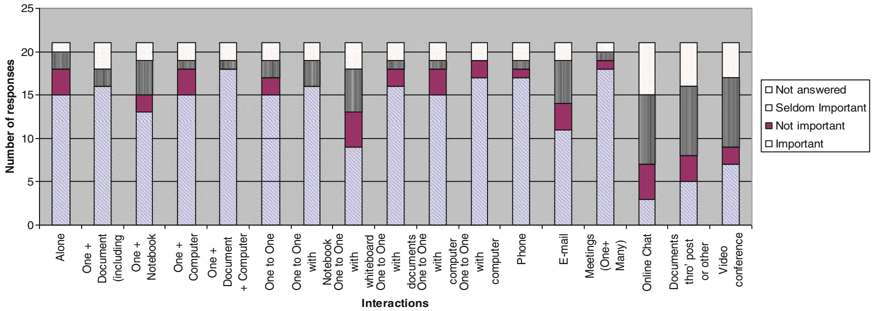


Fig. 3 Importance of types of interactions for generating information

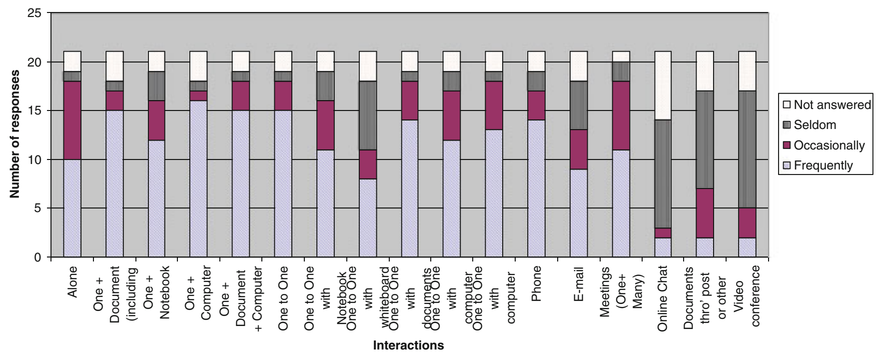


Fig. 4 Frequency of types of interactions for generating information

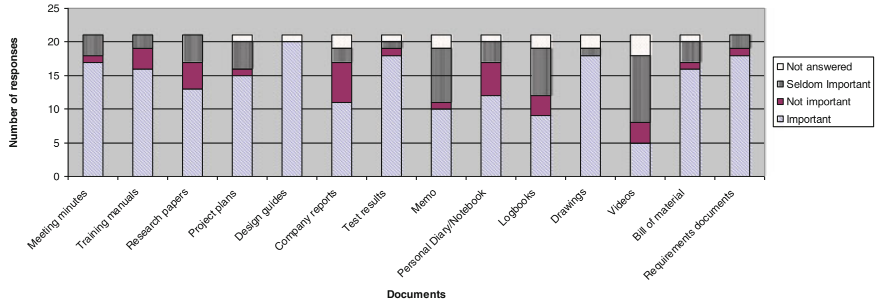


Fig. 5 Importance of capturing information in various documents

information. Even though designers perceive that they spend more than an hour alone, the personal observations reveal that the interaction 'alone' is rarely performed by the designers.

The subjects perceive that the interactions which mostly satisfy the purpose for generating information are 'designer interacting with a computer and/or document' and 'designer interacting another'. It is noted that the all collaborative (i.e. designer interacting with another or many, and with or without tools) interactions are rated less satisfactory, especially meetings. The interactions which most satisfy the purpose for sharing information are 'designer interacting with another including or excluding notebook'. It is interesting to observe that designers' perceive all the interactions as important, with differing levels of satisfaction. This shows that each interaction has its own purpose and one interaction may not be able to replace or override another, even though satisfaction through that type of interaction is less than through another.

4.5 Capturing and Searching Information Versus Types of Interaction

The subjects are conscious about and give importance to capturing information, in all types of interactions. This shows that designers are aware of the various interactions for capturing information. The interactions 'designer interacting with computer and/or document' and 'designer interacting with another in front of computer and/or document' dominate the time for capturing information. The interactions frequently used for capturing information are 'designer interacting with notebook and/or computer and/or document'. Even though designers' perceive that they capture information frequently, the personal observations reveal designers only occasionally capture information in their daily activities.

The subjects rated that they spent considerable amounts of time in each interaction per day for searching information, and most of the interactions are rated as important for finding required information. The interactions 'designer interacting with computer' and 'designer interacting with internet' are used frequently to obtain required information. This is in line with the personal observations where the interaction 'designer interacting with a computer' dominates in searching for information. It is curious to observe that designers prefer to use external media (Internet) to search for required information rather than internal systems and documents.

The subjects rated the capturing information as frequently used for understanding design, communicating with others, for design of similar products, and aiding in redesign. It has been rated low for training novices and for repeatability avoidance.

4.6 Capturing and Reusing Information Versus Documents

Figure 5 shows that the subjects rated all the documents as important to capture except videos and memos. The documents frequently generated are design guides, test results, drawings, bill of materials and requirements document. The documents most seldom generated are logbooks and videos. The correlation between importance and frequency of capturing information is high (0.84, $p < 0.01$). The subjects required between 1 to 5 days for preparing most of the documents. More than 5 days are required for training manuals and research papers. These results indicate that designers are aware of the importance of capturing information in various documents.

Documents that are rated as important for reuse are design guides, project plans, test results, drawings, requirements documents, bill of materials, books, standards and data handbooks. Important reused documents are frequently reused. The correlation between importance of capturing and reusing documents is high (0.84, $p < 0.01$). The correlation between frequency of capturing and reusing documents is also high (0.90, $p < 0.01$). This presents a good trend of capturing and reusing of documents. Figure 6 shows that all the documents could be searched within one hour. But time spent for searching being less than a day is considerable for the following documents: meeting minutes, training manuals, memos and drawings. Also, time spent for searching being less than a week is considerable for the following documents: research papers, test results, drawings, company reports and design guidelines. These results show that considerable attention has to be given to identify the reason for taking more time to find relevant documents.

Personal diary or notebook is mainly available with the designers themselves. It has been rated that most of the documents are available within the respondents' group or directorate. This could be interpreted as: designers primarily look for information within their group and directorate. Even though designers perceive that documents which are not available are negligible, considerable thought has to be given on the validity of this perception. The documents considerably rated and not available are design guidelines, personnel diary and videos. Among these documents, particular attention should be given to design guidelines. The documents which are rated as considerably difficult to access are training manuals, research papers, project plans, company reports, logbook, videos and standards.

The subjects rated indexing mechanisms of most of the documents as good. Research papers are rated as badly indexed. Some of the documents which are mentioned as seldom indexed are test results, logbook, videos, catalogs and requirements documents. Subjects' rated that the accuracy of most of the documents as high. The documents in which accuracy is substantially low are project plans and company reports. The subjects rated the recency of most of the documents as high. The documents in which recency is substantially low are training manuals, company reports, logbooks, videos and bill of materials. The subjects rated the clarity of most of the documents as high. The documents in which clarity is substantially low are meeting minutes, project plans, company reports and logbooks. The subjects rated the completeness of most of the documents as high. The documents in which completeness is substantially low are meeting minutes, training manuals, test results, logbooks and bill of materials.

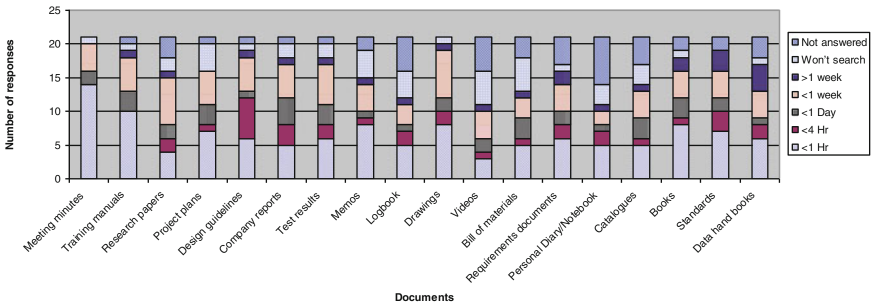


Fig. 6 Amount of time spent for searching various documents

4.7 Behavior of the Designers

The subjects tend to frequently search for more information if required information for taking decision is not available. This behavior would prolong the amount of time spent by subjects on information acquisition and shows that designers do not want to compromise on the required information. The subjects perceived that they get the right information at the right time in 4 or more out of 10 for most of the times. This perception illustrates that there is substantial need for development of support to satisfy the information needs of the subjects. The designers perceive the impact of required information on all important design criteria as very high.

5 Discussion and Conclusions

The primary outcome illustrated through the results discussed in the last section is that triangulation of results is foremost important in the informational studies. Using personal observation and questionnaire methods demonstrate that usage of methods to collect data influence the results generated. Even though personal observation method is time- and effort-consuming and also heavily restricted in the organizational environment, it provides realistic understanding and occurrences of information processes which could leads to develop enhanced information management strategies. The questionnaire brings out the perception of designers which is unrealistic in many results but also needs to take into account while formulating and developing support for information processes. This study provides the current organizational status on information processes. The questionnaire approach presented in this paper could be used by other organization to understand their processes and benchmark with reference to other industries. The core recommendation for the organization involved in this study is that substantial effort should be spend to bring interaction as the core in the information processes so that capture and reuse can be significantly improved. Each interaction has its own purpose and one interaction may not be able to replace or override another, even though satisfaction through that type of interaction is less than through another. The results highlight that the core question to be answered to enrich information processes is 'how to minimize mismatch between information needs, capture and reuse'. Currently substantial amount of time have been invested in capturing processes due to standards regulation rather than understanding reuse value of captured content. Awareness of available resources within the organization and easy retrieval of well-structured resources are necessary to improve poor ratio of 40 % to get right information at the right time.

References

1. Handzic M, Hasan H (2003) The search for an integrated KM framework. In: Handzic M, Hasan H (eds) Australian studies in knowledge management. UOW Press, Wollongong, pp 3–34
2. Gantz JF (2012) Expanding digital universe: a forecast of worldwide information growth through 2010. IDC white paper. Available at: http://www.emc.com/collateral/analyst-reports/expanding-digital-idc-white-paper.pdf. Accessed on 09/07/2012
3. Buchanan S, Gibb F (2007) The information audit: role and scope. Int J Inf Manage 27:159–172
4. Kuffner TA, Ullman DG (1991) The information requests of mechanical design engineers. Des Stud 12(1)
5. Khadilkar D, Stauffer L (1995) Evaluating the reuse of design information: an experimental case study. In: Proceedings of ICED '95, vol 2, pp 484–489
6. Ahmed S (2001) Understanding the use and reuse of experience in engineering design. PhD Dissertation, Cambridge University
7. Aurisicchio M (2005) Characterising information acquisition in engineering design. Ph.D. thesis, Cambridge University
8. Marsh JR (1997) The capture and utilisation of experience in engineering design. Ph.D. thesis, Department of Engineering, University of Cambridge
9. Crabtree RA et al (1997) Case studies of coordination activities and problems in collaborative design. Res Eng Design 9(2):70–84
10. MacGregor SP, Thomson AI, Juster NP (2001) Information sharing within a distributed collaborative design process: a case study. In: Proceedings of international design engineering technical conferences (DETC)
11. Annamalai Vasantha GV, Chakrabarti A (2011) Understanding collaborative activities for knowledge processes in Indian industry. In: MacGregor SP, Carleton T (eds) Sustaining innovation: collaboration models for a complex world. Part of the Innovation, technology and knowledge management series, Springer

Assessing the Performance of Product Development Processes in a Multi-Project Environment in SME

Katharina G. M. Kirner and Udo Lindemann

Abstract Competiveness of small and middle-sized enterprises (SME) correlates with recognizing customer needs and being able to efficiently react to it. At the same time, SME face a limitation of their resources. Therefore, it is crucial to monitor the strength of product variety management (PVM) and its impact on the performance product development processes (PDP) in a multi-project environment. This paper aims at creating the means for SME to gain awareness of the interrelations of PVM and PDP. The latter are described using a dependency model, which has been derived from literature and empirical data gathered in case studies with six SME. The model serves as basis of a self-assessment-tool for SME to support the identification of the need to improve their PDP and the prioritization of improvement methods.

Keywords Small and middle-sized enterprises · Product variety · Product development process performance

1 Introduction

Small and middle-sized enterprises (SME) need to recognize and react to customer needs efficiently to maintain their competitiveness. This results in a high number of subsequent and overlapping product development projects—i.e. a multi-project

K. G. M. Kirner (✉) · U. Lindemann
Institute of Product Development, Technische Universität München,
Boltzmannstrasse 15, 85748 Garching, Germany
e-mail: katharina.kirner@pe.mw.tum.de

U. Lindemann
e-mail: udo.lindemann@pe.mw.tum.de

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_63,

environment. Thus, their business and product strategy regarding the necessary product variety should be aligned with the available resources. This is often not the case, due to a lack of attention for marketing and financial planning.

It is important for a company to determine the appropriate level of variety, in order to maintain its position in the market and to be able to compensate for the increasing operational effort induced by additional product variants.

Consequently, it is crucial to monitor the strength of product variety management (PVM) and its impact on the performance product development processes (PDP) in a multi-project environment. Literature in this area focuses on the impact of product architectures either on PDP, e.g. the composition of design teams [1], or on downstream processes, e.g. supply chain management [2]. Neither the specific circumstances of SME nor a multi-project environment are taken into account sufficiently.

This paper aims at creating the means for SME to gain awareness of the interlinked performance of PVM and PDP. Therefore, it elaborates on how to monitor the impact of PVM on the performance of PDP in order to identify and prioritize the need to improve PDP. With the aim to enable SME to assess the performance of PDP in regard of PVM self-reliantly, the dependency between PDP and PVM will be described and serve as a basis for a self-assessment-tool (SAT) to monitor the performance of PDP in regard of PVM.

1.1 Related Work

SME play an important role in the market, but there are disadvantages they have to face. Not only are their resources limited, but also their environment is rather uncertain [3], as markets and customer wishes are rapidly changing. To maintain or improve their competitive market position, the strategy of a SME needs to be planned carefully. Thus, business and product strategy regarding customer wishes and necessary product variety should be aligned with the available resources. But in reality, the strategy is often not planned, as resources are scarce and e.g. no staff position for strategy planning can be afforded [4]. This is also emphasized by Vossen [5] who describes the lack of attention for marketing and financial planning and Schmidt-Kretschmer et al. [6] who criticize the lack of a holistic approach of requirements management.

Da Silveira [7] emphasizes the strategic importance of product variety, which faces the two aspects of meeting market requirements and maintain an operational performance in regards to manufacturing processes and supply chain management. Thus, he adds that product and part variety should be managed with adaptive and flexibility strategies. The impact of product variety on manufacturing and supply chains [2] is mentioned by several authors.

Although there is research on the interdependencies between product architectures—as an important aspect in PVM—and organisational structures, i.e. product development processes, they only focus on the linkage of process and product

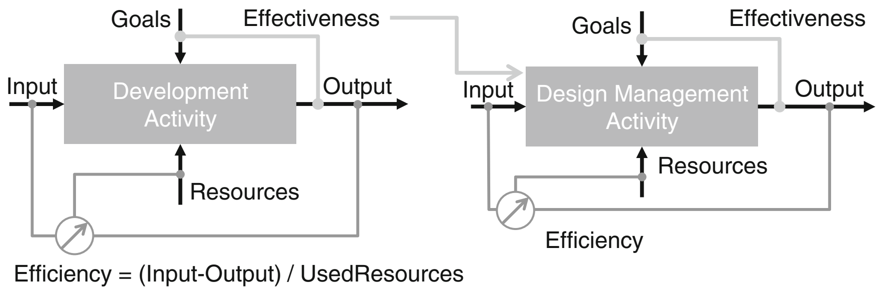


Fig. 1 Model of design performance according to [10]

component networks with a scope of single projects (e.g. [1]). The identification of mismatches between product architecture and organizational structure moreover serves as means to examine the impact of a coordination deficit in product quality [8] of singular projects. Moreover, although the impact of the strategy of PVM on manufacturing and the supply chain has been well researched, the impact of the strategy on the design productivity—for example whether a modular architecture is feasible in certain circumstances—lacks attention in literature [9].

Many authors have contributed to the assessment of performance in product development. Within this paper the model of the performance of product development created by O'Donnel and Duffy [10] serves as a basis for the assessment of the impact of PVM on the performance of PDPs. O'Donnel and Duffy [10] describe design performance using the terms efficiency and effectiveness of development and design management activities (see Fig. 1). The former stand for the concretisation of the product, while design management activities represent tasks, e.g. related to project management, necessary to coordinate the development activities. Within the model by O'Donnel and Duffy [10] efficiency is assessed by comparing the amount of knowledge gained within development activity—by comparing the input and output knowledge—and the used resources. Thus, an activity can only be effective if enough knowledge could be created, while an appropriate amount of resources has been used. Effectiveness is reached if the output of knowledge fulfills the goals that have been set for an activity. The effectiveness of development activities serves as input data for conducting design management activities, as within those development activities are coordinated. An overall efficiency and effectiveness can only be reached if it is strived for a high performance in both types of activities.

Although there is much research on process performance, only few authors have contributed to the question of how the strategy of product variety impacts the performance of the development process.

Lean Development (LD) focuses on the efficiency of processes and its main directive is value orientation [11–13]. The definition of value is essential in order to be able to guide improvement processes [12]. Processes are improved by eliminating waste—i.e. unnecessary activities or time loss—and thus shortening cycle time of process steps and the lead time of the overall process [12]. Methods—so called lean enablers—are used to eliminate waste [14] and structured along the lean principles of value, value stream, flow, pull and perfection [11]. According to Oehmen and Rebentisch [14] different categories of waste (waste sources) are highly linked, impact each other and cause other wastes. Thus, waste sources cause other waste symptoms. In order to successfully eliminate the waste, it is important to identify their root causes [15] and apply the lean tools to them.

Within this research the Lean concept of waste is interpreted using the design performance model by O'Donnell and Duffy [10]. On the one hand waste is understood as a lack in efficiency, i.e. too many resources are consumed during a development activity. Thus, Lean tools are used to identify and analyze inefficiency and ineffectiveness in PDPs. On the other hand waste is understood as a lack in effectiveness, i.e. that the goals for development and design management activities cannot be met due to an insufficient PVM strategy. This equals with the interpretation of value as effectiveness, i.e. setting and reaching the right goals.

Thus, the interrelation between PVM and PDP are described using the concept of symptoms of inefficiency and ineffectiveness and their causes. In order to optimize the interrelations between PVM and PDP—i.e. avoiding the occurrence of symptoms—the causes of inefficiency and ineffectiveness need to be eliminated.

1.2 Implications from Related Work

PVM is well researched, as an abundance of approaches exists as product platforms, different approaches of modularity, product families or customized products. But investigations on how PVM impacts on the development processes are scarce. Literature on the alignment of product architectures and PDPs does not take into account a multi-project environment in SME, and only focus the impact of product architectures on PDPs in single projects and the influence of the latter on product quality. They do not take into account PVM or a multi-project environment. Thus an understanding the interrelations of PVM and PDPs in a multi-project environment needs to be gained. Moreover, the means to assess the performance of both PVM and PDPs in a multi-project environment have to be developed, in order to enable the identification of the improvement of, taking into account the limited resources of SME. These gaps are addressed by in the subsequent sections, as the interrelations between PDP and PVM are be described and a self-assessment-tool (SAT) to monitor the performance of PDP in regard of PVM is presented.

1.3 Research Methodology

The paper describes the interrelations between specific symptoms and causes of inefficiency and ineffectiveness. These specific factors and their interrelations have been gathered by literature review [16], a web-based survey [17] on the understanding of the interrelations of methods to enhance value and waste causes in PDP, and from the results of distinct case studies in six SME [18]. Within these case studies the companies' performance PDP in a multi-project environment in the companies has been analyzed by examining existing documentation, and conducting interviews and workshops with representatives of different hierarchical levels in the enterprise. Thereby, the impact of PVM on the performance of PDP has been investigated in these companies. Based on the analyzes results criteria have been deduced to describe the interrelations between PVM and PDP in the form of a dependency model of symptoms as well as causes of inefficiency and ineffectiveness. These criteria have been incorporated to a procedure to identify symptoms of inefficiency and ineffectiveness in a specific company using a set of deductive questions. A set of inductive questions based to the interrelations between the symptoms and causes of inefficiency and ineffectiveness serves for the identification of the causes in a specific company. This served as basis to develop a self-assessment-tool (SAT) for SME, to facilitate the identification and prioritization of the need to change. By applying the SAT the user is suggested a sequence of steps to improve the performance of PDP in a multi-project environment. The SAT has been evaluated by industrial application.

2 Interrelation of PVM and Product Development Processes

Based on literature review, the results of a web-based survey [17] and empirical data from six case studies [18] a dependency model of criteria has been deduced describing the interrelations between PVM and PDP. The dependency model has been created using matrix-based methodologies as the design structure matrices (DSM) and domain mapping matrices (DMM), which can be depicted in a multiple-domain matrix (MDM) [19]. The dependency model consists of three MDMs—one based on the findings from literature, one based on the results of the survey and one based on the case studies (the latter is shown in Fig. 2). Each of the MDMs contains a set of symptoms of inefficiency and ineffectiveness in the PDP and a set of corresponding causes due to PVM. In a MDM the interrelations between symptoms and causes are modeled in a DMM (dark gray shaded part of Fig. 2, a dependency is indicated if a cause induces a symptom in one of the categories) and interrelations between several causes in an additional DSM (a dependency is modeled if one cause occurred with another cause in at least three of the six companies).

As depicted in Fig. 2, the part of the dependency model, which has been deduced from the six case studies, comprises the following categories of causes of inefficiency and in effectiveness: goals, processes, information flow, documentation, employees and tools. Figure 2 indicates specific causes within each category. The causes induce symptoms of inefficiency and ineffectiveness in the following categories:

	Causes																			Symptoms					
	Planning of strategies and priorities - company perspective	Elicitation of requirements and definition of goals and priorities - project	Lack in use of resources (also competences of employees) and	Lack of process modelling and lack of execution of processes	Lack of process analysis, process monitoring and adaption of processes	Lack of awareness of decisions (responsibilities, criteria, communication	Lack of information flow (execution)	Wrong handling of organisational interfaces	Lack of process standardisation	Lack of project management	lack of modelling of information and artefact flows (Knowledge)	Lack of data management	Lack of documentation	Specialisation of employees in many areas, multitude of tasks	Lack of self-responsibility	Lack of process comprehension and sensivity	Lack of awareness of own responsibilities and tasks	Lack of discipline (not following rules and guidelines such as the process)	Lack of hardware and software tools	Unnecessary Waiting / Delays	Unnecessary Movement	Over-production	Over-processing	Defects	Lack of reuse of existing information
	G1	G2	P1	P2	P3	P4	P5	P6	P7	P8	I1	D1	D2	E1	E2	E3	E4	E5	T1	S1	S2	S3	S4	S5	S6
Causes G1		●			●			●												●		●	●		
G2	●																			●	●	●	●		
P1							●	●					●		●	●		●		●	●				
P2					●		●	●	●				●	●	●		●		●	●	●		●	●	●
P3	●			●			●	●					●		●			●		●	●	●			●
P4																									
P5			●	●	●			●					●						●	●	●			●	
P6	●		●	●	●		●									●		●	●	●	●				
P7				●									●	●			●	●	●	●	●			●	●
P8																				●					
I1																				●					
D1													●					●		●					●
D2			●	●	●		●		●			●			●	●		●	●	●	●				●
E1				●					●							●		●		●	●				●
E2			●	●	●								●			●	●		●	●	●	●			
E3			●					●					●	●	●		●		●	●	●	●			
E4				●					●						●	●			●	●	●				●
E5			●		●			●	●			●	●	●						●	●	●			
T1				●			●	●	●				●		●	●	●			●	●				●

Fig. 2 Dependency model of the interrelations of product variety management (PVM) and product development processes (PDP)—excerpt based on data from case studies [18]

- **S1—Unnecessary Waiting/Delays**—e.g. delays due to a lack of knowledge of project status, task responsibilities or status of documents
- **S2—Unnecessary Movement**—being unable to fulfill planned tasks e.g. in projects due to unplanned tasks in day-to-day business
- **S3—Over-processing**—product oriented, generation of too much detail in documents, the final product, too many or too strict requirements
- **S4—Over-production**—process oriented, executing unnecessary tasks, e.g. process of generating documents that is already exist, unnecessary testing
- **S5—Defects**—defects in drawings, the product etc.
- **S6—Lack of reuse of existing information**—Information existing in a company is not reused

3 Self-Assessment-Tool for SME: Monitoring the Performance of PDP in Regard of PVM

In this section a self-assessment-tool (SAT) is presented (see Fig. 3), which is aimed at enabling SME to gain an understanding of the dependency between PVM and the performance of PDP and to identify and prioritize the need to improve

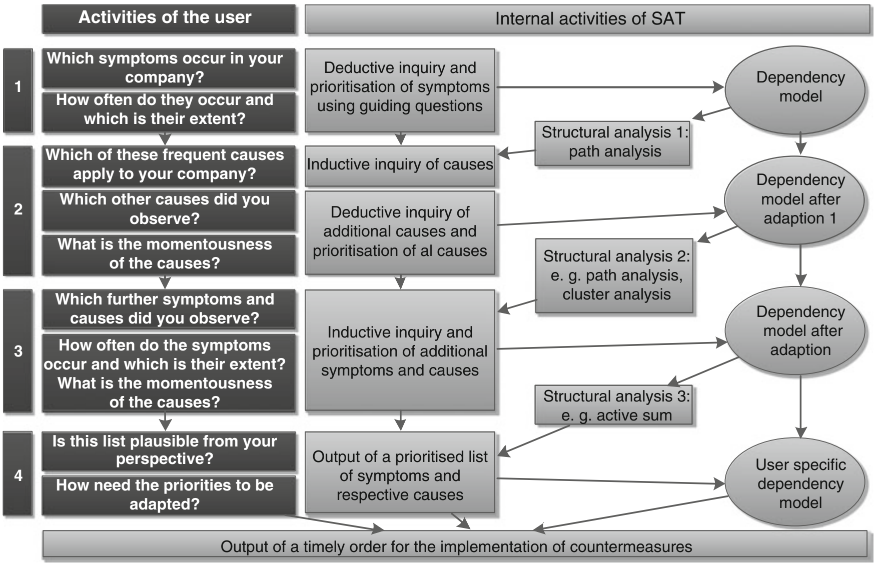


Fig. 3 Application procedure of SAT to monitor the performance of PDP in regard of PVM

specific aspects of PDP. The SAT is based on a comprehensive dependency model of causes and symptoms of inefficiency and ineffectiveness of PDP in regard on PVM in a multi-project environment as described in Sect. 2.

3.1 Applying the SAT

The SAT application procedure is decomposed in four stages as described below. Within these stages the user is iteratively asked to indicate and rate the importance of symptoms as well as causes of inefficiency and ineffectiveness of PDP. This is facilitated by alternating deductive and inductive inquiries that guide the user based on the dependency model. The possibility is maintained to name symptoms and causes that have not been covered in the underlying model up to that point. In order to guide the latter step, the users are asked to indicate a category for the supplementary symptoms and causes, which are suggested based on the dependency model. The iterative as well as inductive and deductive application procedure aims at ensuring a high quality of the obtained results.

On **stage 1** the users are asked to specify any symptoms that occur in their company. Further the user needs to indicate how often and up to which extend these symptoms occur. In order to rate the frequency and extent a scale is available with four levels from very high, high, medium to low. A verbal description for each level is suggested, but the users may change the description or replace it by a numerical scale depending on the circumstances in the specific company.

The deductive inquiry is realized by presenting the users a set of guiding questions corresponding to the symptoms of inefficiency and ineffectiveness in the dependency model. The users do not have to work with the dependency model itself. Based on the users' answers a path analysis [19] is performed in the dependency model. The dependency paths to possible causes are identified for each indicated symptom. Thereby, a list of possible causes is created. The rating of frequency and extent is used to assess the criticality of a symptom and to prioritize the symptoms on stage 4. The higher frequency and extent of a symptom are, e.g. the more delays are caused in PDP. Therefore, this symptom is of a high economic importance.

On **stage 2** the users are presented the list of possible causes, in order to indicate those that apply for the specific company. If none of these causes occurs, the users can specify other causes. The users need to indicate the degree of its momentousness for each of the causes, i.e. how many persons or departments it affects. The rating of the momentousness uses a four level scale from very high to low. A verbal description is available for each level, which again the users can change according to a company's circumstances.

The results of the inductive inquiry of causes—using the list of possible causes—as well as those of the deductive inquiry of further causes are used to adapt the dependency model to the users' companies. Those dependencies, which do not occur according to the users, are removed from the model. Subsequently, path and cluster analyzes are executed for all occurring causes, in order to identify a list of further possible symptoms and causes. The rating of the momentousness of causes is used to prioritize the causes on stage 4. The higher the momentousness, the more people and departments are affected by a cause of inefficiency and in effectiveness and thus the implementation of counter measures might be more complex.

Stage 3 uses the list of further possible symptoms and causes for a final inductive inquiry. Additionally, the users have another possibility to list further symptoms and causes they might not have been aware before or are not part of the underlying dependency model. Thereby, it can be ensured that all relevant symptoms and causes of the specific company are covered.

All user answers are used to adapt the dependency model by only maintaining those symptoms, causes and interrelations, which occur in the specific company, and by adding all symptoms and causes indicated additionally. Based on the resulting company specific model a short structural analysis is carried out in order to identify the most critical symptoms and causes. For example the active sum is calculated for each item by counting the number of other causes and symptoms it is related to. The higher the active sum the higher is the influence of the item in the dependency model and also its criticality. The results of these analyzes are combined with the user rating of extent and frequency of symptoms as well as momentousness of causes. Thereby, a prioritized list of symptoms and causes is generated, in order to indicate a timely order for the implementation of countermeasures ordered from the most to the least critical symptoms based on the criticality of their causes.

On **stage 4** the users inspect the prioritized list regarding its plausibility. They have the possibility to change the prioritization in order to obtain a guideline for the timely order of implementing countermeasures for specific symptoms and their causes.

Finally, all symptoms, causes and their dependencies, which the users listed but have not been part of the dependency model so far, are incorporated in the comprehensive underlying dependency model. Hence, the dependency model grows continuously with every application, in order to assure a continuous improvement of the SAT.

3.2 Example for an Application of the SAT

This section presents the results of an exemplary application of the SAT. In this case stages 1, 2 and 4 are executed, as only criteria from the dependency model are taken into account.

The deductive inquiry of symptoms of inefficiency and ineffectiveness using guiding questions results in the following symptoms, while for each of the symptoms extent and frequency are indicated: on the one hand a symptom occurs in the category S4 *Over-processing*. Employees produce unnecessary documents, which do not add any value in the PDP and are not used in further development processes. This happens rarely, approximately once every month, with an extent of a few hours of delay. On the other hand a symptom of the category S5 *Defects* occurs. Defective documents are generated frequently—once per week—bringing along several days of delay.

Subsequently, cluster and path analyzes of the underlying dependency model result in the following inductive suggestion of possible causes for these symptoms (Table 1).

In this example only part of the suggested causes apply. For symptom S4 *Over-processing* the causes of the category goals G1 “Planning of strategies and

Table 1 Exemplary application of SAT—suggestion of causes for symptoms S4 and S5

Causes for symptom S4—*Over-processing*	Causes for symptom S5—*Defects*
G1—Planning of strategies and priorities—company perspective	P1—Lack in use of resources and workload leveling
G2—Elicitation of requirements and definition of goals and priorities—project perspective	P2—Lack of process modeling and lack of execution of processes
P2—Lack of process modeling and lack of execution of processes	P5—Lack of information flow (execution)
P6—Wrong handling of organizational interfaces between departments	P6—Wrong handling of organizational interfaces between departments
	P7—Lack of process standardization
	D2—Lack of documentation
	T1—Lack of hardware and software tools

			Causes				Symptoms	
			G1	G2	P5	D2	S4	S5
Causes	G1	Planning of strategies and priorities - company perspective		●			●	
	G2	Elicitation of requirements and definition of goals and priorities - project perspective	●				●	
	P5	Lack of information flow (execution)				●		●
	D2	Lack of documentation			●			●
Symptoms	S4	Over-processing	●	●				
	S5	Defects			●	●		

Fig. 4 Company specific dependency model for the assessment of performance of PDP

priorities—company perspective” and G2 “Elicitation of requirements and definition of goals and priorities—project perspective” apply. Symptom S5 *Defects* is caused by one cause in the category process and one in documentation: P5 “Lack of information flow (execution)” and D2 “Lack of documentation”.

In a next step the dependency model can be reduced to a company specific one as depicted in Fig. 4. In order to prioritize the symptoms and causes, their active sums are calculated based on the company specific dependency model. Both seem equally critical. They have the same active sum of 2, as they are both caused by two causes. The same applies for their causes, which only contribute to one symptom of inefficiency or ineffectiveness. At this point, the additional rating of the extent and frequency of symptoms and momentousness of causes by the user allows for a prioritization. The user rated the extent and frequency of S5 higher than those of S4. Thus, the causes of S5 need to be be eliminated first. In order to eliminate the causes P5 and D2 the execution of necessary information flow and documentation needs to be ensured.

4 Discussion and Conclusions

This paper aims at creating the means for SME to gain awareness of the interlinked performance of product variety management (PVM) and product development processes (PDP) in a multi-project environment. Therefore, the interdependency between PVM and PDP is described in a dependency model. The model is derived from literature as well as from the results of a web-based survey and six industrial case studies.

It is the goal to enable SME to gain awareness about the dependency between PVM and PDP and thus of the possible negative impact of PVM on the performance of PDP. Consequently, a self-assessment-tool (SAT) for SME is presented, which uses the dependency model as underlying database. The tools allows for monitoring the performance of PDP in regard of PVM, in order to identify and prioritize the need to improve PDP in a multi-project environment and to support the choice of improvement methods. An example for the application of the tool is presented, which results in a company specific dependency model and the amendment of the initial dependency model.

So far the dependency model is based on literature, survey results and six industrial case studies. Thus, the main limitation of the SAT is the fact that only a small number of companies contributed to the dependency model. Therefore, future work will focus on enhancing the empirical database for the SAT. Moreover, the SAT will be enhanced in regard of supporting the use of the tool, in order to ensure the quality of the obtained results by systematically supporting the user to perform a valid assessment.

References

1. Sosa ME, Eppinger SD, Rowles CR (2004) The misalignment of product architecture and organizational structure in complex product development. Manage Sci 50(12):1674–1689
2. Jiao J, Simpson T, Siddique Z (2007) Product family design and platform-based product development: a state-of-the-art review. J Intell Manuf 18(1):5–29
3. Löfqvist L (2009) Design processes and novelty in small companies: a multiple case study. International conference on engineering design (ICED09), Stanford, USA, pp 265–277
4. Braun T, Gausemeier J, Lindemann U, Orlik L, Vierenkötter A (2004) Design support by improving method transfer—a procedural model and guidelines for strategic product planning in small and medium-sized enterprises. 9th international design conference (DESIGN 2004), Dubrovnik, Croatia, pp 143–148
5. Vossen RW (1998) Relative strengths and weaknesses of small firms in innovation. Int Small Bus J 16(3):88–94
6. Schmidt-Kretschmer M, Gericke K, Blessing L (2007) Managing requirements or being managed by requirements—results of an empirical study. International conference on engineering design (ICED07), Paris, France
7. Da Silveira G (1998) A framework for the management of product variety. Int J Oper Prod Manag 18(3):271–285
8. Gokpinar B, Hopp WJ, Iravani SMR (2010) The impact of misalignment of organizational structure and product architecture on quality in complex product development. Manage Sci 56(3):468–484
9. Ramdas K (2003) Managing product variety: an integrative review and research directions. Prod Oper Manag 12(1):79–101
10. O'Donnell FJ, Duffy AHB (2005) Design performance. Springer, London
11. Haque B, James-Moore M (2004) Applying lean thinking to new product introduction. J Eng Des 15(1):1–31
12. McManus H (2005) Product development value stream mapping (PDVSM). Manual, Lean Advancement Initiative (LAI), Massachusetts Institute of Technology, Cambridge, USA
13. Ward AC (2007) Lean product and process development. The Lean Enterprise Institute, Cambridge
14. Oehmen J, Rebentisch E (2010) Waste in lean product development. LAI paper series lean product development for practitioners. Lean Advancement Initiative (LAI) Massachusetts Institute of Technology, Cambridge, USA
15. Kato J (2005) Development of a process for continuous creation of lean value in product development organizations. Thesis (PhD), Massachusetts Institute of Technology, Cambridge, MA, USA

16. Siyam GI, Kirner KGM, Wynn DC, Lindemann U, Wynn DC, Clarkson PJ (2012) Value and waste dependencies and guidelines. 14th international DSM conference (DSM2012), Kyoto, Japan
17. Kirner KGM, Siyam GI, Lindemann U, Wynn DC, Clarkson PJ (2013) Information in lean product development—assessment of value and waste. International conference on Research into Design (ICoRD13), Chennai, India
18. Eben KGM, Helten K, Lindemann U (2011) Product development processes in small and middle-sized enterprises—identification and elimination of inefficiency caused by product variety. ICED international conference on engineering design (ICED11), Copenhagen, Denmark
19. Lindemann U, Maurer M, Braun T (2009) Structural complexity management—an approach for the field of product design. Springer, Berlin

Information in Lean Product Development: Assessment of Value and Waste

Katharina G. M. Kirner, Ghadir I. Siyam, Udo Lindemann, David C. Wynn and P. John Clarkson

Abstract The value stream in product development (PD) is information flow. Therefore, the value of information needs to be increased, while waste of information needs to be eliminated in lean product development (LPD). Although the concepts value and waste in PD have both been the object of research activities, the dependency between them has been only addressed by a few authors. Therefore, this paper aims to examine the understanding of value and waste of information and their dependency in industrial practice. A web-based survey has been conducted in industry, which resulted in insight in industrial practice regarding definitions of value and waste, approaches to manage and assess value and waste, as well as companies' reasons for and challenges in the implementation of LPD. Finally, the need for further research from an industrial perspective was revealed.

Keywords Lean product development · Value and waste of information

K. G. M. Kirner (✉) · U. Lindemann
Institute of Product Development, Technische Universität München,
Boltzmannstrasse 15 85748 Garching, Germany
e-mail: katharina.kirner@pe.mw.tum.de

U. Lindemann
e-mail: udo.lindemann@pe.mw.tum.de

G. I. Siyam · D. C. Wynn · P. John Clarkson
The University of Cambridge, Department of Engineering, Trumpington Street,
Cambridge CB2 1PZ, UK
e-mail: gs417@eng.cam.ac.uk

D. C. Wynn
e-mail: dcw24@cam.ac.uk

P. John Clarkson
e-mail: pjc10@eng.cam.ac.uk

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_64, © Springer India 2013

1 Introduction

Lean in product development (LPD) has been deployed in order to improve processes and their output in industrial practice [1]. LPD is oriented towards the fulfillment of customer requirements by enhancing value and minimizing waste. The question of how LPD—with its principles, guidelines and techniques—can be better adopted in product development (PD) is attracting increased attention.

Value in product development (VPD) can be defined as 'a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer' [2]. A wide range of tools is associated with Lean Thinking. These tools, such as standardization of processes, effective communication, and a continuous flow of information, aim to increase the value (e.g. [3]).

Womack [2] defines waste as "any human activity which absorbs resources but creates no value". Engineering design can be regarded as an information creation and transformation process that aims to deliver a 'recipe' that satisfies the customer requirements [3]. Thus, in PD the value stream is represented by the flow of information produced within the product development process (PDP) [4].

Therefore, it is crucial to regard waste in PD in terms of information. Waste of information is therefore considered to occur when information is created, transformed and/or transferred without adding any value regarding the fulfillment of customer requirements [5]. Several authors have studied different types of waste in LPD, such as over-production, over-processing, waiting, transportation, unnecessary movement, defective product, and inventory (e. g. [6, 7]).

As stated in previous work [5], we propose that LPD can be used in the PDP more effectively if it focuses on value and waste of information. Further, we propose that the implementation of LPD is more successful, if a company gains a comprehensive understanding of value and waste of information as part of lean thinking. Research in LPD has developed various approaches to enhance value generation and to improve process aspects such as flow by applying lean methods (e. g. take time [8]). Although there has been research on waste types in PD, only few authors focused on waste of information [4, 7]. Moreover, the linkage between value methods and waste types has not been described thoroughly in literature [5].

This paper focuses on the understanding of value and waste in information and the linkage of both aspects. A web-based survey has been conducted in order to investigate the understanding of value and waste of information in practice as well as the dependency between techniques to foster the generation of value and waste types as observed in industry. Moreover, current practices to assess the extent of value and waste and to manage value and waste in practice are gathered.

2 Survey Set-up

The web-based questionnaire on value and waste of information in PD was sent to 450 companies in Germany and the UK. There have been 55 participants in total. Their roles in the company span from design engineer, project or product manager to head of department or combinations of all roles. The industry sectors of their companies comprise aerospace, automotive, consumer goods, furniture industry, heavy equipment, medical engineering, microscopy, plant engineering and construction, ship building, software, telecommunications and the operation in various sectors.

The questionnaire has been developed based on literature review. The results of this literature review are described in detail by Siyam et al. [5]. The survey consists of 32 questions, of which five are open questions and 27 comprise a combination of fixed answers and the option to add a supplementary comments and descriptions.

The 32 questions are grouped in five sections. Section one focuses on the application of lean thinking. The survey participants are asked whether their company makes use of lean in product development and why they adopted it. Moreover, their definition of value and waste, their assessment of common practices to enhance value and of the criticality of common waste types, as well as challenges faced during the implementation of lean practices are gathered. The topic of the second section is assessment of value and waste. Participants can name procedures for and the frequency of value and/or waste measurement, as well as metrics and attributes that are used. The third section of the survey covers the dependency between value and waste. The participants rate the dependency between specific best practices to enhance value and five waste types that were identified as most critical in the literature review. Further questions concern the participants' opinion regarding the need for research to provide support in different research areas of lean. Part four covers general information about the participant, e. g. the person's position in the company and experience in lean, and the company. Finally, the fifth part of the survey covers the possibility to give general comments and to volunteer for further inquiries.

3 Survey Results

In this section we elaborate on the results of the web-based survey on information in LPD. The results are classified into the following topics:

- Understanding of value and waste of information
- Management of value and waste
- Assessment of value and waste
- Dependency between value and waste of information
- General information on implementation of lean in practice
- Perceived need for further research.

Not all of the 51 survey participants answered all questions. The following sections indicate the number of answers for each question.

3.1 Understanding of Value and Waste of Information

Value is understood as receiving the right information at the right time, in the right format by 43.6 % of the participants (number of answers n = 55). At the same time 41.8 % of the answers stated that—additionally o the first definition—value of information is information or data that contributes to features in the product based on customer requirements.

The latter definition is also emphasized by several comments given by the participants. Not only should information be generated based on the actual need for information, but it is also important to fulfill the customers' needs. Moreover, information is considered to be valuable, if it enables the creation of innovative products or services, which exceed the customers' expectations. The majority (37.7 %) of the participants (n = 53) consider waste to be on the one hand information or data that does not contribute to the creation or enhancement of value in order to satisfy customer requirements (definition no. 1). At the same time they define wasteful information as information that is not available for the right person, at the right time and in the appropriate amount (definition no. 2). The reminder of the participants decided almost evenly between the two definitions (30.2 % for no. 1 and 32.1 % for no. 2).

Further, the participants expressed that information impeding value-adding activities are considered as waste. Information overflow, like unnecessary e-mails and test reports without sufficient summary, is one example of such waste.

The participants indicate the importance of differentiating between non-value-added information and activities—which are necessary to complete value-added activities or generate valuable information—and completely wasteful information and activities.

The participants have been asked to rate the criticality of different waste types. The latter have been structured into three dimensions, the transformation of information, the transmission of information and the content of a piece of information [5]. The left part of Fig. 1 shows the distribution of answers over the total scale from no effect (value 1) to very critical effect (value 5). The right part of the figure shows the arithmetical average of all answers.

As depicted in Fig. 1 the main wastes during the transformation or processing of information are rework—rated as critical or very critical by 66 % of the participants—and a poor synchronization of tasks—rated as critical or very critical by 64 %. Regarding the waste of the content of a piece of information defective content (rated as critical or very critical by 62 %) and incompleteness of information (rated as critical or very critical by 66 %) are the most critical wastes. During the transmission or delivery of information the most crucial waste is

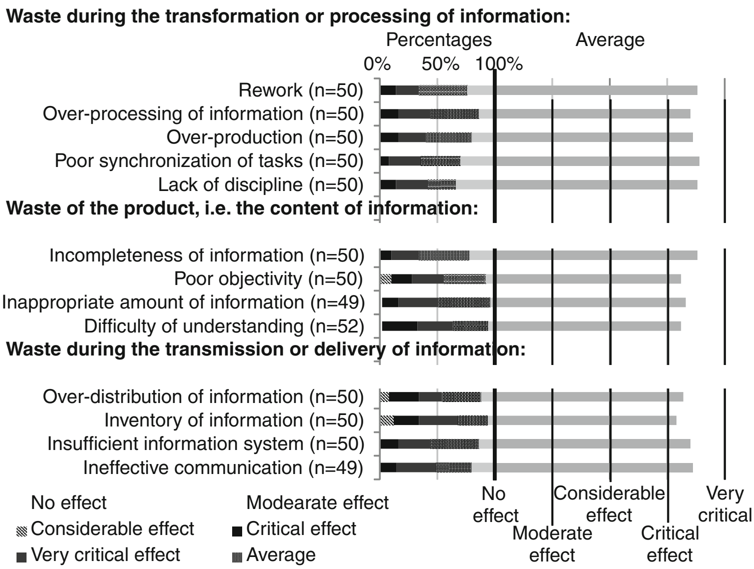


Fig. 1 Results of rating the criticality of waste types

waiting for information, which has been rated as critical or very critical by 64 % of the participants.

Other critical wastes named in the questionnaires are the existence and use of different versions of information by different people involved in the process, unclear responsibilities for pieces of information, a lack of trust in expert estimations, a lack of need-based information deployment and waste due to outdated information systems and inappropriate modeling (e.g. BOM systematics).

3.2 *Management of Value and Waste*

A majority of the participants regard the practices of standardization (67.3 %), integration of supplier and customer (63.8 %), simultaneous engineering (58 %) and communication (63.8 %) as effective and applicable, although it might need a considerable amount of training (Fig. 2, left part: distribution of answers, right part arithmetical average of all answers). The least applied approaches are set-based engineering (38.3 %), pull and flow of information (36.2 %) and adaptability (31.9 %).

The participants state that they use other tools with lean methods. These methods comprise Complexity Management, Design Structure Matrix, Module Oriented Value Engineering, Design-to-Cost, flow charts, swim-lane-diagrams, industry standards, ISO 9000, Total Quality Management, Quality Function Deployment, Failure Mode and Effect Analysis, the morphological chart, Kanban,

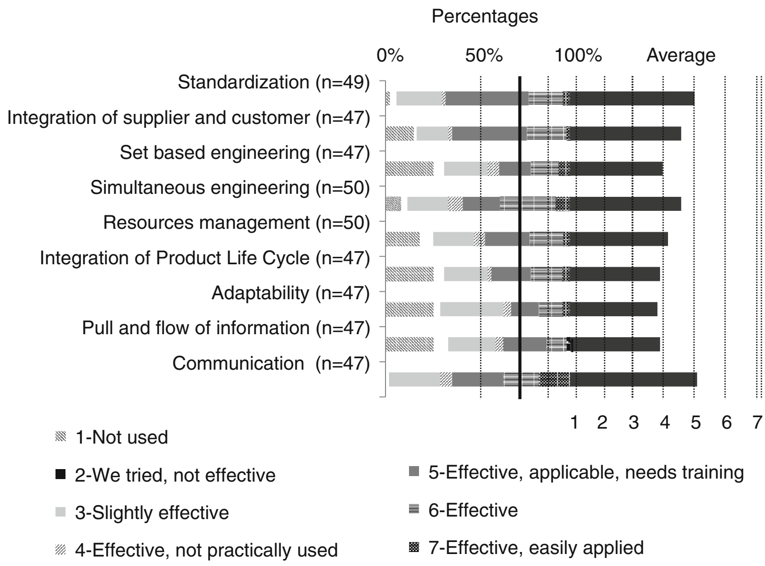


Fig. 2 Rating results of efficiency of practice to enhance value of information

moderation by process attendants from central administration, project management, rapid development cycles (e.g. agile development, SCRUM), knowledge capturing techniques, root cause analysis and best-practice-templates.

3.3 Assessment of Value and Waste

A majority of 54.8 % of the participants stated that they do not assess value or waste of information. While 28.6 % of the participants assess value or waste by frequently measuring specific attributes, such as cost, time, quality and risk. Only 16.7 % have established their own measurement (n = 42).

Further it has been stated that the enterprises' general process monitoring—not focused on lean in PD—is used for the monitoring and identification of challenges. This includes the use of general key performance indicators such as milestone adherence and engineering change order throughput. While in some companies the assessment of value and waste is modeled in workflow systems, other enterprises only apply the assessment in certain areas.

According to 13.4 % of the questionnaires (n = 22) the assessment is carried out monthly, while 86.4 % of the participants state that the measurements are conducted at pre-defined stages, e.g. project milestones.

Figure 3 shows which attributes or measurements are used according to the participants. The metrics used and considered to be easy to measure are cost

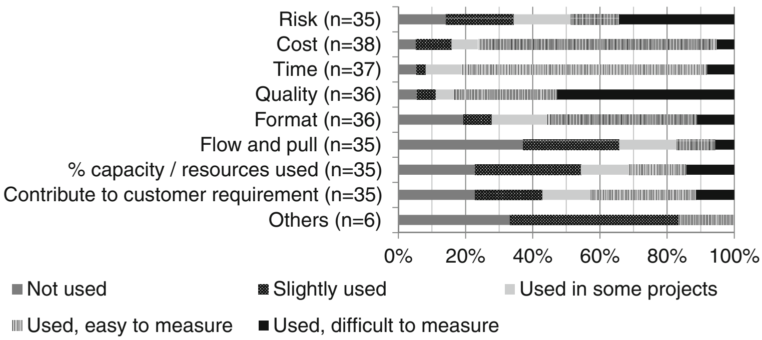


Fig. 3 Rating results of attributes most used to quantify value and/or waste

(71 %), time (73 %), format (44.4 %) and to contribution to customer requirements (31.4 %). Also used but difficult to measure are risk (34.2 %) and quality (52.8 %).

From the additional comments can be concluded that these measures, i.e. cost, time and used resources, are often monitored in terms of project management, but not exclusively used to assess value and/or waste.

Being asked which attributes had an impact on value and waste in PD the participants considered uncertainty (76.2 %, n = 42), a lack of measurement culture (44.2 %, n = 43) and the dynamics of PD processes (51.2 %, n = 43) to have a high impact on value and waste in PD.

Further the participants stated the impact on value of the following other aspects: a lack of decisions, an unclear decision structure, a change of requirements within the process, a lack of transparency of responsibilities, information status and over-all strategy, a high variety of technologies in one product, a lack of a mature marketing strategy before product definition and competition between separate departments.

3.4 Dependency Between Value and Waste of Information

The participants have been asked to rate the dependency between the five waste types rework, over-processing, over-distribution, defective content and waiting, which have been identified as the most critical in the literature review [5] and the most effective value methods standardization, management of resources and effective communication methods [5]. In 49.33 % of the questionnaires fostering an efficient and effective communication is considered to have a high positive impact regarding the elimination of waste. Also the comments given by the participants reflect the importance of communication as the basic requirement for a lean enterprise.

In more detail communication has the highest positive impact on the waste occurrence (73.3 % for waiting, 46.7 % for rework, 38.7 % for over-processing, 43.3 % for over-distribution of information) except for the defective content of

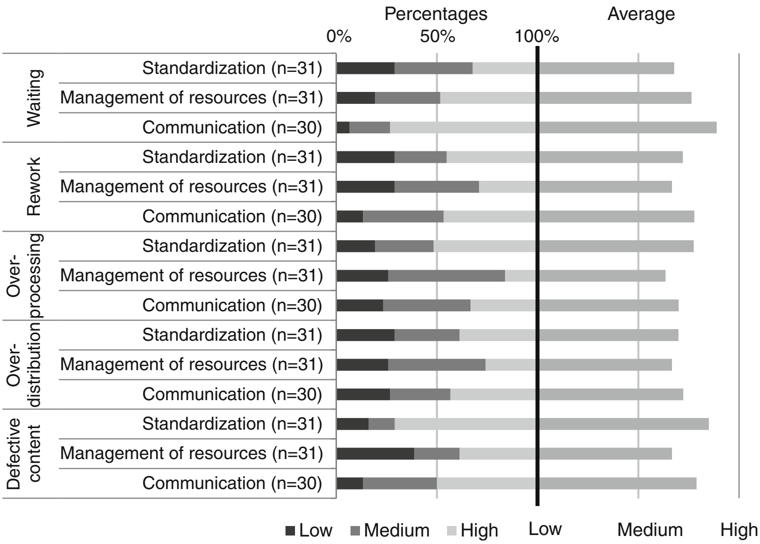


Fig. 4 Rating results of the impact of value methods on waste types

information (50 %). The latter is supposed to be eliminated best by standardization (71 % in Fig. 4). Management of resources is regarded as the approach with the least impact on the elimination of waste. Nevertheless, it is considered by a majority of all participants to have at least a medium impact on all wastes.

3.5 General Information on Implementation of Lean in the Company

When asked about whether Lean methods have been implemented in the participants' organizations 5.2 % (n = 58) stated that they had not implemented Lean in their product development processes. A percentage of 32.8 stated that they had implemented LPD, but were still trying to define lean (e.g. appropriate methods to be applied, involved teams). Further, a fraction of 20.7 % answered that they had adopted general lean tools with no specific strategy (e.g. Value Stream Mapping, Lean Principles). 15.5 % stated that they had implemented LPD with a specific focus, while 25.9 % indicated that several of these aspects apply.

The aims of the implementation of LPD differed as follows: 20.9 % named processes and activity analysis (e.g. visualization, set-based engineering), 4.7 % people (i.e. culture, leadership, and training), 2.3 % information (i.e. quality, flow, format), 2.3 % customer (i.e. requirements) and 69.8 % a combination of two or more of these aspects as focus of the implementation of LPD. In further comments the companies' orientation on value generation have been also indicated as a focus of LPD implementation.

The reasons for adopting lean have been gathered in an open question and can be summarized as follows. A majority stated that they implemented LPD as part of a holistic company strategy aiming at process improvement, increasing efficiency and effectiveness, e. g. resources management, process orientation, visualization of progress, reducing time to market, development cost and risk, increasing the reliability of delivery time and quality. Furthermore, the need to change regarding efficiency and competence development evolved due to planned strategic decisions for the companies' future. Moreover, previous success of Lean Production serves as a main driver for LPD. Finally, the urge to increase the ability to innovate, to enhance competitiveness and to involve customers in development are important factors for the implementation of LPD.

The companies faced a variety of problems during the implementation of LPD. The statement that tools, which have been developed for lean implementation (e.g. Value Stream Mapping, standardization) are difficult to apply and/or we have gained limited benefit has been named by 39.5 % of the participants (n = 38). Moreover, the dynamic and iterative process of product development was considered as limiting by 42.1 %. Finally, both challenges have been faced by 18.4 %.

The participants have been asked to list further challenges they encountered during the implementation of LPD. These challenges can be summarized as follows:

- Challenges due to application of Lean Production approaches to PD
- Difficulty to apply the general principles of LPD
- Shortage of resources
- Challenge to define the appropriate level of standardization
- Lack of acceptance of the value of standardization
- Challenge of coordination of standardized processes between customer and development organization.
- Cultural barriers (company culture differs depending on organization, departments, sites, countries).
- Challenge of clear understanding of descriptions (e.g. of waste types).
- Lack of commitment or management support
- Difficulty to achieve success quickly—conflict of high effort and low benefit in the beginning
- Lack of means to visualize the improvements due to LPD (e.g. contribution to companies' goals).

3.6 Perceived Need for Further Research

We asked the participants to state whether they consider it as important to further explore the following aspects using a scale from a low (value of 1) to a high (value of 10) importance. A number of 33 participants answered this question. For each aspect the average rating is as shown in Table 1.

Table 1 Perceived need for further research

Proposed research topic	Average rating of importance
Further analysis of waste causes	8
Reshaping lean principles for a better application in PD	7
Further analysis of waste types	6
Determining the impact of methods on the occurrence of waste	6
Categorizing and weighting value	6
(Further) Development of lean modeling tools (e.g. value stream mapping)	6
(Further) Development of measurements	5

Thus, the participants consider as most important research on waste causes and further development of lean principles to facilitate their application in industrial practice. The latter is also stated frequently as the most important issue, which needs to be addressed by researchers aiming to develop LPD. Moreover, the need to evaluate and validate developed LPD methods in industrial practice is expressed in order to ensure the availability of easy manageable principles and methods. Explicitly the development of methods allowing for quick analyzes and improvement approaches in LPD ensuring quick wins and thus a high acceptance of the LPD implementation.

Additionally, the prerequisites for a successful application of LPD methods regarding organization, processes and persons in industrial practice should gain higher attention, as well as the development of objectively measurable criteria e.g. for value, waste or the success of LPD. Finally, psychological aspects such as collaboration in teams, conflict resolution and emotional competency should be explored.

4 Conclusions

Value in PD is widely understood on the one hand as receiving the right information at the right time, in the right format and on the other hand as information that contributes to the fulfillment of customer requirements. Waste in PD is perceived as the opposite, while further information impeding value-adding activities is considered as waste. Thus, the understanding of value and waste in PD in practice aligns to the academic perspective. Notwithstanding from the latter, the dependency between value and waste in PD can be observed in industry and is rated according to its strength.

Regarding the management of value and waste in PD, the participants evaluated the applicability of lean methods to enhance value and eliminate waste. Further a list of aspects has been deduced, which are affecting value and waste negatively. The results covering the assessment of value and waste show that both aspects are mostly measured indirectly in the course of the enterprises' general process monitoring using general key performance indicators. Lastly, the need for the development or improvement of lean methods and tools for LPD ensuring for a better applicability in practice as current approaches is deduced.

This paper is part of ongoing research aiming to gain a comprehensive understanding of the dependency between value and waste of information in LPD and to develop support to improve PD based on the integrated assessment of value and waste of information in PD. Therefore, the results presented in this paper will be evaluated in workshops and interviews with representatives from industry and serve as a basis for the development of an approach to assess in further understanding and managing value and waste of information in PD.

References

1. Browning TR (2003) On customer value and improvement in product development process. Syst Eng 6(1):49–61
2. Womack JP, Jones DT (1996) Lean thinking. Simon Schuster, New York
3. Browning TR, Deyst JJ, Eppinger SD, Whitney DE (2000) Complex system product development: adding value by creating information and reducing risk. In: Tenth annual international symposium of INCOSE, Minneapolis
4. Graebsch M, Seering WP, Lindemann U (2007) Assessing information waste in lean product development. International conference on engineering design (ICED07), Paris
5. Siyam G, Kirner K, Wynn DC, Lindemann U, Clarkson PJ (2012) Relating waste types to value methods in lean product development. International design conference (DESIGN 2012), Dubrovnik
6. McManus H (2005) Product development value stream mapping (PDVSM), manual, lean advancement initiative (LAI). Massachusetts Institute of Technology, Cambridge
7. Oehmen J, Rebentisch E (2010) Waste in lean product development, LAI Paper Series "lean product development for practitioners," lean advancement initiative (LAI). Massachusetts Institute of Technology, Cambridge
8. Oppenheim BW (2004) Lean product development flow. Syst Eng 7(4):352–376

A Method to Understand and Improve Your Engineering Processes Using Value Stream Mapping

Mikael Ström, Göran Gustafsson, Ingrid Fritzell and Gustav Göransson

Abstract This paper describes two ways of mapping engineering processes in product development—Value Stream Mapping (VSM) and a simplified variant of VSM—which are compared with Process Mapping (PM). PM is closely related to VSM but applied differently although the goal—to identify possible process improvements—is often the same. The results of the study indicate that simplified ways of doing VSM are the most feasible. They are easier to get started with, they have a higher potential for improvement of the process and one gets an instant overview of the mapped process. Further, it is more likely that the improvement will be implemented when the users are committed through their involvement in the mapping process.

Keywords Value stream mapping · Process mapping · Lean

M. Ström (✉)
Product Realization, Swerea IVF AB, 104 SE-431 22 Mölndal, Sweden
e-mail: mikael.strom@swerea.se

G. Gustafsson · G. Göransson
Department of Product and Production, Development Chalmers University of Technology, SE-412 96 Gothenburg, Sweden
e-mail: gorang@chalmers.se

G. Göransson
e-mail: goranssg@alumni.chalmers.se

I. Fritzell
Volvo Car Corporation, SE-405 31 Gothenburg, Sweden
e-mail: ingrid.fritzell@volvocars.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_65, © Springer India 2013

1 Introduction

The increased global competition during the last decades, when quality and short time to market has been the key to survival, has forced companies to streamline their processes [1]. Since the discovery of Toyota's superiority in quality and lead time in the nineties, many companies have turned to the lean philosophy as a potential solution to their needs [2]. From having had the initial focus on manufacturing, the lean movement has more recently spread to other functions like product development (PD) [3].

One lean method, Value Stream Mapping (VSM), see Sect. 3.2, has successfully been used to revamp manufacturing processes. By visualizing the production flow, VSM helps to map processes and identify wasteful activities and serve as an input for continuous improvement [4]. Wasteful activities and other problems detected when using VSM often fit into different categories of waste. Examples of such in PD are found in [3]. They are scatter, hand-off and wishful thinking.

It is relevant to ask if VSM can also be applied to PD processes. However, PD consists of a flow of information rather than a flow of physical products. Information can exist in different versions and at different places simultaneously which makes mapping of a PD process different and more complicated. Furthermore, iterations that in manufacturing are considered as waste are in PD a natural part of the process. VSM therefore needs to be adapted in order to be applicable in a PD context.

Traditionally, different kinds of processes were mapped using methods such as IDEF0 [5], Activity Diagrams of UML [6] or Event Process Chains [7]. The actual mapping was often carried out by a dedicated process mapper who put questions to interviewed individuals working in the process and used a computer tool like e.g. MS Visio or ARIS. The required tools and the required knowledge about the mapping method created a threshold for individuals to use the method and to utilize the outcome of the mapping.

This research aims to lower the threshold for getting started with VSM and adapt the methodology to PD processes. The aim is also to make it an integrated part of everyday life of the PD team.

2 Research Questions

Following the introduction above we pose two research questions:

- How is VSM used in PD in Swedish industrial firms?
- How can VSM be adapted to suit a PD process?

3 Theoretical Framework

3.1 Process Mapping in General

The Oxford Advanced Learner's Dictionary of Current English [8] defines a process as "a series of things that are done in order to achieve a particular result" and modeling as "the work of making a simple description of a system or a process that can be used to explain it". During recent decades, a myriad of different ways to model processes have appeared. Examples are phase/stage-based models, activity networks, IDEF0, UML activity diagrams and Design Structure Matrices (DSM) [9]. To this group belongs also VSM. A number of different reasons drive the need for using process models, for example to provide a base for how to plan, execute and manage projects [10], serve as a support for continuous improvement efforts or for creation of a coherent picture of how the work is done [11–13]. The demand for a process model can also be derived from requirements from standards regulating quality assurance systems or internal company policies [10].

3.2 What is VSM?

VSM has evolved from what Toyota calls the material and information flow diagram, which the company has used to teach the Toyota Production System (TPS) to its suppliers [1]. Rother and Shook [4] were the first to convert Toyota's way of working with VSM to a practical guide, called Learning to see. This focuses on mapping in production but the method has later been adapted to and used also in other disciplines such as administration, office processes, healthcare and supply chain [14–16]. VSM provides support for understanding the flow of material and information required to make the final product and for analyzing possible improvements. By focusing on the customer, value creation and the removal of waste, an effective and efficient process flow can be accomplished [4]. VSM can be used as a tool for communication, planning and/or continuous improvement efforts [4, 17, 18].

VSM is a visual method using predefined notation and symbols, for example to indicate movement and storage of material. Accurate metrics are also collected to assess the value or identify bottlenecks of the process. The method basically consists of four steps: (1) set the scope, (2) identify the current state of the chosen process, (3) draw a future, desired state and finally (4) make a work plan to ensure the implementation of identified improvement areas [4] (Fig. 1).

As previously mentioned, it is difficult to use the VSM method from production in a complex PD environment. Furthermore, PD is generally characterized by long cycle times, which makes it difficult and time-wasting to collect accurate metrics [19]. Extensive cross-functional integration is also often required and consequently

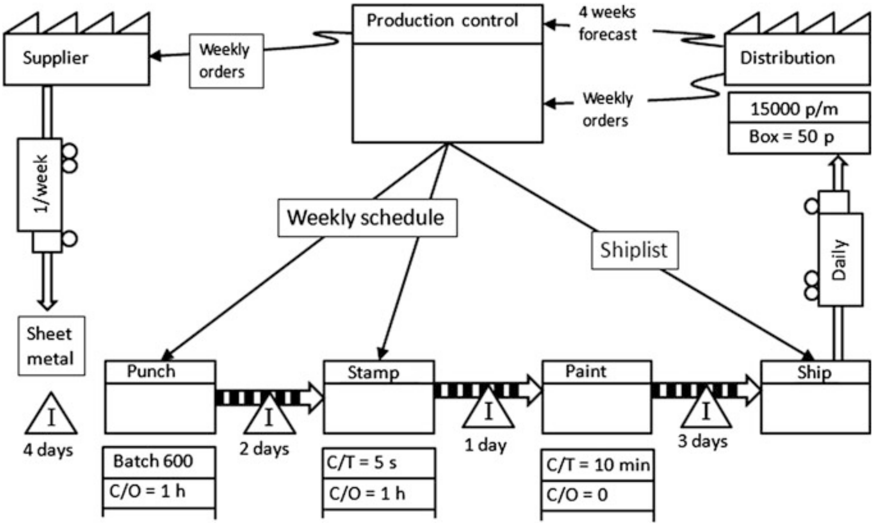


Fig. 1 Example of VSM map, inspired by Rother and Shook, to show the principle of the syntax

puts different demands on how to visualize such a process [17]. However, these should not be reasons for not trying to adapt VSM to PD [20].

One of the first VSM adaptations to PD was made by Morgan [17], who used the production method Learning to see as a basis. Another early effort was made by Millard [18]. His method consists of a Gantt chart or a Ward/LEI map for mapping on a high level combined with a process flow map and a design structure matrix for mapping on a detailed level. McManus [21] developed an extension of Millard's work resulting in a PD VSM manual. Other adaptations of VSM have for example been made by Locher [19] and Mascitelli [20]. Both are strongly influenced by Rother and Shook's original method, but Mascitelli further expands it by mapping on several hierarchical levels.

4 Methodology

4.1 Research Approach

Since the number of practitioners of VSM is still limited, a quantitative study would be difficult to make. A qualitative approach [22] has therefore been selected. It is suitable for developing in-depth understanding, which corresponds to the aim here to understand the application of VSM. The study consists of a literature review, a case study, and a field test of a revised VSM method, see Fig. 2.

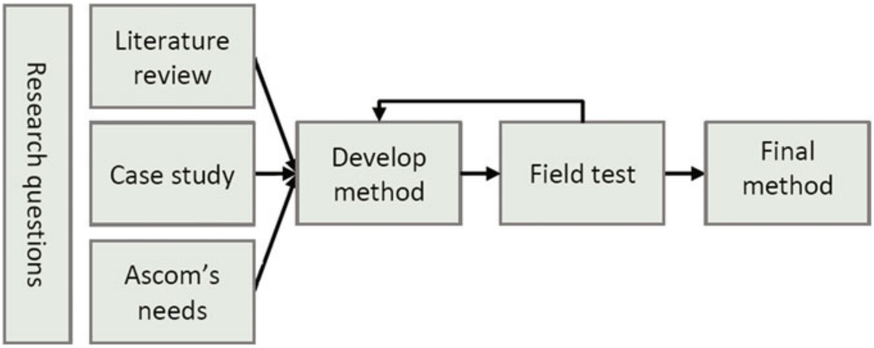


Fig. 2 An overview of applied methods [23]

4.1.1 Case Study

As a complement to the literature review, a multiple-case [24] study of four firms was made to find out how and why they use VSM in PD. The firms are active in respectively radar technology, space technology, information technology and automotive industry. The study consisted of semi-structured interviews with people who had previous experience of using VSM in PD.

4.1.2 Field Test

Action research [25] was used in three separate field tests to gain experience and to develop, test and evaluate an adapted VSM method. The tests were conducted at the telecom firm Ascom Wireless Solutions (Ascom) in Gothenburg, Sweden, which has 1,150 employees.

The field tests followed the procedure below:

1. A VSM method adapted to PD was created through comparison between and evaluations of the findings from the literature review and the case study.
2. Three processes were selected based on suggestions from Ascom.
3. The VSM method was used on one of the processes in the form of a workshop facilitated by two of the authors of this paper.
4. Feedback from the participants after the workshop was used to refine the VSM method.
5. Steps three and four were repeated on the two remaining processes.

The results from the field tests, along with the results from the literature review and the case study, were used to answer the second research question.

5 Results

5.1 General Results

The case study revealed that the firms basically followed the pattern proposed in the literature, but also that they simplified the method to suit the process and the participants. While the literature [17, 18] shows adaptations of VSM to PD by expanding the method, the firms have done the exact opposite and instead use less strict notation and fewer or no metrics at all. Three of them develop software and electronic products, and one of the firms also mechanical ones. The fourth firm develops heavy vehicles. In their VSM operations, three of the firms involve people who work in the actual processes themselves and one also persons working upstream and downstream of the process. The approach of the fourth firm is to make VSM part of the daily work.

The field tests at Ascom indicated that VSM could be simplified even more without losing its main function, i.e. to understand and improve PD processes. Focus was on creating a shared picture of the process with indirect emphasis on value and waste.

An important part of the production oriented method Learning to see is to measure the value adding time for each activity [4]. This is much more difficult to do in PD than in manufacturing. Judging from the literature, there is no good definition of value and waste in PD and it is therefore hard to determine what is value adding or not. Furthermore, the case study indicated that attempts to quantify value could result in empty discussions around it. However, it is of course important to question how separate activities contribute to the end result. As a firm gets more experience from working with VSM, more of the underlying theory can be added to the method. This might even be required since when processes become more efficient it will be more difficult to find new improvement areas.

5.2 New VSM Adapted to PD

We call this new adapted version VSM-PD.

5.2.1 Step 1: Preparation

The relevant key stakeholders agree on the desired scope of the VSM-PD operation, e.g.:

- Create a shared vision of a future state of the process
- Reduce process lead time
- Decide which parts of the process to focus on.

Participants are selected to discuss the above in a workshop. A suitable group size is 6–9 people including:

A facilitator who guides the group through the workshop and acts as a time keeper. The facilitator has knowledge of VSM-PD and shall push and challenge the participants to come up with new ideas.

Participants—the ones mapping the process. The group should consist of:

- A workshop owner responsible for the implementation of improvement suggestions
- People working in the process (not people who only *think* that they know how the work is carried out)
- People working upstream and downstream of the parts of the process focused on (i.e. those who deliver the input to the process and use the output from it)
- People affecting the process without participating in it, for example decision makers
- People necessary in order to achieve a potential future state, i.e. those with mandates to change the analyzed process.

The duration of the workshop depends on the scope and size of the process. Two consecutive half-days are probably sufficient in most cases. An all-day event is exhausting and therefore not recommended, especially since the work that requires particular focus and creativity like future-state mapping and creation of countermeasures is carried out at the end of the workshop. Separating the event into two half-days also gives time for reflection and could hence improve the results, but it is important to use two *consecutive* days in order not to lose any information.

It is recommended that the participants are informed well in advance about the workshop, its purpose and why they should take part in it so that they can familiarize themselves with the VSM-PD method and prepare for the improvement effort.

The following aids are required for the workshop: pens, a roll of wide writing paper, relevant documents and computers to show working procedures etc. and sticky notes (yellow for activities, pink for problems and blue for measures. Other colors can be useful to have in spare if the need arises to visualize for example decisions, iterations etc.).

5.2.2 Step 2: Workshop

The workshop begins with a short introduction by the facilitator including the purpose of doing VSM-PD and a basic description of the method.

This is followed by a discussion regarding the purpose of the process. Both the internal and the external customers are discussed in order to create consensus. The group then defines input to and output from the process. These are written on yellow sticky notes and put on a large sheet of paper placed on a table. The sticky notes here and in the following replace the graphical notation of the more complex

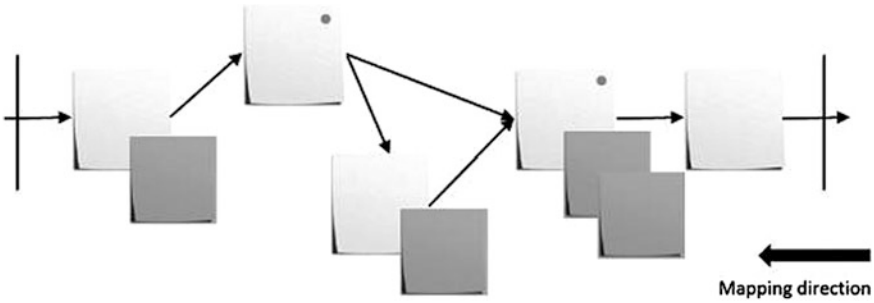


Fig. 3 Mapping is done backwards. Main process steps are marked with *green* dots (*dark grey*). *Yellow* notes (*light grey*) denote activities and *pink* notes (*dark grey*) root cause analysis

VSM methods found in the literature. The borders of the process are marked with black lines and dependencies on other processes are discussed to avoid sub-optimization.

The mapping of the current state is now carried out by starting at the end of the process in focus and working backwards in the flow. By doing so, the participants are forced to consider the customer perspective (Figs. 3, 4).

The current state map shall be created as a teamwork where all participants contribute by placing sticky notes on the paper. This is in contrast to traditional PM where one person often interviews the others and creates the map using a computer tool.

The participants explain their activities on yellow sticky notes. If possible, they show each other the documents and tools that they work with. The level of detail depends on the time available, but it is important that all participants clearly understand each activity and who performs it. The opinions may vary regarding activities and their internal order in the process, and a single current state map might therefore not even exist. However, discovering that employees have different work procedures (and discussing why they have that) can alone be worth the time spent.

The last task of day one is to identify problems by discussing the process activity by activity. Problems are elicited by identifying wasteful and other circumstances which limit the yield of the process. Solutions to problems should not

Fig. 4 Current state map from field test at Ascom

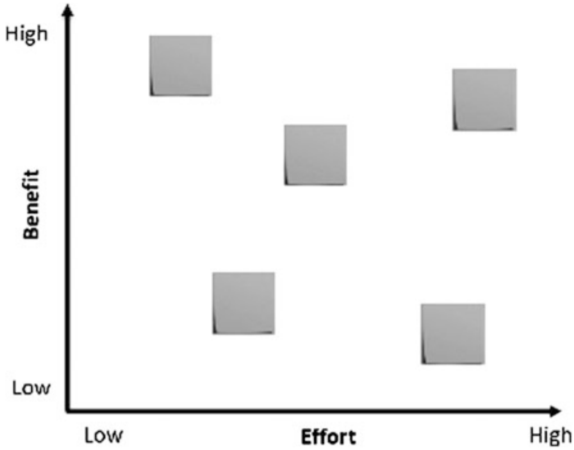


Fig. 5 Improvements, written on blue sticky notes, are placed on the pick chart according to the effort to realize them and their expected benefit. Alternatives in the *top left* corner consequently have the lowest (best) effort/benefit ratio

be discussed at this stage though, before the group has a clear and complete picture of the focused process.

It is important not only to detect problems, but also to find their root causes. The facilitator can for example ask 'why' a couple of times. The identified root causes are written on pink sticky notes which are put at appropriate locations in the flow.

When all root causes are identified, the group decides on the most serious problem areas. Finally, the most important activities in the process are marked with green dots (Fig. 3) and will be used as a basis for the future state map.

The second day begins with the creation of a future state map where the problem areas shall be eliminated. With the sticky notes marked with green dots as a framework, new sticky notes in blue are written and arranged to form an improved flow. A trick to force the group to think differently is to ask "How can you achieve this in half the time?" It is important that the participants can picture themselves working like this within 3–6 months. Otherwise there is a chance that the group ends up with improvement suggestions that are too difficult to implement. Finally, the suggestions are synchronized with the identified problems in the current state map so that no relevant issues remain untreated.

The suggested improvements shall now be ranked by the team using a pick chart (Fig. 5), and people responsible for implementing those chosen shall be appointed. It is the workshop owner's duty to make sure that these tasks are followed up.

5.2.3 Step 3: Implementation and Follow-Up

A follow-up meeting, which the workshop owner is responsible for arranging, shall be held to evaluate the improvement efforts and to resolve problems that may have occurred during implementation. All participants in the workshop, regardless of if they are involved in the implementation efforts or not, shall receive feedback on this in order for them not to lose their interest to participate in similar future activities. The same information should preferably also be communicated at department meetings to create motivation among other employees for further improvement efforts.

5.2.4 Example of Application in One of the Field Tests

Ascom's design and handling procedure of components regulated by law—so called critical components—is one example where VSM-PD was used. The map created contained sticky notes of five different colors representing activities, information, problems, countermeasures, and future state. In total 37 problems were found along with 25 countermeasures, which were ranked using a pick chart. The participants also reached consensus on the process. A future state map was created in a very short time, i.e. in about 15 min.

6 Discussion

Three different sources of information were used in the study, i.e. a literature review, a multiple-case study and action research in the form of a field test. The enquiry in the case study did not contain any questions suggesting modification of VSM, but all of the studied firms have anyway adapted VSM in a similar way. This together with the fact that the field test of VSM-PD produced a considerable number of improvements to the processes in focus strengthens the results of the study and contributes to the trustworthiness of the results.

There is at least one aspect that *may* perhaps have affected the outcome of the study: the VSM methods in the existing literature are developed mainly by American researchers who have investigated American firms, while the case study was carried out by Swedish researchers in Swedish firms. Without further investigation the possibility cannot be ruled out that there are cultural and/or other differences between the two countries that have influenced the results, but that is outside the scope of this paper to find out.

7 Conclusions

From the results of this study we conclude the following regarding the application of VSM to PD:

- In the studied Swedish firms VSM was used in different simplified ways compared to what was found in the literature.
- The further modified VSM-PD method proposed and described in this study was found to be not only suitable for, but also very useful in PD work.

Acknowledgments The authors are very grateful for the help from Ascom Wireless Solutions to conduct this study, and the support from the Swedish Foundation for Strategic Research to publish the results.

References

1. Liker J (2004) The toyota way—14 management principles from the world's greatest manufacturer. McGraw-Hill, New York
2. Womack JP, Jones T, Roos D (1990) The machine that changed the world: the story of lean production. Rawson Associates, New York
3. Ward AC (2009) Lean product and process development. The Lean Enterprise Institute, Hungary
4. Rother M, Shook J (1998) Learning to see—value stream mapping to add value and eliminate muda. The Lean Enterprise Institute, Hungary
5. US Air Force (1981) Integrated computer aided manufacturing (ICAM), Architecture Part II, vol 5—Function modeling manual (IDEF0). Air Force Material Laboratory, Wright-Patterson AFB
6. www.omg.org, access date July 29th, 2012
7. Scheer A-W (1999) ARIS business process modeling. Springer Verlag, Berlin
8. Hornby A (2010) Oxford advanced learner's dictionary of current english. Oxford University Press, Oxford
9. Ulrich KT, Eppinger SD (2012) Product design and development. McGraw-Hill, New York
10. Browning TR, Fricke E, Negele H (2006) Key concepts in modeling product development processes. Syst Eng 9(2):104–128
11. Galloway D (1999) Mapping work processes. ASQC Quality Press, Milwaukee
12. Ulrich KT, Eppinger SD (2008) Product design and development. McGraw-Hill, New York
13. Damelio R (1996) The basics of process mapping. Quality Resources, Florida
14. Tapping D, Shuker T (2003) Value stream management for the lean office. Productivity Press, New York
15. Keyte B, Locher D (2004) The complete lean enterprise: value stream mapping for administrative and office processes. Productivity Press, New York
16. Graban M (2009) Lean hospitals: improving quality, patient safety, and employee satisfaction. CRC Press, Florida
17. Morgan JM (2002) High performance product development: a systems approach to a lean product development process. Univ Michigan
18. Millard RL (2001) Value stream mapping for product development. Massachusetts Inst Technol
19. Locher DA (2008) Value stream mapping for lean development. Productivity Press, New York
20. Mascitelli R (2007) Lean product development guidebook—everything your design team needs to improve efficiency and slash time-to-market. Technol Perspect
21. McManus HL (2005) Product development value stream mapping (PDVSM) manual. Lean Aerosp Initiative
22. Bryman A, Bell E (2011) Business research methods. Oxford University Press, Oxford
23. Fritzell I, Göransson G (2012) Value stream mapping in product development—adapting value stream mapping at Ascom Wireless Solutions. Master's thesis, Chalmers University of Technology
24. Yin RK (2009) Case study research: design and methods. SAGE Publications Inc, USA
25. Wallén G (1996) Vetenskapsteori och forskningsmetodik (in Swedish). Studentlitteratur, Sweden

Lifecycle Challenges in Long Life and Regulated Industry Products

S. A. Srinivasa Moorthy

Abstract With the rapid commoditization of electronics, its content in the products are going up and this has resulted in shorter lifecycle of the systems and components. As the performance per dollar increases, speed of obsolescence of components is quicker. Most of the industries are adjusting to this rapid change to stay in business even though this puts lots of strain on their business. Changes can be replacement for obsolete parts, compaction, aesthetic changes etc. While this may be fine with industries like Consumer, Automotive etc. there are class of products and industries (also known as domains) which have a different set of requirements. Products in the Avionics and Medical domain not only have a very long life but also very tightly regulated by the bodies like Federal Aviation Administration (FAA) and Food and Drug Administration (FDA). This puts additional challenge of getting the product approved and certified whenever changes are made. This paper looks at the different challenges that product with long lifecycle encounter and how some of those issues are addressed. In many cases, impact of a small change can be very profound and unless a well designed process is in place. Otherwise addressing the life cycle challenges can be tricky. Added to this is the unique development processes used in Medical Devices and Avionics Devices development. In both these cases the uniqueness comes into effect due to the safety and reliability requirements of the products as they deal with patients and passengers. This paper deals with two types of challenges: (1) First one are the issues that designers need to address when they are designing the system so that they don't have issues later due to long life (Preventive), (2) Challenges that need to addressed when product has lifecycle issues (Reactive).

S. A. Srinivasa Moorthy (✉)
VP-Design Engineering and Head Sanmina-SCI India Design Center, Sanmina-SCI Technology India Private Limited, A3- Phase II, MEPZ Special Economic Zone, NH 45 Tambaram, Chennai 600004, India
e-mail: srinivasa.moorthy@sanmina-sci.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_66, © Springer India 2013

Keywords NPI (new product introduction) · Outsourcing · WEEE · FDA · FAA · Domains · Avionics · Medical devices · MDSS · EASA · COTS · Obsolescence

1 Introduction

With increased focus on outsourcing, product design process has undergone a paradigm shift. Today about 95 % of electronics product manufacturing is outsourced. Primary driver for the outsourcing is the cost of product, effective utilization of capital invested and above all globalization of markets. With the increased outsourcing product management has undergone drastic change. With the reduced time-to-market and increased competition understanding the Product Life Cycle (PLC) has become very important. PLC was not attracting attention when a product design and manufacturing is done in house under one roof. Most transactions were informal and unstructured. With increased competition and global market pressure companies have started outsourcing the manufacturing to save on cost and reduce the capital expenses. In a scenario like this managing product becomes very critical and especially managing the product till it is withdrawn is even more challenging. This especially became critical when the product had a long service life. Compounding this problem are the issues that arise when the products and its usage are covered by regulatory bodies. Medical Devices and Avionics Products are two such categories that are regulated by Government bodies. In this paper some of the Product Life Cycle issues of long life product are discussed. This paper outlines the strategies for managing the products whose lifecycles are long and controlled by agencies and especially in the context of outsourced manufacturing.

2 Brief Introduction to Product Lifecycle

Human's have a life cycle which is very predictable and defined as shown in the Fig. 1. We can see that human life goes through defined phases and finally fade away.

Likewise products do have very clearly defined phases of life cycle before the product is withdrawn. In fact, it is interesting to note that withdrawing a product in

Fig. 1 Human life cycle

Fig. 2 Product life cycle

a formal way was never a topic of discussion and now this has become the prime driver for lots of Product Life Cycle issues [1]. Primary reasons are the environmental laws and the demand for safe disposal of electronic waste when the product is pulled out of service. Typical electronic product life cycle is represented is the Fig. 2.

Products have very clear defined phases of lifecycle starting from Concept to final withdrawal. Understanding this lifecycle allows us to design a product and manage it well throughout its life. In the above figure Life Cycle looks well defined and discrete with clear interfaces between phases. But when a product is under development most of the activities need close interaction with the participating teams like Industrial Design, HW and SW Design, Manufacturing, New Product Introduction (NPI) and Operations. When the design and manufacturing is under one roof this process was simple and easy to implement. As the outsourcing to external partners caught on, managing the product became a challenge. This inter relationship is explained in the Fig. 3. We can see in each phase corresponding to the design team activity there is a corresponding activity from the manufacturing which is crucial for the product development and managing.

While most of us are familiar with the activities in each phase one crucial thing to note is the explicit product withdrawal phase which is driven by the new environmental standards like Reduction of Hazardous Substances (RoHS) and Waste Electronic and Electrical Equipment (WEEE) directive. These standards

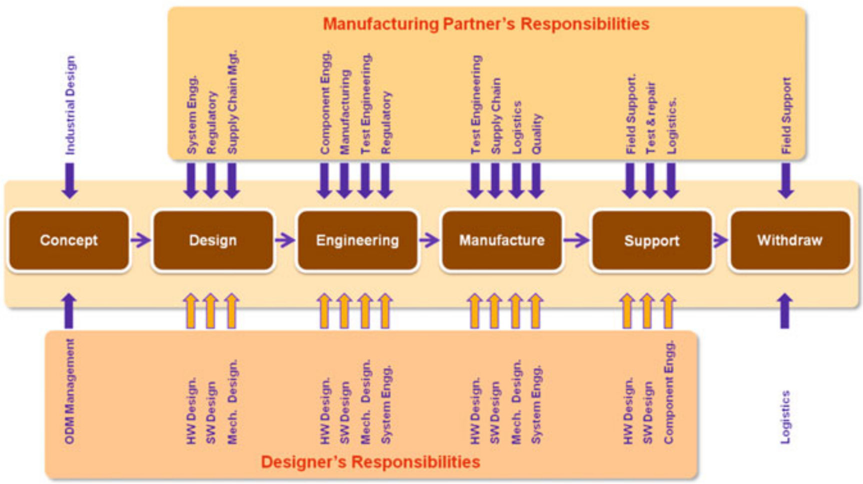


Fig. 3 Lifecycle and activity interactions

explicitly put the onus of product recycling as well as disposal in the hands of the manufacturer and expect written compliance to the same. They also need documentation and procedures to demonstrate the safe disassembly and safe disposability of products. It is this aspect that is becoming a big issue in older products which need a refresh or upgrade or ability to dispose to meet the requirements. In most cases meeting the environmental requirements will have to be addressed from the design phase, while that will be a challenge in old and matured products as there is little flexibility to make them meet the requirements. Assuming older products are subjected to product refresh, outsourced manufacturing complicates the refresh/redesign process.

Looking at the Life Cycle from this perspective it becomes very clear that in the scenario of outsourcing, a completely different approach to the product life cycle management is needed. To understand the intricacies of the in house and outsourced design and manufacturing let us refer to the Table 1 which compares some of the issues between these two. While the list is not exhaustive one nevertheless show the importance of issues.

Looking at the above table we can get an overview of the difference in approaches between in house and outsourced product design and manufacturing. Also we can see the emergence of the simple fact that outsourcing needs extreme discipline and rigorous process for success. In fact it is this aspect that brings the Product Lifecycle Management challenges.

Table 1 Characteristics of in house and outsourced product development and manufacture

S. no	In house development and manufacturing	Outsourced design and manufacturing
1	Most of the discussions and activities happen in house in a very informal way and decisions sometimes based on personal relationship	Discussions need to be structured and documented and signed off. Identification of a clear owner with responsibility is a must
2	Focus of development is on technology and not on the feasibility of manufacturing resulting in the manufacturing team doing what the design team wants leading escalated manufacturing cost.	Focus is on manufacturability, availability, cost and product support. Elaborate checklist and guidelines need to be followed for a product release
3	Multiple iterations are a norm with no or very minimal processes and documentation leading personal time of developers being spent in the assembly line	Extremely defined process with each stage reviewed and signed off. Difficult to implement on the fly changes and needs complete documentation
4	*"Technology First—Rest is Next"* attitude. This results in manufacturing aspects not getting priority	Focus is on manufacturing and all activities like assembly, testing, vendor development, packaging gets equal priority
5	Less structured process and with minimal documentation. Most of the times informal with dependence on tribal knowledge	Rigorous process following and proper documentation to the extent lack of documentation can stall the progress

Products are classified into multiple domains such as Automotive, Consumer, Industrial, Telecommunication, Networking, Avionics and Medical Devices depending on where they are used. It is important to note that each domain has distinct characteristics based on its usage and the product development process. While a long life of the product creates Life Cycle issues, the domain they operate (especially Medical and Avionics domain) have a larger impact on the product life cycle due to process intensity that is mandated. Both Medical and Avionics development mandates strict process and documentation requirements for both old and new products, due to the safety aspect of the products.

3 Regulated Industry Products Development and Manufacture

While the conventional Product development process is linear, development processes of Medical and Avionics products have lots of checks and balances. Also design and manufacturing data have to be documented and submitted to the regulatory agencies like FAA and FDA. While passenger aircrafts avionics are regulated by Federal Aviation Administration (FAA) Medical Devices are regulated by Food and Drug Administration (FDA) in USA. Primary reason for this is the safety of humans involved both in Aircrafts and Medical Devices. In both cases the developers have to prove the process they have followed is sound and meets the safety standards and also all the products are produced in conformance with the standards. The data pertaining to this have to be retained for audit purpose any time. Typically most countries use standards defined by these two bodies as a de facto standard. Europe does have its own standards European Aviation Safety Agency (EASA) and Medical Device Safety Service (MDSS) to be used in European Union.

Both the agencies have a very rigorous process for the approval of product that are either new or products which are in use is and due for enhanced for functionality. Regulated industry products are classified into different groups based on the risk during use. For products to be used in USA, typically there are 3 classes in Medical Devices and 5 classes in Avionics devices as mandated by FDA and FAA respectively. In the case of Medical Devices [2] FDA classifies the products as Class I, Class II and Class III with Class I being highest risk device capable of causing fatality (like Pacemakers etc.) and Class III being the lowest risk device like Thermometer etc. Similarly in Avionics FAA [3] have 5 classes of safety with Class E being the highest risk device and Class A being the low risk device. When a regulated industry product faces Life Cycle issue (e.g. component obsolescence) the development process for alleviating this has to follow the development process mandated by the regulatory agencies which is very important.

In general the processes followed for development are similar. The Fig. 4 shows the generic product development cycle for regulated industry products.

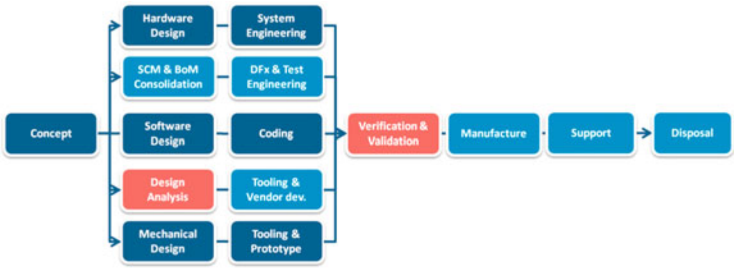


Fig. 4 Generic regulated industry product development process

When Medical and Avionics product are developed, there are two unique processes which are important. First process is ***Design Analysis***. Design Analysis is a process which is done to ensure the product safe and reliable and the second set of processes is ***Verification and Validation*** which ensures product meets all the Safety and Reliability goals. While this is a generic process depending on the medical or avionics domain process varies in a subtle way.

For Medical Devices, Fig. 5 shows the development process for development.

From the above we can see the significant process is the review process at every stage. Additionally this review process is applicable for both the new products and existing products which undergo changes. It is this aspect that creates challenges in managing the product life cycle of Medical Devices when the product is matured and needs a change only.

In the similar way Avionics product do have a rigorous product development process as shown in the Fig. 6. Avionics Product development is much more detailed and rigorous with reviews and validations done by the agencies and experts approved by the FAA.

From the two process flow diagrams we can see that two essential elements that need critical attention. First one is thorough review in every stage and the second is

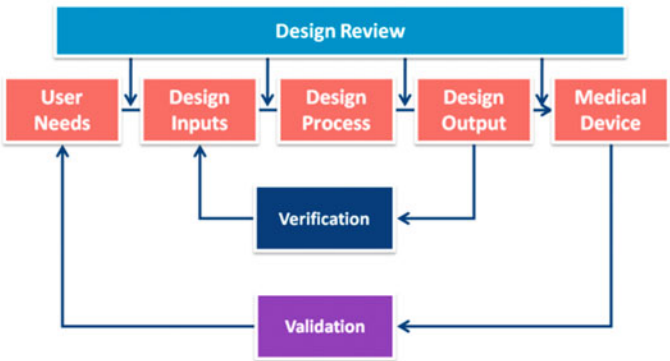


Fig. 5 Product development process for medical devices

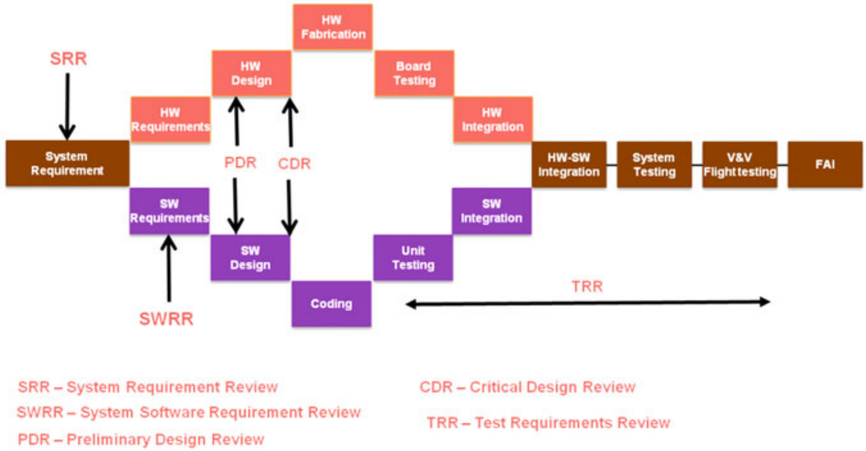


Fig. 6 Product development process for avionics devices

documenting the results in every stage. A generalized process flow is listed as below;

1. Document every stage of the development process
2. Review every stage of development both entry and exit of every stage
3. Verify the results at every stage
4. Validate the output at every stage
5. Maintain the history of development at every stage.

Effectively the above process ensures the history of the product development including the decisions taken and the review records need to logged in and recorded. Finally these logs and reports form the main part of documentation that need to be submitted to the agencies like FAA and FDA for certification purpose. In the case of Medical Devices FDA calls these records as Device History Files (DHF) and Device Master Record (DMR). In the case EU certification these are called as Technical Construction File (TCF).

4 Product Life Cycle Issues

We had looked at the generic product development cycle and regulated industry specific development processes especially for long life products. Let us now look at the key aspects that impact the Product Life cycle. Out of multiple issues which impact the Life Cycle of a product; the following are the key issues that have the maximum impact and needs attention.

1. Component Obsolescence
2. Component Availability

3. Technology Churn
4. International Standards like environmental compliance
5. Skill and knowledge
6. Product Support issues
7. Merger and Acquisition.

4.1 Component Obsolescence

Component Obsolescence is the single biggest contributor for PLC issue. Most of the times we assume the obsolescence of a part take a long to happen. But with the technology development and market conditions component vendor obsolete the parts much earlier. This puts a stress on constant lookout for any obsolescence by the components vendors. While most vendors have standard process of obsolescence based on market conditions and age of the part this can be show stopper. Only Electronic Manufacturing Service (EMS) vendors and some of the large Original Equipment Manufacturer (OEMs) have process to address this successfully. In most cases ability to address Obsolescence is skill that is very unique to companies.

4.2 Component Availability

Most of the designers think that when they select a part they assume the component availability is a non issue. However in reality unless proper procurement and supply chain management strategy is followed even simple parts can become a problem due to market conditions [4, 5]. In fact commodity parts like Memories, Capacitors experience frequent supply chokes (also called as parts on allocation where component manufacturers ration the sale). This can lead to production stoppage or increase in product cost and in some cases both. It is essential that designers select parts and alternatives during the design phase to ensure component is available without any issue.

4.3 Technology Churn

One of the new entrants into the list of issues is the Technology Churn. A decade back the speed of change of semiconductor technology was not as rapid as it is today. The rate of change in the semiconductor technology today doesn't guarantee that a part which is manufactured with the latest technology need not be backward compatible to the same part with an older technology. Devices manufactured with the current technologies have faster rise times leading problems in the older design. In many cases while they functionally work, they fail in compliance standards like Electro Magnetic Compatibility/Electro Magnetic Interference (EMC/EMI).

4.4 International Standards and Environmental Compliance

Environmental compliance brought in the 21st century has been the biggest contributor to lifecycle issues. Global standards like RoHS and WEEE and related country specific standards have created life cycle issue for products which were designed before these legislations were framed. Their continued manufacture and sale now forces them to meet the new environmental standards. In most cases the effort needed to implement the compliance is very high and companies struggle with this. This is becoming a biggest lifecycle support issue for both OEMs and EMS vendors.

4.5 Skill and Knowledge

Next biggest non technical challenge is the product knowledge management. Product knowledge typically gets lost as the time progresses and gets aggravated when the manufacturing is outsourced and the organization loses it's connect with the product. This is especially becoming critical when the product has a long life. In most cases the engineers who were involved in the original product development have either moved to other projects or have left the organization. In most product companies product sustenance strategy is never done consciously and when a lifecycle issue (like component obsolescence) crops up the situation turns panic. Sustenance of matured products needs deep engineering skills for successful revamp of a product.

4.6 Support Issues

This is an interesting problem where clients insist on retaining the product and expect the OEM support as long as they use it. Most hospitals and aviation industry do have this requirement as the equipment cost a lot and they will be profitable only when the product is used for 15–20 years. In most cases the support will be contract bound and OEMs are obliged to support and this becomes a challenge when the product is too old to support and retrofitting needs certification approvals.

4.7 Merger and Acquisitions

Unique products come out of startups but this also comes with a risk of start up getting sold out to a bigger company. In most cases the acquisition happens because the buyer feels threatened by the products from start up so they buy the start up only to kill the product. This leaves the early customers with a product which has no support leading unhappy customers. Another fallout of the M&A is the core engineering team of the startup leaves as soon as the acquisition is over leaving the product without any support for further improvement or follows up products.

5 Strategies for Managing Product Life Cycle Issues

Having seen the lifecycle details and the issues associated with that let us briefly see some of the strategies that we should use to tackle the product Life Cycle issues. For the best management of Product Life Cycle primary requirement is the thorough understanding of the product life cycle of the product and the domain. If a product is designed with Product Life Cycle in mind many problems can be addressed easily up front during design as well as during its active life. In this section we will outline some of the strategies that we can use to address the lifecycle issue.

- When designing electronic products select critical parts like CPUs from a vendor who has a very clear road map especially drop in replaceable enhanced part. Many vendors keep enhancing their offering with little or no care for the existing users leaving the existing users high and dry. Connected to this issue ensure is the tools chain associated with the CPUs need to be well established and supported.
- Put in place a mechanism which proactively tracks the obsolescence well in advance and leaves enough time for redesign if needed. Most EMS vendors have robust mechanism. But they typically use that for ensuring smooth supply chain. Taking help from them proactively will go a long way in addressing the life cycle issues.
- Track the performance of the critical parts from the field carefully. Have a communication mechanism connecting the development team, manufacturing partner and the field support teams. The reason is in most organizations field support team, development team and manufacturing team will not be connected in real-time. So components failures as well as performance issues don't get the due visibility in time. This blinds the teams in addressing issues on time and by the time problem scales up things become unmanageable.
- Connect with your EMS partner's supply chain to understand the component availability trend and up front work with them to design in alternate parts to avoid single vendor situation. Most companies look for an alternate only when

the existing part runs into availability issue and the alternate part invariably needs tuning and this leading to burning midnight oil. Sensible thing will be to make provision for one or two steps higher capacity parts as in most cases as the volume increases higher capacity parts will be cheaper than the currently used ones!

- If programmable devices are used always make provision to program them after assembly. This allows easy assembly process as well as field upgrades. This is especially true for Flash memories and Programmable Logic parts. Also ensure when multiple programmable parts are used in a single system compatible versions are captured in the system and verified by the software so that if any one part has a different program system detects it easily and ensures compatible versions run in the system.
- If the system needs calibration implement the system in such a way it can calibrate itself. Complex calibration process complicates the product support very much and building this as a part of the product will be beneficial. In most cases calibration is the least addressed issue and comes as a post manufacturing issue and not as a design parameter.
- Incorporate a dedicated Life Cycle tracking process as part of product's technical documentation capturing decisions taken to address life cycle related issues.

While the above captures some of the strategies (not exhaustive) there are a few non technical strategies that help in tackling the life cycle issues. Let us see a few of them.

- Document the tribal knowledge existing in the organization in whatever form so that it will help in tackling the product issues later
- Focus on functionality not on technology, most long life products work in the field immaterial of what technology they use. The key is the functioning of the product not what technology it is made of
- Obsolescence is inevitable and can't be avoided, so build your designs anticipating that in a proactive fashion rather than reacting to obsolescence. The same is true to globalization of market for the products
- In a regulated industry product, strike a balance between hardware and software. Hardware changes are easier to verify and validate as compared to verification and validation of software and hence making hardware only changes are much easier to get approved. Best approach is to have the architecture as a platform based one which helps addressing lifecycle issues and product functionality doesn't depend on the underlying hardware.

6 Conclusion

Finally to sum it up, longer the products life more the lifecycle issue and if the products are from regulated industry it gets more complicated. Best solution is to design the product with lifecycle in mind. As the product matures proactively address the issue and make incremental changes which helps in managing lifecycle issue much more effectively.

References

1. Saaksvuori A, Immonen A product life cycle management (ISBN 978-3-540-78173-8)
2. King PH, Fries RC Design of bio medical devices (ISBN 0-8247-0889-X)
3. Hilderman V, Baghai T Avionics certification (ISBN 978-1-885544-25-4
4. http://www.authorizeddirectory.com/pdfs/fake-parts-threaten-electronics-market.pdf
5. http://www.wnd.com/2012/05/fake-electronics-feared-undermining-u-s-defense/

Idea Management: The Importance of Ideas to Design Business Success

Camille Chinneck and Simon Bolton

Abstract Ideas are the life-blood of design. This paper presents a theoretical review of current trends in Idea Management (IM) within the front-end of New Product Development (NPD) literature. It identifies 28 success factors for managing and generating ideas within organizations and five emerging research themes. This is important to design as the Fuzzy Front-End (FFE) is one of the greatest opportunities for improving the overall innovation process [1]. Three idea management trends are discussed: (1) quantity versus quality: a shift from generating as many new ideas as possible to maximizing the number of good ideas (2) internal versus external practices: an increasing importance placed on implementing external ideas, and (3) ad-hoc versus systematic: companies are starting to apply a systematic approach to idea generation aligned with corporate design strategy. It will conclude by discussing future research opportunities in idea management and highlights the implications for design managers.

Keywords Idea management · Front end of innovation · Idea generation · Importance of ideas · New product development

C. Chinneck (✉) · S. Bolton
Center for Competitive Creative Design, Cranfield University, Cranfield, Bedfordshire MK43 0AL, UK
e-mail: c.chinneck@cranfield.ac.uk

S. Bolton
e-mail: s.bolton@cranfield.ac.uk

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_67, © Springer India 2013

1 Introduction

In this paper, we identify the themes and emerging trends in Idea Management (IM) within the front-end of innovation literature. The knowledge contribution is the identification of five IM themes and their level of establishment in the field. It is accepted that the innovation process is too important to be left to chance. The same rationale applies to ideas, as they need to be effectively managed as an antecedent to innovation. Prior studies have shown that IM and idea generation are in serious need of improved management [2]. Managing ideas is a complex issue [3] but when implemented effectively, idea management has been found to increase sales from new products by 7.2 % [4].

The context of this research is the front-end of innovation, also known as the "fuzzy front-end" [5], which is generally accepted to be the phase where initial product concepts are conceived [1, 6]. Research on the fuzzy front-end (FFE) has been receiving an increasing amount of attention since it was identified to be one of the greatest opportunities for improving the overall innovation process [1]. The FFE activities are important to design as they typically involve high levels of technical and market uncertainty, impacting on idea generation, idea screening and concept development. These front-end activities are critical to design management practices as they lay the foundations of the subsequent NPD process, prior to an idea being fully defined.

Innovation has been defined as the successful implementation of creative ideas within an organization [7]. Idea Management is the process of recognizing the need for ideas, generating and evaluating them [3]. Definitions such as these have been criticized for neglected elements such as idea sourcing [8]. In order to avoid ambiguity, definitions for the key constructs were found from the literature and are presented in Table 1. There is a lack of universally accepted definitions for these terms within the literature [8]. For example, the terms 'fuzzy front-end' and 'front-end of innovation' are one and the same [9].

The rest of the paper is structured as follows; Sect. 2 describes the methodology within a two-element literature review and key topics, Sect. 3 discusses emerging IM themes, Sect. 4 details 28 success factors for IM and idea generation followed by Sect. 5 which outlines three IM trends. The paper concludes with implications for design managers as well as future research opportunities. These findings are of particular interest to academics and practitioners involved in design management and front-end innovation.

2 Literature Review

2.1 Method

The literature review was split into two elements: an exploratory subject review of 86 papers and a systematic review of 134 papers. The literature review and resulting analysis identified best practices, key topics and emerging trends in IM

Table 1 Literature definitions of idea management, fuzzy front-end, idea and concept

Construct	Author	Definition
Idea management	Vandenbosch et al. [3]	"…the concept of idea management, defined as the process of recognizing the need for ideas, and generating and evaluating them" (p. 260)
	Bakker et al. [35]	"The knowledge management system (as a tool for idea management) can only facilitate the capturing, selection and enhancing of ideas among members of the organization" (p. 302)
	Boeddrich [36]	"… (idea management = phase before the project decision)…" (p. 275)
Fuzzy Front-End	Koen et al. [1]	"…those activities that take place prior to the formal, well-structured New Product and Process Development or "Stage-Gate" process…" (p. 46)
	Smith and Reinertsen [5]	"It is the fuzzy zone between when the opportunity is known and when we mount a serious effort on the development project" (p. 49)
	Reid and Brentani [37]	"…the time and activity prior to an organisation's first screen of a new product idea…" (p. 170)
	Murphy and Kumar [29]	"…from the generation of an idea to its approval for development…" (p. 5)
	Kim and Wilemon [38]	"…the period between when an opportunity is first considered and when an idea is judged ready for development." (p. 270)
	Reinertsen [39]	"…the time between when you could have started development and when you actually do, the fuzzy front-end." (p. 4)
Idea	Montoya-Weiss and O'Driscoll [40]	"An idea is defined as the initial, most embryonic form of a new product or service idea-typically a one-line description accompanied by a high-level technical diagram." (p. 154)
	Knudsen et al. [15]	"…ideas are general concepts of what might be technically or economically feasible…" (p. 124)
	Brem and Voigt [9]	"…an idea is a proposal for an action, which either reacts to recent developments or proactively utilizes them." (p. 360)
Concept	Ulrich and Eppinger [41]	"A product concept is an approximate description of the technology, working principles, and form of the product." (p. 108)
	Montoya-Weiss and O'Driscoll [40]	"A concept…is defined as a form, technology, plus a clear statement of customer benefit" (p. 145)
	Backman et al. [42]	"…'concept' has the meaning of a 'development concept', that is, a set of proposed solutions complying with a set of fixed constraints." (p. 20)

Source Provided in table

and idea generation. The exploratory review consisted of a broad search via subject area covering all available journals in four databases; Scopus, ABI, EBSCO, and Web of Knowledge. The purpose for this two-element approach was so that the knowledge from internationally recognized journals as well as highly relevant subject knowledge in other journals was utilized.

The key topics and emerging trends were identified from the systematic review in three key innovation journals; *Journal of Product Innovation Management*, *R and D Management*, and *Technovation*. These journals were selected for two reasons; (1) all of them are graded by the ABS Journal Quality Guide [10] as grade three or four star world elite innovation journals, and (2) these journals revealed the highest number of relevant papers from the performed keyword search strings.

Of the 134 papers analyzed from three top ranked journals, 39 % were theoretical, 33 % research, 27 % practice and 1 % policy. The literature type was determined according to the characterization established by Wallace and Wray [11]. The literature type is fairly evenly split between theoretical, research and practice, however, there is a very low percentage of policy literature. This is most likely due to the academic audience the papers are targeting. A total of 107 (80 %) papers provided empirical evidence to support their arguments.

2.2 Key Topics

Figure 1 below illustrates these emerging topics in representative circles, with their relative size indicating the number of relevant papers reviewed in that topic. The analysis of the reviewed papers reveals three dominant topics, with NPD being the most common with 22 papers, followed jointly by the fuzzy front-end and open innovation with 18 papers each. It should be noted that the shown number of papers addressing these broad topics is not necessarily an indicator of their importance.

The results suggest that these topics are more established within the literature. Ideation (or idea generation), IM and Knowledge Management (KM) had equal numbers of relevant papers. In order to identify and gain a deeper understanding of the important areas within the research, sub-themes were grouped into overarching themes, further detailed in Sect. 3.

3 Emerging Idea Management Themes

The results of the thematic coding analysis, as described by Robson [12], are illustrated in Table 2. These particular sub-themes were filtered from a list of over 320 topics. These topics were recorded in an Excel database. In order for a topic to survive the filtering process it had to satisfy two decision-making criteria; (1) the topic had to be mentioned in three or more papers within a top journal, and (2) the sum total for each topic across all three journals had to amount to 10 or more separate paper mentions. This filtering process ensured that no theme was included that was not identified as important by at least 10 authors in top journals. The resulting 15 sub-themes were then grouped together into five overarching themes of *process*, *ideas*, *knowledge*, *innovation type*, and *people*. These extracted themes and sub-themes provide insight into important areas discussed within the literature in relation to Idea Management and idea generation.

The sub-themes marked with an asterisk were acknowledged as important across all three journals. This suggests they are accepted and relevant across a broader range of disciplines. It could also mean that these marked sub-themes are well established due to their clear definitions within the literature. It also demonstrates the growing importance of *process* and *ideas* as key factors in Idea Management and idea generation. Figure 2 displays the five research themes and number of relevant papers published in each year addressing that theme.

All of the identified themes relate to the role of Idea Management and can be grouped under organizational culture. Within the papers reviewed, the theme of *ideas* was the most well established theme covering the widest range of years. In comparison, *innovation type*, *people*, and *knowledge* are less well established covering 14 years overall. The median years for each theme are similar with 2006 being the median year for three themes. The most published years for the themes are all fairly recent. These results support the statement that this research addresses areas receiving greater attention and importance in the literature in recent years.

The majority of papers discussing *process*, *ideas* and *innovation type*, did so in a high level of detail as opposed to mentioning the topic or discussing it briefly. This trend does not apply to the themes of *knowledge* and *people*. The number of papers that mention *knowledge* and the number discussing it in detail were equal, whilst papers discussing the theme of *people* were equally spread over a brief discussion of the topic and a detailed discussion. This suggests that *knowledge* and *people* are less established as influencing factors on the front-end of innovation when compared to the themes of *process*, *ideas* and *innovation type*. This result could be influenced to differing levels of specificity in labeling the sub-themes and the keyword strategy used to collect the papers.

4 Idea Management and Idea Generation Success Factors

A total of 28 success factors have been found for Idea Management and idea generation, detailed in Table 3. As previously stated, these particular factors were collected from a systematic review of three top innovation journals and an exploratory subject search. These factors were explicitly stated to be important to IM and idea generation practices by authors in the front-end literature. It should be noted that this is not a complete set of success factors for IM and idea generation. We acknowledge that other relevant success factors may not be covered. We suspect that the reason for this is due to the product development context of this

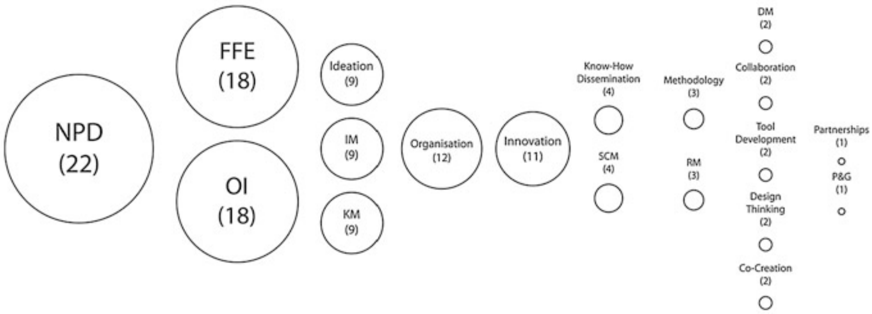


Fig. 1 Key topics from reviewed literature. *Source* Authors

research and the lack of a common language and understanding about how ideas are managed during the uncertain fuzzy front-end phase [1].

The resulting success factors were grouped into two broad categories of process and people. These factors include having a clear business purpose for the ideation event, understanding the window of opportunity, tapping into a diverse pool of idea contributors, and developing an idea through collaboration [13]. Additional success factors include having creative employees, a systematic idea generation process, available time for generating ideas, and a selection and idea evaluation method [4].

Two common mistakes are made in the innovation process; not understanding the difference between incremental versus radical ideas, and not recognizing the value of idea fragments [14]. Successful innovations are often not the result of a single idea, but of a 'bundle or ensemble of ideas and knowledge' [3]. Users are more prone to providing incremental ideas born from deep understanding of their needs rather than suppliers who tend to suggest more technical based solutions aligned to their capabilities [15]. Idea generation techniques that generate the highest numbers of actionable ideas allow for the 'natural role playing of personality types' [16]. This is important if companies want to generate as many actionable ideas as possible. The main role of IM is in ensuring these ideas are captured and managed effectively.

5 Emerging Idea Management Trends

5.1 Idea Quantity Versus Quality

Despite the fact that all innovation starts with an idea, little attention has been paid in the literature to understanding the phase of idea creation [17]. Rather than managing the ideation process, the most common approach has been to generate a large number of ideas [18]. This method was originally known as Osborn's principle that quantity yields quality [19]. There is a shifting focus from generating

Table 2 Emerging themes and sub-themes breakdown

Overarching themes	Sub-themes				
Process (99)	NPD (31)	Formal versus informal process[a] (20)	FFE (22)	Network effects (13)	Creativity (11)
Ideas (70)	External sources of ideas[a] (24)	Internal sources of ideas[a] (17)	Idea generation (15)	Evaluating ideas (14)	
Knowledge (31)	Tacit knowledge (18)	Knowledge dissemination[a] (13)			
Innovation type (29)	Radical innovation[a] (15)	Incremental innovation[a] (14)			
People (27)	Communication[a] (14)	Intrinsic versus extrinsic motivations[a] (13)			

Source Authors
(x) number of papers addressing topic in 3 journals
[a] topic addressed across all 3 journals

Fig. 2 Timeline reveals the establishment of idea management themes by publication volume. *Source* Authors

as many new ideas as possible to maximizing the number of good ideas that are fed into the NPD pipeline.

Idea quality has been identified to be an important, yet neglected, factor to consider with innovation ideas [20]. There is debate in the literature as to how many raw ideas are required to generate one commercially successful innovation. A vast range of answers have been proposed from 3,000 [21], 100 [22] to 6.6 [1]. This suggests that it is more important that good ideas are effectively managed and implemented over and above generating a large quantity of ideas [1].

5.2 Internal Versus External Practices

Increasing importance is being placed on the sourcing and implementation of external ideas, particularly from collaboration with customers, suppliers and partners. An organization's ability to identify, acquire, and utilize external ideas can be seen as a critical factor in regards to market success [23]. External impacting factors have been identified as an organization's network capabilities, industry structure, competition, and rate of technological change [14].

A key emerging trend is the move from a closed innovation paradigm to an open innovation paradigm in which external ideas are exploited for competitive advantage [24]. Seeking ideas from outside the firm applies best to consumer goods industries [25]. This trend is particularly important to IM as ideas from external sources will need to be managed differently from internal ideas due to barriers such as the 'not invented here' (NIH) syndrome [26]. The absorptive capacity is a critical part of innovation capability [27] in order to internally implement external ideas.

5.3 Ad-Hoc Versus Systematic

Innovation in organizations is often left as an informal ad-hoc process and has been stated to occur by serendipity rather than deliberate management [28]. This view that innovation can only be achieved through ad-hoc processes appears to be changing. This emerging trend reflects how companies are recognizing the need to apply a more systematic approach to idea generation and evaluation, aligned with corporate design strategy. Ideas that are more closely aligned to strategy, which tend to be formally formed, are more likely to lead to a commercially successful product for the marketplace [2].

Actual go/no go decisions are affected by highly subjective criteria such as top management's 'gut feel' [29]. It was found that a large multinational company spent between 5,500 and 11,000 h of total manager assessment time to evaluate 20,000 ideas [30]. This means that organizations have the potential to save a significant amount of time by implementing an effective IM system. All in all, this trend has to do with approaching the problem of finding the right balance between intent and spontaneity with an elusive phenomenon [31].

Table 3 28 idea management and idea generation success factors

Theme	Idea management	Source	Idea generation	Source
Process	Use a systematic process	Little [4]	Generate by association	Wagner and Hayashi [43]
	Give available time for idea generation	Little [4]	Build idea chains	Wagner and Hayashi 43
	Employ an idea selection and evaluation method	Little [4]	Use theme-based generation	Wagner and Hayashi 43
	Establish a clear business purpose	Gamlin et al. [13]	Ensure strategy alignment	Cooper and Edgett [44]
	Understand window of opportunity	Gamlin et al. [13]	Use external stimuli	Anderson [45]
	Reframe challenges	Gamlin et al. [13]	Use a loosely structured technique	Callaghan [16]
	Understand the differences between incremental and radical ideas	Davila et al. [14]	Utilize highly networked individuals	Bond III et al. [46]
	Recognize the value of idea fragments	Davila et al. [14]	Include prompting questions in tools	Wagner and Hayashi 43
People	Have creative employees	Little [4]	Use tools which break conceptual and cognitive sets	Brennan and Dooley [47]
	Tap into diverse pool of idea contributors	Gamlin et al. [13]	Allow role playing of personality types	Callaghan [16]
	Facilitate collaboration	Björk and Magnusson [20]	Make analogies	Ulrich and Eppinger [41]
	Continual idea commitment	Griffiths-Hemans and Grover [51]	Involve lead users	von Hippel [48]
	Collective ownership	Vandenbosch et al. [3]	Group communication	Van Dijk and Van Den Ende [49]
	High idea submission participation	Vandenbosch et al. [3]	Encourage knowledge sharing	Calantone et al. [50]

Source Provided in table–full references available upon request

6 Conclusion and Implications

This paper has presented a set of emerging Idea Management trends and themes from reviewing the front-end innovation literature. A timeline was presented which demonstrated the growing importance of the five identified emerging IM themes. The trends are important to design because of their close relation to Idea Management and front-end design activities. In addition, 28 best practice success factors were identified from the literature: 14 for Idea Management and 14 for idea generation. We argue that IM is an important emerging research area in need of better tools, methods and processes.

Ideas are important to business success because they are the starting point to all innovations [32]. The value of idea fragments and the differences between incremental and radical ideas were found to be important among other factors. An integrated and effective IM system has benefits such as helping to foster an innovation culture in which employee ideas are valued.

A surprising finding was that 'gut feel' of senior executives emerged as a common influencing factor during critical go/no go decisions. We feel that highly subjective criteria should be avoided when evaluating important innovation opportunities. The decision-making process should be made explicit in order to disseminate knowledge to employees, in particular, the criteria being used to judge good ideas from the bad ones. This in turn, should facilitate the generation of more good quality ideas that can meet these criteria.

6.1 Implications for Design Managers

There are several implications for design managers planning to integrate an effective IM system. It is recommended that loosely structured techniques should be used for idea generation, which allows for participants to be creative whilst facilitating suggestions in-line with an aligned innovation strategy. Strategic alignment is especially important when sourcing ideas externally [22]. It is recommended that design managers recognize that the idea source impacts the types of ideas generated [15, 34].

The political processes taking place during the transfer of an idea through from conceptualization to NPD is also of importance. Design managers may consider providing employees with idea selling training to ensure that ideas are given an equal chance to be evaluated. Another benefit of an effective IM system is that it will save managerial time spent on evaluating ideas. The final success of IM strongly depends on the right process structure for the different kinds of ideas and the corresponding organizational implementation [9].

6.2 Future Research Opportunities

There is a general lack of clarity, definition and understanding within the FFE regarding the nature of ideas. There is an opportunity to develop effective idea evaluation and ranking methods to save a substantial amount of managerial time. It has been found that traditional financial analysis techniques do not work for early, embryonic ideas [22].

Organizations generate a higher quantity of ideas [26] but their dynamics hinder the number of novel ideas coming to light. Although research exists on organizational barriers to creativity, there is less on how to effectively minimize these barriers to allow more novel ideas to survive the evaluation process. A poor idea evaluation scheme will kill excellent ideas and favor the survival of less innovative ideas. This involves balancing the need for more innovative ideas and an organization taking on greater risk.

The impact of multiple strategic orientations on market information and its implementation is not currently known [33]. The literature suggests that people are more creative and dedicated when they are motivated by intrinsic factors such as enjoying the idea generation process rather than monetary rewards. An interesting research question is how to encourage employee's intrinsic motivations to increase their rate of idea submission [15].

A users' knowledge of underlying technology has an effect on their ability to contribute with incremental or radical ideas [34]. There is an opportunity to better manage this trade-off in novelty versus feasibility in order to incorporate the best of both. These gaps can be addressed through implementing appropriate IM and idea generation tools and templates. The next step of this research will be to undertake a series of controlled experimental case studies [12], focusing on empirically evaluating the impact of the success factors in Fast Moving Consumer Goods (FMCG) scenarios.

Acknowledgments The authors would like to extend their thanks to Procter & Gamble and the Engineering and Physical Sciences Research Council for sponsoring this research.

References

1. Koen O, Ajamian G, Burkart R, Clamen A, Davidson J, D'Amore R, Elkins C, Herald K, Incorvia M, Johnson A, Karol R, Seibert R, Slavejkov A, Wagner K (2001) Providing clarity and a common language to the "fuzzy front end". Res Technol Manag 44:46–55
2. Barczak G, Griffin A, Kahn KB (2009) Perspective: trends and drivers of success in NPD practices: results of the 2003 PDMA best practices study. J Prod Innov Manage 26:3–23
3. Vandenbosch B, Saatcioglu A, Fay S (2006) Idea management: a systemic view. J Manage Stud 43:260
4. Arthur DL (2005) How companies use innovation to improve profitability and growth. Innov Excellence Study. Boston. Available at: [http://www.adlittle.uk.com/reports_uk.html?&no_cache=1&extsearch=innovation&view=53]

5. Smith PG, Reinertsen DG (1991) Developing products in half the time. Wiley, New York
6. Khurana A, Rosenthal SR (1998) Towards holistic “front ends” in new product development. J Prod Innov Manage 15:57–74
7. Amabile TM, Conti R, Coon H, Lazenby J, Herron M (1996) Assessing the work environment for creativity. Acad Manag J 39:1154–1184
8. Soukhoroukova A, Spann M, Skiera B (2012) Sourcing, filtering, and evaluating new product ideas: an empirical exploration of the performance of idea markets. J Prod Innov Manage 29:100–112
9. Brem A, Voigt K-I (2009) Integration of market pull and technology push in the corporate front end and innovation management—insights from the German software industry. Technovation 29:351–367
10. Harvey C, Kelly A, Morris H, Rowlinson M (2010) Academic journal quality guide. The association of business schools, Version 4, London
11. Wallace M, Wray A (2006) Critical reading and writing for postgraduates. Sage, London
12. Robson C (2011) Real world research: a resource for users of social research methods in applied settings. Wiley, London
13. Gamlin JN, Yourd R, Patrick V (2007) Unlock creativity with “active” idea management. Res Technol Manag 50:13–16
14. Davila T, Epstein MJ, Shelton R (2006) Making innovation work: how to manage it, measure it, and profit from it. Wharton School Publishing, New Jersey
15. Knudsen MP (2007) The relative importance of interfirm relationships andknowledge transfer for new product development success. J Prod Innov Manage 24:117–138
16. Callaghan E (2009) Personalities of design thinking. Des Manag J 4:20–32
17. Dahl DW, Moreau P (2002) The influence and value of analogical thinking during new product ideation. J Mark Res 39:47–60
18. Goldenberg J, Mazursky D, Solomon S (1999) Toward identifying the inventive templates of new products: a channeled ideation approach 36:200–210
19. Osborn AF (1963) Applied imagination: principles and procedures for creative problem-solving. Scribner, New York
20. Björk J, Magnusson M (2009) Where do good innovation ideas come from? Exploring the influence of network connectivity on innovation idea quality. J Prod Innov Manage 26:662–670
21. Stevens G, Burley J (1997) 3,000 raw ideas equal 1 commercial success! Res Technol Manag 40:16–27
22. Cooper RG, Edgett SJ (2007) Generating new product ideas: feeding the innovation funnel. Product Development Institute, Ancaster
23. Van Aken JE, Weggeman MP (2000) Managing learning in informal innovation networks 30:139–149
24. Chesborough HW (2003) Open innovation: the new imperative for creating and profiting from technology. Harvard Business Press, Boston
25. Huston L, Sakkab N (2006) Connect and develop: inside Procter & Gamble’s new model for innovation. Harvard Bus Rev 84:58–66
26. Majaro S (1992) Managing ideas for profit: the creative gap. McGraw-Hill, New York
27. Tang HK (1998) An integrative model of innovation in organizations. Technovation 18:297–309
28. Desouza KC, Dombrowski C, Awazu Y, Baloh P, Papagari S, Jha S, Kim JY (2009) Crafting organizational innovation processes. Innov Manag Policy Pract 11:6–33
29. Murphy SA, Kumar V (1997) The front end of new product development: a Canadian survey. R and D Manag 27:5–15
30. Reitzig M (2011) Is your company choosing the best innovation ideas? MIT Sloan Manag Rev 52:47–52
31. Conway S (1995) Informal boundary-spanning communication in the innovation process: an empirical study. Technol Anal Strateg Manag 7:327–342

32. Koc T, Ceylan C (2007) Factors impacting the innovative capacity in large-scale companies. Technovation 27:105–114
33. Magnusson PR (2009) Exploring the contributions of involving ordinary users in ideation of technology-based services. J Prod Innov Manage 26:578–593
34. Spanjol J, Qualls WJ, Rosa JA (2011) How many and what kind? The role of strategic orientation in new product ideation. J Prod Innov Manage 28:236–250
35. Bakker H, Boersma K, Oreel S (2006) Creativity (ideas) management in industrial R&D organizations: a crea-political process model and an empirical illustration of corus RD&T. Creativity Innov Manage 15:296–309
36. Boeddrich HJ (2004) Ideas in the workplace: a new approach towards organising the fuzzy front end of the innovation process. Creativity Innov Manage 13:274–285
37. Reid SE, De Brentani U (2004) The fuzzy front end of new product development for discontinuous innovations: a theoretical model. J Prod Innov Manage 21:170–184
38. Kim J, Wilemon D (2002) Sources and assessment of complexity in NPD projects. R and D Manage 33:16–30
39. Reinertsen D (1994) Streamlining the fuzzy front-end. World Class Des Manufacture 1:4–8
40. Montoya-Weiss MM, O'Driscoll TM (2000) From experience: applying performance support technology in the fuzzy front end. J Prod Innov Manage 17:143–161
41. Ulrich KT, Eppinger SD (2000) Product design and development. Irwin McGraw-Hill, USA
42. Backman M, Börjesson S, Setterberg S (2007) Working with concepts in the fuzzy front end: exploring the context for innovation for different types of concepts at volvo cars. R and D Manag 37:17–28
43. Wagner C, Hayashi A (1994) A new way to create winning product ideas. J Prod Innov Manag 11:146–155
44. Cooper RG, Edgett S (2008) Ideation for product innovation: what are the best methods? PDMA Visions Magazine 32:12–17
45. Anderson BF (1975) Cognitive Psychology. Academic Press, New York
46. Bond EU, Walker BA, Hutt MD, Reingen PH (2004) Reputational effectiveness in cross-functional working relationships. J Prod Innov Manage 21:44–60
47. Brennan A, Dooley L (2005) Networked creativity: a structured management framework for stimulating innovation. Technovation 25:1388–1399
48. Von Hippel E (1988) The Sources of innovation. Oxford University Press, New York
49. Van Dijk C, Van Den Ende J (2002) Suggestion systems: transferring employee creativity into practicable ideas. R and D Manag 32:387–395
50. Calantone RJ, Cavusgil ST, Zhao Y (2002) Learning orientation, firm innovation capability, and firm performance. Ind Mark Manage 31:515–524
51. Griffiths-Hemans J, Grover R (2006) Setting the stage for creative new products: investigating the idea fruition process. J Acad Mark Sci 34:27–39

The Role of Experimental Design Approach in Decision Gates During New Product Development

Gajanan P. Kulkarni, Mary Mathew and S. Saleem Ahmed

Abstract Experimental Design Technique (EDT) in combination with stage gate strategy is a powerful tool for providing critical information to designers during New Product Development (NPD) as well as product redesign activities. It systematically evaluates new product design strategy and facilitates redesign of existing products. The benefit of applying this technique to NPD is to speed up the development process by allowing product design team to make more informed decisions based on the generated experimental design data. The risk that designers face every time when they take decisions at every stage of NPD is high. Going with right decisions and refusing the wrong ones should be the driving force throughout product development process. To understand the decision making challenges of a designer, this paper illustrates go-no-go decisions in a sample of graduate students who attempted to design a "green stool" as part of their class assignment. Factors common to and factors exclusive to the various design stages are analyzed and described using EDT. Although this integrated "experimental design go-no-go approach" was not used initially by the design students, our analysis on the process is done post factor.

Keywords New product development · Experimental design technique · Go-no-go decision gates

G. P. Kulkarni (✉) · M. Mathew · S. S. Ahmed
Centre for Product Design and Manufacturing, Indian Institute of Science, Bangalore, India
e-mail: gajanankulkarni87@gmail.com

M. Mathew
e-mail: mmathew@mgmt.iisc.ernet.in

S. S. Ahmed
e-mail: saleem@cpdm.iisc.ernet.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_68, © Springer India 2013

1 Introduction

New product development is one of the most fundamental activities bringing long term success to business firms. Developing new products and redesigning existing ones are difficult procedures as these are extensive, expensive and laborious ventures [1, 2]. According to Leavitt et al. [3] an estimated one third of the average organization's sales is derived from new products. Companies are always in search of new products which can potentially capture markets, provide competitive edge over others, and grab customer's attention with less time to market [3].

Designers start from generating new product ideas and converting potential ideas step by step into successful products by performing trial and error during New Product Development (NPD). Experimental design is an efficient technique for conducting statistically designed experiments which are important components of product and process design and development [4, 5]. Thus, experimentation is the true guide for designers to show check posts in terms of analyzing performance parameter, critical factors and evaluation criteria in order to move in the right direction of a product development process map. Blake et al. states that, "Experimental Design Technique (EDT) is a powerful tool that can be used in designing robust products, reducing time to market, improving product quality and reliability and reducing life-cycle cost" [5, 6].

Designers have to make decisions in order to move to the next product development stage and this is a mandatory part of any NPD process from idea-to-launch; which decides the product's success or failure. To avoid the decision making errors which lead to product failure, designers and product developers navigate through go and no-go decisions throughout the NPD process. This evaluation of every product development stage is better understood as 'gates' or 'convergent points' [7–9]. Over past thirty years the Stage Gate strategy proposed by Robert Cooper, has continually emerged as a useful tool for business firms in launching new products to market.

1.1 Background

EDT has application in planning during various NPD stages. Albeit that this method is around for decades, it is argued that the operational implementation of EDT has been a challenge for designers. The post facto study of a green stool design project is done using EDT partially; to identify performance parameters (factors common to) of all stool development stages and critical factors (factors exclusive to) for individual stages.

From the case of green stool design project it is apparent that; the designers did not rigorously follow the stage-gate system [10] while carrying their individual projects but they did logically experience the stool development stages and critical decision making points at those stages. The decisions taken at every product development stage worked as a turning point and guided them towards successful completion of the green stool design project. The "go" decision is like a green signal of confirmation from an appropriate expert reviewer for a specific stage gate which allows designers to keep moving to the next stage gate until the final stage is reached [2].

1.2 Objective and Content of Paper

Considering the green stool design project from experimental design and stage-gate system perspective; we realized that design students would have used these techniques integratedly during their actual project runs. From designers and product developers viewpoint; the mentioned techniques go hand in hand and excellently support each other towards overall thoughtful understanding of NPD process. Taking this as a motive, we have developed post facto analysis for four sample stool design projects in this paper. Using these case study analyses; we have written this paper has the following objectives

1. Understanding the literature on EDT in a designer's context and illustrating the use of this technique in the context of product design and development stages.
2. The post facto analysis of a stool project is done for three reasons
   a. To identify performance parameter and critical factors of various green stool development stages by partially following experimental design stages
   b. To determine the quality assessment criteria for evaluation of four stool cases using Garvin [11] eight critical dimensions of product quality
   c. Recognizing decision gates during the green stool development stages taking into consideration the critical factors identified using EDT.

In the subsequent sections; the authors would take readers to go through the journey of case studies on green stool design project. Section 2 demonstrates a brief description of the stool project covering an actual project task given to the design students, tracking of the activities performed by them during this project and an in-depth narration of selected four sample stools considered for this paper. In Sect. 3 literatures on EDT is studied from designers point of view. Section 4 aims at the post facto analysis of four stool cases where factors and evaluation criteria are found out as an outcome of partial application of the experimental design technique. Development stages and go-no-go gates in stool development process are identified in Sect. 5. Conclusions are made in later section.

2 Description of Green Stool Design Project

The green stool design project was a major part of a graduate level three credit course titled Product Design, conducted at Centre for Product Design and Manufacturing at Indian Institute of Science, Bangalore. Eleven graduate design students enrolled for this course and individually completed the green stool design project over the period of two months as a part of this course. The instructor's objective behind offering this project was teaching students to experience the process of form development by journeying through the NPD process. To be precise designers selected a particular letter form as metaphor for the stool. Using this metaphor as a point of inspiration they explored and evolved various interesting product forms and finally shortlisted one potential form and developed a meaningful product which was the green stool. The involvement of higher levels of technology and mechanisms was not the aim of this assignment. Design students generated new ideas, created various creative forms, used different materials, manufacturing processes and developed their final product. The role of the expert reviewer throughout this project was played by the instructor having industrial exposure and experience in the product development field. Designers consulted with the instructor during various stool development phases for making an appropriate decision and proceed further. A market survey was not done for this project, but designers designed their green stools taking into account a suitable customer and a market profile. The final evaluation of the green stool was done by the instructor, as an end customer would do.

2.1 Project Task

The task given to design students for this project was, "Design a 'Green Stool'. It need not be green in colour, but be made with eco-friendly material, cost effective manufacturing process, and must be made with minimum possible energy. The new design of the stool shall be for anyone who will feel proud to possess one due to its inherent values and style statement. It can be for any user in any market of designer's choice, but should definitely be suitable for mass manufacturing. Designer can make suitable assumptions and state them in his/her product brief before proceeding with the design process. It should adopt a theme in form of a character which should communicate environmental consciousness in its form and meaning".

2.2 Green Stool Development Activities

The brainstorming session was done by designers to come up with several themes as a metaphor. Students thought about diversified themes such as—*Symbols, Stones, Colors, Trees, Musical Notes, Birds, and Animals*. After considering all the theme options; the instructor finally selected '*Symbol*' as a metaphor for the development of stool design. Designers independently formulated their own stool design briefs. Eleven designers divided into three groups for carrying out ergonomic, technical and cultural studies of stool. The data collected from this study was shared amongst the eleven designers. Table 1 shows various stool development phases and the activities conducted by the designers during these phases.

Table 1 Development phase wise description of stool design project

Stool development phases	Description of activities during phases
Preliminary phase	**Green stool design brief declaration** • Identifying primary and secondary stool design requirements • Defining customer/end user profile and market profile • Selecting a specific symbol as metaphor **Data collection** *Ergonomic aspects* • Seating ergonomics • Anthropometric aspect of seat design—seat height, seat depth, seat width, stool weight, stool stability etc *Technical aspects* • Materials for stool—wood, metal, plastic, other materials and physical and mechanical properties of materials • Manufacturing processes for wooden, metal and plastic stools *Cultural aspects* • Indian activities connected to stool—listed activities done by men, women, children/teenagers and elder people • Indian culture and beliefs • Visual demands—from environment, market, customer and cost perspective *Design trends* Designers looked at various stools types like four and three legged stools, bar stools, foldable stools, Eco-friendly stools etc.
Ideation and concept development	Concept sketching, concept selection, exploration of concept selected, building mock up/soft models for concepts, concept evaluation
Prototype development phase	• Appropriate material and manufacturing process selection • Manufacturer selection • Green stool manufacturing and its testing
Assessment phase	Final green stool evaluation by expert reviewer /evaluator

2.3 Description of Green Stool Design Cases

For this case study we are considering four sample stool design cases developed by the graduate design students for the following activities described in Table 1. Explanation of four green stools developed by designers as the project outcome is shown in detail here in Table 2.

3 EDT in Designers Context

The credit of pioneering experimental design approach goes to Sir Ronald Fisher who firstly used this technique for performing experiments in agricultural field during 1920s. Presently, the revolutionary impact of EDT in various industries has

Table 2 Detail description of four green stool sample cases

Stool name	The Raga	Curlicue	Eco stool	On stool
Symbol selected as a metaphor	Letter '**R/r**'	Letter '**S/s**'	**Recycle symbol**	**Power button symbol**
Meaning of metaphor and inspiration	Designer interested in Symbolizing '**3Rs**' of environment—**Reduce, Reuse, Recycle** in stool	The inspiration behind letter '**S**' which stands for **sustainability** in stool design	**Recyclability** expression in stool remind people responsibilities towards environment	Used power button as metaphor which can evoke a thought of **energy usage or saving**
Customer and market profile	Adults, unisex Global market	Adults, unisex Global market	Adults, unisex Global market	Adults, unisex Global market
No of concepts generated	30	40	25	20
Mock up models made	Paper model	Cardboard model CAD model	Paper model CAD model	Clay model CAD model
Materials and manufacturing processes	Cane strings Stainless steel pipe Bending, Welding, Knitting	Rubber wood Stainless steel pipe Bending, Welding, Cutting, Drilling	Polypropylene sheet Stainless steel pipe Bending, Welding, Cutting, Drilling	Wooden plank Stainless steel Bending, Welding, Cutting, Drilling
Final green stool prototype				

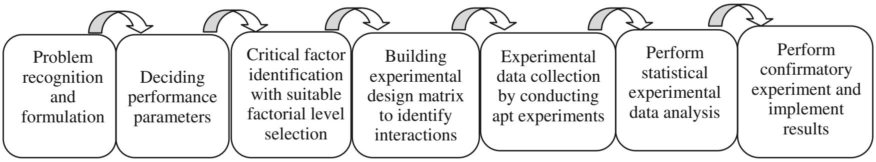


Fig. 1 Main stages of experimental design during NPD

broadened its application for NPD, redesigning existing product/process and product quality improvement. Experimental design is one of the most significant techniques, denotes plan for performing experiments during various stages of NPD process [12]. It helps in deciding 'performance parameters'—factors remain common throughout all stages of NPD and 'critical factors'—factors specific to individual stages. After setting the factorial levels for critical factors, 'experimental matrix' can be generated. This matrix can create enormous valuable information about possibilities in designing experiments for new innovative products development. By running appropriate limited experiments efficiently or checking possibilities from experimental design matrix; designers can save large portion of cycle time and resources in physical product development [13, 17]. Referring Antony et al. the seven stages involved in experimental design process during NPD is shown in Fig. 1 [5, 15, 16].

Ellekjær and Bisgaard [17] elaborated the objective of experimental design during four product development stages namely, conceptualization, prototype building, manufacturability/pilot production, and final production stage as shown in Table 3.

Though many authors have vastly described the application of experimental design, in reality there is a gap between ED and its practical application which is restricting designers and product developers to use this technique on real time product development problems. As per Carlsson [14], even the best industries fail to use experimental design into practice due to poor awareness, knowledge and use of experimental design [5, 14].

Table 3 Objectives of EDT during four product development stages [17]

Ideation and conceptualization	Prototype development	Manufacturing and pilot production stage	Final production
New idea generation	Product performance	Product manufacturability	Process simplicity and process yield
Test existing and establish new theories and concepts	Robustness and reliability	Sensitivity to component variation	Quality of product and process
Validating proof of concept	Sensitivity to component variation	Tolerancing (parameters allowed limit specification)	Reliability of product and process
Handling if-else situation	Simplicity	Simplicity, reliability and cost	Cost

4 Post Facto Analysis

Our post facto analysis for this case study considers four green stool design cases reported in Sect. 2.3. This analysis was conducted on the basis of investigation on stool project task, the design brief made by the four design students, understanding the development stages of green stool project, final functional stool prototypes, interviews of designers and discussion with the instructor. As a part of post facto analysis EDT is partially (first three stages shown in Fig. 1 excluding factorial level selection) used to identify major performance parameters and most prioritized critical factors. The outcomes of EDT and stage gate strategy are integrated to propose the role of experimental design based go-no-go approach. This approach has a scope for understanding inputs and outputs to decision gates during NPD and product/process improvement during redesign.

'Performance parameters' were the major factors/features which designers strictly tried to imbibe in their final green stools prototypes and carried throughout all development stages. These were strict constraints which closely guided the final presentation of the green stool. 'Critical factors' were those prioritized factors/features which were very specific for each stool development stage that may influence performance parameters.

The critical factors in evaluation are nothing but the core features, that expert evaluator considered for the evaluation of four stool designs. For seeking the market potential of green stool prototypes, the expert evaluated these stools from customer's point of view understanding the customer profiles chosen by the designers in their project design brief. Though form development was the major objective for this project; evaluation of the final green stools was based on—sensory, functional and emotional properties of the stool which customers usually seek during such product purchase. Table 4 shows performance parameters and critical factors identified and common for all four green stool design cases as per their priority.

For quality based evaluation of a product; Garvin [11] has proposed eight critical dimensions of the product quality related to the product development and these serve as the pillars for strategic analysis namely,—performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality [18]. The common quality based evaluation criteria for these functional green stool prototypes are identified after a rigorous investigation of the stool prototypes and discussed with the evaluator to understand his evaluation perspective. Finally, with common evaluation thinking; identified quality evaluation criteria are categorized according to Garvin's eight critical dimensional quality aspects as described in Table 5. Actual evaluation of the four sample stool prototypes was done based on most of the critical features mentioned below.

Table 4 Performance parameters and critical factors for various stool development stages

Performance parameters—factors/features common to all stages of green stool design
• *Sustainability*—Usage of eco-friendly materials and manufacturing processes, minimum use of resources (materials, manufacturing processes, energy etc.)
• *Durability*—Robust stool design for long service life and it should be strong enough to take weight up to 100 Kgs in sitting and standing position
• *Portability*—Easy to move from one place to other place or easy transportation
• *Mass manufacturability*—easily bulk produced
• *Emotional and religious sentiment*—finally developed stool should not hurt emotional and religious feeling of user using it
• *Critical factors*—factors/features completely exclusive to individual stages to green stool design
Critical factors in ideation and conceptualization stage
Critical factors in theme (as a metaphor) selection
• *Method of ideation*—precise selection of ideation method for generating metaphors
• *Expressive Style of theme*—fashion, manner, mode, trend of theme selected etc.
• *Feasibility of theme*—extensive possibility of theme exploration during ideation
• *Form variety*—to understand diversity range of shape, figure, outline, structure etc.
• *Theme flexibility*—capability to undergo with change as per designers willingness
Critical factors in concept development and selection
• *Method used for Conceptualization*—thumbnail sketches, doodling, paper/clay models, playing with scrap
• *Supporting symbol form*—retaining the form of stool concept as per symbol selected
• *Concept novelty value*—stool concept newness and avoiding duplication of existing ones
• *Concept transforming viability*—practicability of concept transforming into actual stool
• *Concept Catchiness*—potential of stool concept to attract viewers/customers
• *Concept selection criteria*—evaluation criteria set by designer and expert reviewer
Critical factors in green stool development
• *Stool performance analysis*—refined concept analyzed for performance prediction using various s/w tools
• *Mock up modeling*—Stool concept feasibility checking by making clay, soft models, CAD models, paper models etc.
• *Materials and manufacturing process selection*—selecting materials and processes which lead towards green /eco-friendly stool design
• *Resources/design variation sensitivity*—thinking about alternatives materials and manufacturing processes or alternative modified design in case of non availability of manufacturing facility
• *Simplicity*—predicting ease of use, manufacture and maintenance
Critical factors in manufacturing and production
• *Manufacturer selection*—checking availability of manufacturing process facilities and feasibility to manufacturer to develop stool as per finalized technical specifications
• *Method of testing*—to test stool strength and performance—force application while sitting and standing, joint checking, weight balance, fittings etc.
Critical factors in evaluation of sensory properties
• *Visible aesthetical stool characteristics*—customers attention spots in stool prototype
• *Stool features*—features that customers can grab just by using the stool
• *Impression of eco-friendliness of stool*—specific characteristics showing sense of green stool design

(continued)

Table 4 (continued)

• *Simplicity in design*—ease of use, green stool depicts obvious metaphor behind its design
Critical factors in evaluation of functional properties
• *Basic performance features*—most fundamental functions of stool
• *Durability, Reliability, Conformance and serviceability*
Critical factors in evaluation of emotional properties
• *Emotional attachment towards product*
• *Hidden insights about product*
• *Perception about product quality and features*

Table 5 Identification of stool quality evaluation criteria

Critical features related to product concept quality	Quality evaluation criteria related to green stool
Performance	Sitting comfort, Weight balance (in standing and sitting position), Portability
Features	Colour, Shape, Texture, Form, Rhythm, Sleek, Eco-friendly design, Contemporary/Modern design trend, Skillfulness in design,Customer sensitive design, Harmony, Sustainable resource usage, Elegance, Light weight and sturdy, Easy to clean, Cost
Reliability	Mass production and storage, User friendliness, Seat design, 3R's (reduce, reuse, recycle), Stool life
Conformance	Adherence to specifications and symbol, Conformance on shape /configuration /contour, Sense of robustness, Sense of comfort, Healthy sitting, Product completeness, Damage proofness, Sense of green stool
Durability	Stool strength, Stability and support
Serviceability	Manufacturing supportability, Stool maintenance and repair, Stool component replacements, Competence
Aesthetics	Stool beauty, Catchiness, Appearance, Style, Artistic sense, Ratio proportion, Symmetry
Perceived quality	Affordability, Sense of pride, Inherent cultural values, Customer adaptability, Deep product thinking, Intelligence in product, Market stool trends, Visual unity of stool design

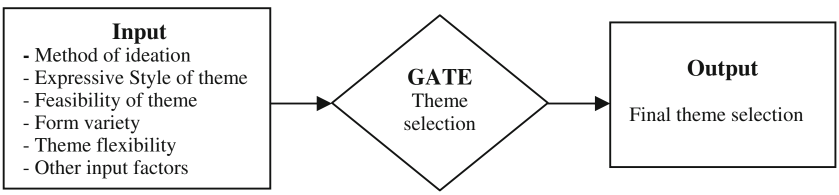


Fig. 2 Input–output diagram for decision gate

5 Experimental Design Based Go-no-go Approach in Green Stool Project

The Go-no-go decision gates are product development stage driven decision points where customer–market requirements, evaluation criteria and product lifecycle activities are closely reviewed by expert reviewers from product idea-to-launch [2, 7, 19]. During stool design project; design students navigated through stool development stages which were interpolated by number of go-no-go decision points. Each previous stool development stage had not proceeded to the next stage without mutual 'go' decisions of student and instructor (expert reviewer) while 'no-go' was a point of disagreement for the designer from reviewer to reaffirm the stage-gate again. In this product form development project; from theme selection to final green stool launch process was a funnel with seven development stages and a number of go-no-go decision points.

Using Table 4 where experimental design is used for stool development process; we can clearly identify the stool development stages and the important decision gates for designers. The identified critical factors have given more clarification towards the inputs and the outputs of green stool project decision gates. For example—'selection of theme as a metaphor' was one of the important decision gates (decision making point) for the designers during ideation stage, where inputs and outputs to decision gates can be highly predicted by considering critical factors (refer Table 4) in theme selection. The general input output diagram for 'theme selection' gate is shown in Fig. 2. Similarly the input–output diagrams for other decision gates can be made for better decision making.

The development stages and the decision gates were confirmed with designers and the reviewer. EDT based stage gate strategy is used as a representation tool for showing go-no-go gates as shown (Fig. 3), the right side shows stool development stages with go-no-go decision gates in between depicted by a diamond outline [7, 9, 10, 19].

6 Conclusions

Experimental design technique in combination with stage gate strategy is used for a post facto study of the green stool design project of graduate students, who used a generic NPD process. We tried to explore the EDT approach and described it during various NPD stages from designer's perspective. Using integrated experimental design based go-no-go approach, designers can understand development stages, decision gates in NPD process and can take decisions in better sense at particular gates to improve their decision making abilities. This can be done by understanding inputs and outputs to particular decision gate. Inputs to decision gate can be highly predicted by looking at the most prioritized critical factors identified using EDT at that particular stage. This 'input-gate-output' insight from

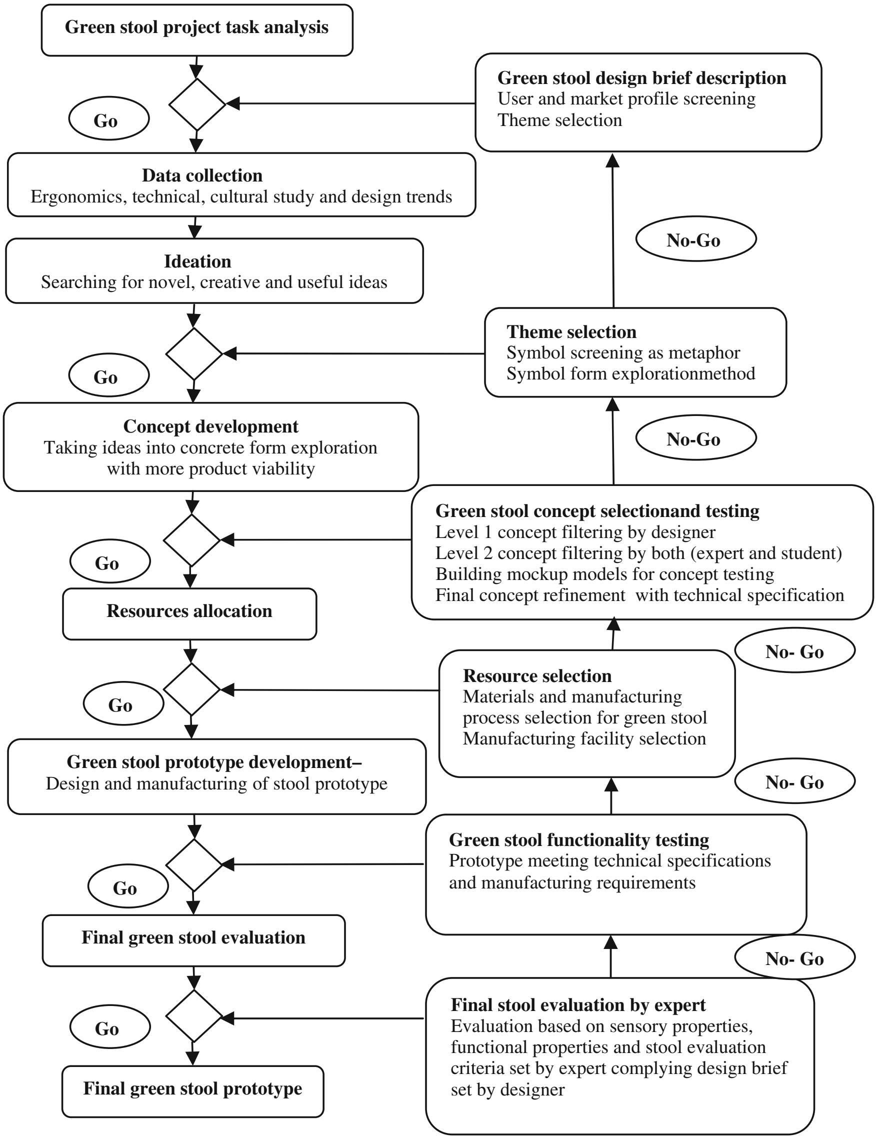


Fig. 3 Experimental design based go-no-go approach for green stool project [9] (inputs and outputs to decision gates are not shown in this figure)

experimental design can help to decide 'go' and 'no-go' decisions at a particular stage-gate in the NPD process. More analysis of this project with all stake-holders as decision-makers will throw insights regarding the decisions made at various stages. This combined approach can be used for any NPD and product redesign activity.

Acknowledgments We appreciate the work of designers Anand, Ankit, Pragati and Subin at CPDM, IISc.

References

1. Clark KB, Wheelwright SC (1995) The product development challenge: competing through speed, quality, and creativity. In: A Harvard Business Review Book. Harvard Business School Press, Boston
2. Cooper RG (1993) Winning at new products—accelerating the process from idea to launch, 2nd edn. Perseus Books, Cambridge
3. Leavitt P, Brown M, Wright S (2004) New product development: a guide for your journey to best-practice processes. American productivity and quality center, Huston
4. Montgomery DC (1999) Experimental design for product and process design and development. R Stat Soc Stat 48(2): 159–177
5. Zhang Z (1998) Application of experimental design in new product development. TQM Mag 10(6):432–437
6. Blake S, Launsby RG, Weese DL (1994) Experimental design meets the realities of the 1990s. In: Quality progress, pp 99–101
7. Cooper RG (1990) Stage-gate systems: a new tool for managing new products. In: Business Horizons, pp 44–54
8. Hart S, Baker M (1994) Learning from success: multiple convergent processing in new product development. Int Mark Rev 11(1):77–92
9. Tzokas N, Hultink EJ, Hart S (2004) Navigating the new product development process. Ind Mark Manag 33: 619–626
10. Cooper RG (2009) How companies are reinventing their idea-to-launch methodologies. Res Technol Manag 52(2): 47–57
11. Garvin DA (1987) Competing on the eight dimensions of quality. Harvard Bus Rev 65(6): 101–109
12. Almquist E, Wyner G (2001) Boost your marketing ROI with experimental design. Harvard Bus Rev 79(9): 135–141
13. Page AL (1993) Assessing new product development practices and performances: establishing crucial norms. J Prod Innov Manag 10:273–290
14. Carlsson M (1996) Conceptual and empirical aspects of TQM implementation in engineering organizations. In: The R&D management conference: quality and R&D. Twente Quality Center, Enschede, pp 84–99
15. Antony J, Perry D, Wang C, Kumar M (2006) An application of Taguchi method of experimental design for new product design and development process. Assembly Autom 26(1):18–24
16. Antony J et al. (2001) 10 steps to optimal production. Quality 40(9): 45–49
17. Ellekjær MR, Bisgaard S (1998) The use of experimental design in the development of new products. Int J Qual Sci 3(3): 254–274
18. Naes T, Nyvold TE (2004) Creative design: an efficient tool for product development. Food Qual Prefer 15: 97–104
19. Cooper RG (2005) Stage-Gate is a registered trademark (www.stage-gate.com) of the Product Development Institute Inc (www.prod-dev.com)

Design Professionals Involved in Design Management: Roles and Interactions in Different Scenarios: A Systematic Review

Cláudia Souza Libânio and Fernando Gonçalves Amaral

Abstract: Design management has gained relevance among practitioners and researchers worldwide, and many have been the attempts to conceptualize it formally over last years. However, the role of design professionals acting in design management, as well as their interactions with other team members are seldom explored. This article examines the characteristics of design professionals in design management at both Brazilian and international levels. A literature systematic review was carried out in order to map these scenarios, highlighting different professional profiles according to their working environment and the organizational structure. Through this study, the various roles of design professionals involved in design management were identified, their personal profiles were examined, as well as the main differences arising from two different scenarios.

Keyword Design management · Human factors · Design activity · Designers

1 Introduction

Over the past decades design management has been discussed and conceived as a multidisciplinary activity that brings together working partners and integrates design within an organizational environment [1]. Aiming at a formal conceptualization and

C. S. Libânio (✉)
Business Administration UniRitter, Porto Alegre, Brasil Rua Orfanotrófio, 555 Porto Alegre, RS, Brazil
e-mail: clasl@terra.com.br

C. S. Libânio · F. G. Amaral
PPGEP UFRGS, Porto Alegre, Brasil Av. Osvaldo Aranha, 99, Porto Alegre, RS, Brazil
e-mail: amaral@producao.ufrgs.br

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_69,

attempting to arrive at a meaning that can be effectively used in companies, some design management definitions have been proposed that highlight not only the levels of organizational activities but also their actors along with their respective roles and forms of action. The Design Council [2], for instance, defines design management as the total activity of design, which goes from implementing and organizing the entire development process of new products and services to managing and achieving a company's best performance. The Portuguese Design Center (CPD) [3] defines design management forms of action inside companies in a twofold manner: first, at project level, in which a design manager's role is to manage people, services and products during all phases of a project; and, second, at corporate level as a whole, in which a design manager will foster the development of new products favorably.

Regardless all the attempts at conceptualizing design management, the role of designers within design management, as well as their interactions with other team members and their personal profiles are seldom explored. In such a context, this article examines the characteristics of a design professional at both Brazilian and international levels through a systematic review of research literature available on the subject that specifically refers to the role of designer in design management. First, an analysis of a design professional profile as suggested by a few authors, including their competences, skills, and personal characteristics. The main differences perceived within local and international scenarios are pointed out, not only with respect to a designer's profile but also to his or her professional training. Finally, a few remarks are made and suggestions for further research are presented.

1.1 Design Professionals

In companies, design management consists on managing all aspects of design at two levels: the corporate and the project level [3, 4]. At corporate level, a design manager acts on the company's strategies by fostering a design culture and aligning it with the corporate goals. According to CPD [3], at this level a manager will be responsible, among other tasks, for connecting activities with the company's strategies. At project level, however, the design professional is focused on managing the company's projects operationally.

At corporate level, therefore, design professionals can act either in close collaboration with the company's senior staff or in a design department, being it a department internal to the organization or an outsourced design service. Borja de Mozota [5] argues that a few design tools should be used in corporate decision-making processes, such as design input at senior staff level or within a company's own design department, among others. She also notes that at senior staff level design activities can be the sole responsibility of a design director, a design manager, or a director who belongs to a quality control and design area or a communications and design area. It is inside a design department that the positions of project manager and designers are to be found.

The roles and responsibilities of a design manager are strictly related to the size and structure of a particular company. According to Pereira [6], in large sized companies the design manager's role is that of supervising teams engaged in each project, adapting him/herself to the particularities of each. He or she has to demonstrate a broad view of the whole enterprise and foster integration among the company's operational and strategic sectors. In small sized companies, on the other hand, the author argues that a design manager's task is to identify actions that contribute to integrate projects with a company's pre-established goals, even though he or she is not responsible for supervising each business unit. The design manager must pursue actions leading to the integration of project development with the corporate goals. Regardless the company's structure, Best [4] states that the design manager needs to promote the best design strategy as possible when conceiving an organization as a whole. The author also argues that for this to happen stakeholders should first be convinced of the significance of a particular design strategy for the company. Several are the abilities or skills required for a design manager position. Among them we will find leadership, entrepreneurship, vast technical knowledge, managerial skills, and a proactive profile, to mention a few. A design manager should be able to coordinate, motivate and persuade a team. Bruce et al. [7] highlight the individual competences among the essential features required for good designers, arguing that lacking them is a major cause for failure in design projects. Some views of a designer's competence are described below.

1.2 Designer's Competences

Nedo *apud* Bruce et al. [7] mention the following competences for designers: objective creativity; technical knowledge; color and conceptual design; organizational, planning, problem solving, and commercial skills; commitment; enthusiasm; self-confidence; results orientation; team orientation; strategic thinking; consumer/customer focus; relationship-building skills; presentational skills; and flexibility. Among them, we can find competences related to knowledge, abilities, and attitudes.

Ruas et al. [8] argue that the notion of individual competences bears different lines of thinking based on different approaches, such as the Anglo-Saxon and the French. Anglo-Saxon scholars share a more pragmatic perspective, while members of the "French school" add elements from Sociology and Labour Economics to the notion of individual competences. According to the authors, the concept of competence must not be mistaken for that of performance, for the latter can be seen as a quantification of performance, while the former consists of a tool for achieving a desired performance. With reference to competences and skills, Borja de Mozota [5] suggests five competences in design, such as: compromise, enthusiasm, self-confidence, results and team orientation, high standards, creativity, technical and conceptual ability, organizational, planning, problem solving,

Table 1 Designer competence model, according to Ruas and Mozota

Competences	Description
Knowledge	Technical, scientific, concept, and color
Skills	Creativity, strategic thinking, presentations skills, commercial skills
Attitudes	Commitment, enthusiasm, self-confidence, results orientation, relationship building, problem solving

Source Adapted from Ruas et al. [8] and Borja de Mozota [5]

commercial skills, gathering and using of information, strategic thinking, consumer focus, relationship building, influence, presentation skills and flexibility. Based on the classification of competences proposed by Ruas [8], it is possible to group together the designer skills referred to by Borja de Mozota [5], as shown in Table 1.

According to Ruas' and Mozota's competence model for designers (Table 1) and Moura and Bitencourt's understanding of competences [9], all the technical and scientific competences can be represented as knowledge, or knowing, such as, for instance, color and concept knowledge. Skills, in turn, are those related to knowing how to do, such as creativity, strategic thinking, as well as presentation and commercial skills. Attitudes, conceived as knowing how to act, relate to commitment, enthusiasm, results orientation, self-confidence, relationship building, and problem solving.

In the scenario view briefly described, a systematic review of research literature on design management was carried out aiming, first, to have a better understanding of the profile of design professionals in companies, and, second, to identify different perspectives on design professionals' role in Brazil and abroad. In the following sections, the methodological procedures are described, the main findings are presented, and a few guidelines for future research are suggested, as well as some paths to be followed.

2 Methodological Procedures

A systematic review of applied and exploratory nature was carried out for the purposes of the present study. Both Brazilian and international research literature were reviewed in an attempt to contrast Brazilian and foreign views on the subject of design management. For the Brazilian literature review, theses and dissertations dealing fully or in part with the role of design professionals in design management written within the past 20 years were searched over postgraduate programs offered at local universities. For the international literature review the Science Direct Info website was the main source for searching articles published over the same period.

This search was carried out initially on the WWW using digital databases as a primary search engine. In the Brazilian search the following databases were accessed for finding theses and dissertations: CAPES Website, Domínio Público Website

(Public Domain), and the Brazilian digital library for theses and dissertations available at the Brazilian Institute for Information in Science and Technology (IBICT) Website. The keywords used for searching materials in Brazilian Portuguese were: gestão de design (design management), design estratégico (strategic design), designer, and gestor de design (design manager). A refined search was made among the 278 publications retrieved aiming at excluding the ones that did not fall under our subject of research. As a means of checking whether those research works dealt fully or in part with the professional designer's role in design management, a selection was made based on the reading of paper abstracts, keywords, and introductions whenever they were available on-line. After refining the selection of theses and dissertations, their respective bibliography was analyzed as an attempt at identifying works that had not been found on the initial search. Two dissertations and one thesis were found during the analysis.

The Science Direct Website was the main scientific database used for international research literature retrieval, and the following search options were applied: journals only, titles published within the last 20 years, containing the terms "design management," "strategic design," "design manager," and "designer," and within the subject area of design management and related fields, such as business, management, decision sciences, arts, humanities, engineering, and finance. The search resulted in 913 publications retrieved, of which 880 had to be excluded for not dealing specifically with our theme of interest. The large number of works excluded was due to a wide range of meanings of the term "design". This refinement was made through a careful reading and analysis of the title, abstract, and keywords of each publication.

In brief, the Brazilian search has identified 40 research publications partly or fully addressing the role of the design professional in design management. Figures for the international literature search amounted to 33 articles for the same criteria.

3 Results

Forty Brazilian publications—3 theses and 37 dissertations—and 33 articles published in international journals were found that dealt with the role of designers in design management. All publications retrieved and analyzed were organized as follows: journal of publication; region of publication; keywords; year of publication; and reference to designers in design management in Brazilian and internationals publications.

3.1 Journal of Publication

Design Studies is the main publication journal comprising 17 out of a total of articles. Computers in Industry appears with 3 articles. Technovation, Automation in Construction and Long Range Planning contributed with 2 articles each. Finally, Journal of Materials Processing Technology, International Journal of Production Economics, International Journal of Industrial Ergonomics, International Journal of Human–Computer Studies, Procedia–Social and Behavioral Sciences, Computers and Industrial Engineering and Artificial Intelligence in Engineering appear with 1 article each.

3.2 Region of Publication

In Brazil, most of the research works were written in the South region, amounting to 24 publications. The South–East region appears next with 14 publications and the North–East with 2 publications addressing designers in design management, as shown as Fig. 1.

Figure 2 shows the countries of origin of the international publications. The United Kingdom has contributed with 22 of the authors, followed by China with 9, and the Netherlands with 7 authors. Then, there are 6 authors from France and Spain, 5 from Italy, and 4 from the United States and Taiwan. Thailand has contributed with 3 authors, and Iceland, Denmark, Korea, Australia, Finland, Poland, and Turkey with 1 author each.

Fig. 1 Number of theses and dissertations per State in Brazil. *Source* The authors

Fig. 2 Authors per country (except Brazil). *Source* The authors

3.3 Keywords in Brazilian Publications

The most frequently used keywords in the Brazilian publications searched were "design", "gestão de design," and "gestão do design" (both are translated as "design management"), with 18, 12, and 8 occurrences, respectively. These keywords plus "estratégia" ("strategy"), "competitividade" ("competitiveness"), "inovação" ("innovation"); and "design estratégico" ("strategic design") correspond to 80 % of total occurrences. The other keywords "gestão" ("management"), "projeto" ("project"), and "MPEs" (an abbreviation standing for Micro and Small Businesses), "Design industrial" ("industrial design"), "metodologia de projeto" ("project methodology"), "processo de design" ("design process"), "moda" ("fashion industries"), and "polo moveleiro" ("furniture industries") appear to be less important in the research publications analyzed.

3.4 Keywords in International Publications

The most frequently used keywords in the international articles can be seen in Fig. 3. The term "design management," the keyword with the greatest number of occurrences, appears in 16 out of 33 international articles, which is indicative that more than 50 % of the publications has focused directly on the subject of design management. The keyword "case study(ies)" appears next, pointing to a research procedure used in some research works. "Collaborative design," and "product design" are used in 4 publications each. "Design process(es), "Design cognition", "Communication", and "Design strategy(ies)" are used in 3 publications each. All of these terms represent 80 % of the total keywords found in the publications, as we can see in the line in Fig. 3.

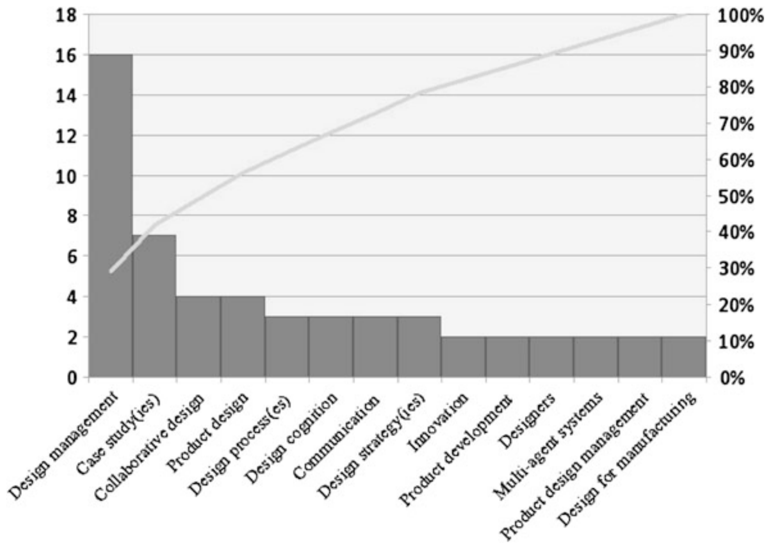


Fig. 3 Most frequently used keywords in the international articles. *Source* The authors

Keywords used in common by both Brazilian and international studies are: "design management", "innovation", and "design process(es)".

3.5 Year of Publication

For the years 1994 and 1996 only Brazilian publications were found according to the search criteria used, while in 1999 the international publications begin to appear. On the whole, the last five years have concentrated more than one half of the publications under research as shown in Table 2.

3.6 Reference to Design Professionals in Brazilian and International Publications

The roles and functions of design professionals in design management were referred to in 16 Brazilian publications. In the 24 remaining ones neither were those professionals clearly identified and acknowledged, nor were their roles and functions clearly defined.

Seventy-one percent of the international publications have mentioned precisely the essential characteristics and requirements for design professionals, such as competences (knowledge, skills, attitudes), leadership, entrepreneurship,

Table 2 Comparison of publications in Brazil and abroad per year

Years	Brazilian publications	International publications	Total number of publications
1994	1	0	1
1996	1	0	1
1999	1	1	2
2000	1	2	3
2001	3	3	6
2002	1	0	1
2003	3	6	9
2004	2	1	3
2005	4	4	8
2006	6	2	8
2007	1	5	6
2008	4	2	6
2009	7	3	10
2010	5	4	9

proactivity, communication, and integration abilities. In the searched articles the designer is constantly mentioned, but the figures of a manager or a design manager are referred to only in 27 % of those studies.

4 Discussion

The Brazilian theses and dissertations published over the 1990 do not address in a clear and well defined manner the design manager's role, and sometimes they deal briefly with the functions of that professional within design management. It can be noted that the studies are focused on the phases of productive processes, giving no emphasis at all to the integration of a design team with other departments inside a company. Nevertheless, the designer seems to be assuming an important role in the scope of product development. There is only one international article published during the 1990s (in 1999) that presents a framework for design management and includes the design manager in that framework. This article also addresses the characteristics of a designer and strongly highlights the designer's competences. The figure of a design manager, or of a designer with a wider access and integration to a company's high staff, has gradually begun to appear in the Brazilian publications since the 2000s. In that period emphasis has been given also to a greater integration of the teams involved in each project.

Among the researched articles published from 2004 to 2010 it is possible to observe an increasing debate around the figure of the design manager. This suggests that sometimes in large scale companies there will be more room for a design professional who acts directly in cooperation with the company's high staff and who is directly linked to another design professional: the design team's project manager. On the other hand, in small-sized companies, the professional in charge of design management can be the project management team leader him/herself, who also has a direct connection and access to the company's high staff. Martins [10] asserts that a design manager's task includes all the creation process of tangible and intangible products. For large companies, the author states that it is a design manager's task the supervision of teams involved in each project and that he or she should adapt him/herself to the particularities of their actions. Pereira [6], in turn, states that a holistic view of the business scope is needed in order to integrate the operational units into the context of a company's global strategy. Martins [10] also suggests that, in small-sized companies, the task of a team supervisor is excluded due to the absence of business units. The author emphasizes, however, that a design manager has to define actions guiding the project process integrated to the organization's goals and strategies.

In the 2004–2010 Brazilian publications [10–12], concepts of leadership and competence are related to the design manager's profile. Those attributes are relevant, therefore, and point to an urge for a broader understanding not only of a designer's position dimensions, but also of their significance to a successful performance in that function. In the international publications, a deeper understanding is shown with regard to the significance of the design team's integration with other participants of a project [13, 14]. Concepts such as shared knowledge [15], organizations' and professionals' competences [7, 16], design team leadership [17] are mentioned, as well as concepts of design as a knowledge agent and knowledge integrator inside organizations [18, 19]. In some study cases [14, 18], it is possible to notice that the researched companies have a sound knowledge of design management and demonstrate to use design policies as well. A large part of the international articles, however, do not mention specifically the figure of a manager or a design manager.

A major issue addressed in some of the Brazilian publications [20–22] refers to local academic training programs in Design. More specifically, these publications deal with professional training for young designers entering the job market and focus on the poor knowledge acquisition of management concepts in the scope of undergraduate programs in Industrial Design. Issues are raised concerning design manager's training, and some authors argue that such a professional could not necessarily be a designer. According to Gallina [21], it is of primordial importance that the professional responsible for a design department inside a company should not only have a clear prospect of a sector potentialities and opportunities, but also take them into account and use them as values to be built into every aspect of a project. In the international articles analyzed, on the other hand, designer's training does not seem to be an explicit issue. Bertola and Teixeira [18] argue that, in Italy, many designers are entrepreneurs, which explains a tradition of applying design competences to manage available resources and guide business strategic decision-making processes. Candi [23] goes further by stating that quite often there is design even without the figure of a designer, or without acknowledging his or her figure as such. Our reading and analysis of those articles reveal that such a little mentioning of the figure of a manager or design manager is due to the design professionals profile abroad. Not only professional training, but also the personal characteristics and skills of international designers help them to have a job profile that fully matches the requirements of a design manager position.

5 Conclusions

The data collected in our research suggest that there has been an increasing and gradual change in the Brazilian and international understanding of the roles, responsibilities, and skills needed for a design professional over time. The figure of the design manager, however, has not been clearly defined, nor has his or her role in design management been clearly understood yet.

Certain professional characteristics have been discussed in specialized journals first at international level, and later at Brazilian level in academic publications. Leadership, autonomy, competences (knowledge, skills, and attitudes), entrepreneurship, pro-activity, communication, integration and teamwork have been highlighted as major characteristics of design professionals, both in the Brazilian and international publications examined. Regardless of their mentioning, those characteristics have not been studied in depth in the searched publications. Furthermore, a great professional development can be noticed abroad when contrasted to the Brazilian context. It is possible to conclude that the difference between the Brazilian and the international contexts is a result of the professional environment in which a designer works, but a great deal of that difference is due to our current professional training, as well as to the individual personal profile.

In face of the relevance of a deeper understanding of design management by designers, a question may be raised whether Brazilian professionals are appropriately prepared to assume leadership and other management roles inside organizations. A further question may also be raised, then, with respect to a more appropriate training for future design managers. This brings to the fact that we lack a wider perspective on the subject, for very few are the Brazilian undergraduate and postgraduate schools that include disciplines in the field of management in their regular course programs.

In conclusion, this research points to an urge to intensify the exchange of knowledge among Brazilian researchers in different regions of the country, thus increasing the number of papers presented in local conferences and research articles published in Brazilian journals, for this type of publication is easier to be accessed than theses and dissertations. By fostering the spread and exchange of knowledge on the understanding of design management from a Brazilian perspective, studies developed here shall not only succeed in keeping up with leading research works abroad and global trends on the field of design management, but also contribute more effectively to the development of the designer profession as a whole at Brazilian level.

References

1. Libânio CS, Amaral FG (2011) Aspectos da Gestão de design abordados em Dissertações e Teses no Brasil: uma Revisão Sistemática. Revista Produção Online 11(2):565–594
2. Design council (2010) Available at: www.designcouncil.org.uk. Accessed Aug 2010
3. CPD—Centro Português design (1997) Manual de Gestão do design, Porto, Portugal
4. Best K (2006) Design management: managing design strategy, process and implementation. Ava, Switzerland
5. Borja de Mozota B (2003) Design management: using design to build brand value and corporate innovation. Allworth, New York
6. Pereira D (2009) Competências da Gestão Estratégica do Design no Pólo Moveleiro do Alto Vale do Rio Negro (SC), Master Dissertation, Universidade Técnica Federal do Paraná, Ponta Grossa
7. Bruce M, Cooper R, Vazquez D (1999) Effective design management for small businesses. Des Stud 20(3):297–315
8. Ruas RL, Antonello CS, Boff LH (2005) Os novos horizontes da gestão: aprendizagem organizacional e competências. Bookman, Porto Alegre
9. Moura MCC, Bitencourt CC (2006) A articulação entre estratégia e o desenvolvimento de competências gerenciais. In: RAE, São Paulo: vol 5(1)
10. Martins RFF (2004) A gestão de design como uma estratégia organizacional: um modelo de integração do design em organizações, Teses, Universidade Federal de Santa Catarina, Florianópolis
11. Brito da Silva S (2009) As forças da gestão do design nos níveis estratégico, tático e operacional: um estudo de caso na Electrolux do Brasil S.A, Dissertação (Mestrado), Universidade Federal do Paraná, Curitiba
12. Dickie IB (2010) Gestão de design aplicada: estratégias de comunicação no contexto do design sustentável, Dissertação (Mestrado), Universidade Federal de Santa Catarina, Florianópolis
13. Reid FJM et al (2000) The management of electronics engineering design teams: linking tactics to changing conditions. Des Stud 21:75–97
14. Lauche K (2005) Job design for good design practice. Des Stud 26:191–213
15. Kleinsmann M, Valkenburg R (2008) Barriers and enablers for creating shared understanding in co-design projects. Des Stud 29:369–386
16. Belkadi F, Bonjour E, Dulmet M (2007) Competency characterisation by means of work situation modeling. Comput Ind 58(2):164–178
17. Lee KCK, Cassidy T (2007) Principles of design leadership for industrial design teams in Taiwan. Des Stud 28:437–462
18. Bertola P, Teixeira JC (2003) Design as a knowledge agent: how design as a knowledge process is embedded into organizations to foster innovation. Des Stud 24(2):181–194
19. Girard P, Robin V (2006) Analysis of collaboration for project design management. Comput Ind 57:817–826
20. Avendaño LEC (2002) Resgate do Protagonismo do Desenhista Industrial Através da Gestão do Design. In: 5° CIPD, Anais…, Rio de Janeiro
21. Gallina MC (2006) Ações do líder na gestão design como auxílio na formação do branding: um estudo de caso em uma empresa do setor do mobiliário, Dissertação (Mestrado), Universidade Federal do Paraná, Curitiba
22. Andrade MB (2009) Análise da Gestão de Projetos de Design nos Escritórios e Prestadores de Serviços em Design de Porto Alegre: Proposta baseada em estudos de caso, Master Dissertation, Universidade Federal do Rio Grande do Sul, Porto Alegre
23. Candi M (2010) The sound of silence: re-visiting silent design in the internet age. Des Stud 31(2):187–202

Design Professional Activity Analysis in Design Management: A Case Study in the Brazilian Metallurgical Market

Cláudia Souza Libânio, Giana Carli Lorenzini, Camila Rucks and Fernando Gonçalves Amaral

Abstract This study aims to highlight the role of Design Management in two metallurgical firms in Brazil. Considering the importance of combining theoretical concepts to the business reality, the methodological procedures were divided into two exploratory steps. In the first one, a literature review was performed by bibliometric analysis about the theme 'Design Management', mapping the international scientific production developed over the last 20 years. In the second step, two case studies were developed. The companies chosen belong to the metallurgical industry in Brazil, considered a traditional segment in the country that needs to understand design as a strategic tool. The bibliometric analysis results showed the evolution on the subject, as well as highlighted the multidisciplinary nature of design management, encouraging a pluralistic view. In the research inside companies it was possible to realize the importance of design teams' integration with other areas that participate in the Design Management process.

Keywords Brazilian metallurgical firms · Designer · Design management

---

C. S. Libânio (✉)
Business Administration UniRitter, Porto Alegre, Brazil
e-mail: clasl@terra.com.br

G. C. Lorenzini · C. Rucks · F. G. Amaral
Production Engineering Post-Graduation Program, School of Engineering, Federal University of Rio Grande do Sul, Porto Alegre, Brazil
e-mail: giana@producao.ufrgs.br

C. Rucks
e-mail: camila.rucks@ufrgs.br

F. G. Amaral
e-mail: amaral@producao.ufrgs.br

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_70, © Springer India 2013

1 Introduction

The debate about Design Management (DM) is evolving and has been spread mainly by studies carried out in institutions such as the Design Management Institute (DMI) [1], the International Council of Societies of Industrial Design (ICSID) [2], the Portuguese Design Center [3], and the European Institute of Design (IED) [4]. The theoretical debate promoted academically can also be reflected in corporate practices, promoting several interpretations about the role of design inside enterprises [5–7]. The design can be understood as a multidisciplinary activity that combines creativity and product development processes within the organization. More than just associate design as an aesthetic feature of finished products, companies are investing in design as a strategic tool that helps to produce new concepts and innovative ways of using products [8–12]. Thus, definitions of the Design Management are arising and trying to find an explanation specifically applied to business.

ICSID adopted Tomas Maldonado's [13] concept, dated in 1977, noting that the act of designing something includes the coordination and integration of all factors involved in the process of giving form and meaning for a product. In 1990, Gorb [14] considered the relationship between the design features that a company has and the strategic objectives of this company, suggesting a definition of Design Management that puts together design and business.

Nowadays, the Design Management is understood as a broad and global action, able to position the design on a higher level of responsibility inside a corporation. In this sense, DM establishes the appropriate insertion of the design in the company through the management of human and material resources—from the conception phase of a project until the launch of a new product, integrating specialized areas to senior management [15]. In the context of this research, the Borja de Mozota's definition [11] of Design Management was adopted.

Visualizing DM as a "bridge between design and business", McBride [16] defended the leadership focused on design and strategy, transforming experiences, companies and opportunities. Thus the design becomes an agent of organizational knowledge, which enables companies to sustain strategic partnerships and better understanding of users, supporting innovation processes [17]. Therefore, the collaborative work of design professionals that encourages the design management is essential to create special conditions to innovate in an organizational arrangement [18].

In Brazil, some government programs have been implemented—such as the Brazilian Program Design (PBD), Program Design Brazil, Brazil Innovation and Technological Development Support Program (PRODETEC)—in an attempt to align practices with design process and innovation management, but there is still a certain lack of design professionals prepared to work in strategic positions within companies, as identified in national studies [19–21].

This research aims to highlight and analyze the role of Design Management in two metallurgical industries in Brazil. The choice for the metallurgy was done because of its national importance as a traditional export industry linked with another important industry in the country—the furniture industry which deals in a significant way with the main aspects of design—and because there was identified the need to implement best practices in product process development and design. This is also an important sector, which applies a lot of complex process and technologies, influencing suppliers, industries, and the segment as a whole. To enable the study, there was done a conceptual review through a bibliometric analysis on the subject of Design Management, followed by two case studies according to the Brazilian reality.

2 Methodological Procedures

This paper begins presenting the description of the methodological procedures performed, emphasizing the steps of the bibliometric analysis. The results are presented in conjunction with the discussion of case studies developed in two metallurgical firms.

2.1 Step 1: Bibliometric Analysis

As a first step, it was conducted a literature review, guided by an exploratory bibliometric analysis. The systematic evaluation on a particular branch of knowledge can show how some knowledge areas or topics have evolved and how they have contributed to the science and the development of others studies. Thus, this type of analysis procedure helps to identify trends and research centers; studies the dispersion and obsolescence of scientific literature; provides productivity and quality of studies and analyzes processes of citation and co-citation; measures the growth of certain areas and the emergence of new subjects [22, 23].

The bibliometric analysis in this paper was structured by mapping international scientific production about Design Management published in English. The period of time used in the present research was set from 1992 to 2010, considering the challenges in the design expertise, as pointed by Borja de Mozota et al. [24]. The analysis was started from a research question, which guided the sequence of subsequent proceedings. Each step has been defined, measured and held by two independent researchers in order to ensure the accuracy of the data obtained. Some other systematic reviews and bibliometric analysis were applied as sources of reference for the proceedings [25]. These studies investigated topics related to processes of innovation and new product development [26], innovation in manufacturing [27], the manufacturing strategy [28]. The Table 1 shows the pre-established criteria, in accordance with the objective proposed.

Table 1 Steps of the bibliometric analysis

Standard steps for the review of literature with bibliometric analysis	Steps performed in the review of literature with bibliometric analysis about design management
(1) Defining the scientific question	What is the current stage of intellectual production on the theme design management?
(2) Identifying the databases to be searched; keywords	The database researched was the Web of Science with the keyword 'design management'
(3) Establishing criteria for inclusion/ exclusion of items	The papers included must follow the criteria: – Article or review article; published from 1992 to 2010 – Article should present: design Management as a business strategy and area of knowledge in business, empirical studies on the strategic role of design in business and its relationship with organizational systems, specialized professional and skills development in the area – Articles related to the areas, selectable in search engines: management, industrial engineering, multidisciplinary engineering, manufacturing engineering, operations research management science, business, multidisciplinary sciences, development planning, social issues, communication, education scientific disciplines
(4) Conducting search in the databases and on the strategy set	From October to November (2011) searches were made on the papers, conducted by two independent researchers
(5) Comparing and setting the selection of articles	The search of the three researchers was compared, with identical results, with a total of 95 articles found
(6) Applying criteria for selection and exclusions	58 articles were eliminated, leaving 35 articles for full reading
(7) Reviewing the studies included and preparing critical summary	Critical summary containing the identification number of each article; database; English title, author(s), journal, year of publication, abstract, business sector, aim, method, major results/conclusion
(8) Quantifying and qualifying the data	Data were quantified from the support of analysis capabilities available at the database (Web of Science) and through the utilization of three different softwares (Sitkis, Histcite, and Ucinet)
(9) Presentating the results	Results organized from the main data extracted of the studies, their main objectives, countries of publication, and conclusions

Source Adapted of Brereton et al. [40]

2.2 Step 2: Analysis Performed—Case Studies

Analysis were carried out in two companies of the metallurgical market defined by convenience. Companies participating in this study were chosen because they are the two largest metallurgical companies in Southern Brazil, developers of products for the furniture industry and fashion, with award-winning design products nationally and also regulated by quality certification. Both companies are leaders in their market segment and retain professionals able to supporting a culture of strategic design. Although these companies do not represent the entire Brazilian metallurgical market, they are representative in this segment because of their performance over the years; their relation with other national industries; their influence in regional market.

The in-depth interviews were conducted [29] with design professionals holding senior positions in the Department of Product Development. Each interview was conducted individually, and it lasted approximately 90 min. For conducting the interviews, it was used a semi-structured and qualitative script. The set of questions in the script was based on information extracted from the main topics of the bibliometric review and current data of the industrial sector. The subjects investigated were: the perception of design by senior managers of the company, formalization and design processes, conflicts in design teams, requirements to integrate the design team. Data analysis was performed using the methodology of content analysis as proposed by Bardin [30].

3 Results and Discussion

The results presented here show the emphasis drawn from the literature regarding the proposed approach. Subsequently, the empirical results collected in two metallurgical enterprises were contrasted with the literature review to identify the current position of Design Management in these two Brazilian companies.

3.1 Design Management: Concepts and Propositions

Through the bibliometric analysis of literature it was possible to find ninety-five potentially relevant studies. After the reading of these studies, a new filtering was applied considering the research objectives initially proposed. It resulted in thirty-five international studies selected to final evaluation. The data extracted from these articles were supported by specific softwares (Sitkis, Ucinet, and Histcite).

According to the data collected, it was perceived a certain conservatism in both the methodological procedures and in the definition of the objectives proposed in literature. Of the 35 articles, 18 of them proposed principles, guidelines, methodologies or program implementation of the Design Management; 13 analyzed the Design Management from the concepts and processes for competitive advantage, and 11 studied the professional training of designers and teams in the process of Design Management. Regarding the methodological choices, 26 were case studies or experimental studies, and 15 were the propositions of models or modeling concepts from theoretical frameworks.

The results obtained in the first stage showed a positive development and a growing body of research in the field of Design Management. It was also noted that the implementation process of the design is interesting not only because of the current situation of a company, but also because of the development of management related to creative design skills, based on the real value of design as an alternative source of income and competitive advantage.

According to the studies, the design is part of a dynamic industrial perspective, driven by social, environmental, economic enterprises that move and change their processes towards innovation. Long processes of development in competitive markets may require coordination of multiple design activities in product development. Each activity requires analysis and recognition of problems and generation of relevant information [31], which implies Design Management to contribute to the design strategy.

The ways that the company chooses to organize its design relations with other industries, suppliers and their position in the chain proved to be decisive for the competitiveness achieved [32]. In larger companies, with processes formalized and design professionals integrated and well trained, the literature showed positive results for design within firms [33]. The measurement of performance under the guidance of design efficiency and effectiveness was also highlighted as an important point [34] when considering the different design activities in companies.

The volume of cases analyzed showed the positive impacts of design that has its activities managed in support of corporative and strategic objectives. Sectors such as furniture and clothing were recurring sources of research, however, there was noticed the lack of studies in other economically important sectors—such as the metallurgical sector—which encourages further research in this area.

3.2 Case Studies

Both companies evaluated are from the same market segment—metallurgy—but with different characteristics and histories. In order to maintain the identity of these companies preserved, these were addressed in this article as 'Company A' and 'Company B'.

Company A was founded 34 years ago and, nowadays, it represents a joint venture between a Brazilian and an Italian companies, producing metal accessories for the sectors of decoration and fashion. This metallurgical company is an innovative medium size enterprise, which focuses on quality standards and follows labor and environmental legislations. The design team of Company A is composed by: a professional with a degree and a Postgraduate course in Design, a professional with a degree in Design, three Undergraduate students in Design and eight professionals with technical course in Mechanics. The respondent has served the Company A for 13 years as Design Manager, and he was responsible for all product development.

Company B was founded 27 years ago and has been developing innovative accessories in metal for footwear, fashion clothes, and decoration. This enterprise is a traditional Brazilian metallurgical company, with medium size structure, which follows labor and environmental legislations. Two owners who work in the corporative management compose the executive board structure. The design team in this company has a Technologist in Fashion and Style with a Postgraduate degree in Design and a professional with a Postgraduate degree and a Master degree in Design. The respondent served as a Technical Analyst and was responsible for the development of products for the decoration's line, for the main product's collections development and for some specific projects.

3.3 Product Development Processes in Two Metallurgical Companies

It was observed that the two companies have been dealing with innovation in an incremental way, with focus on material innovation and improvement in quality, however these companies do not cover the entire production chain. It was pointed out by the companies to be an important factor the region where they are located, with other similar companies around using the same universe of materials, suppliers, references (in relation to international trends) and even the same manpower. It was also noted that innovation and new product releases still occur more often to follow national and international trends instead of an attitude to search for innovative solutions to supply the market and amaze their customers.

In Company A the request of a product development starts with the customer, who makes the order to the Commercial Area. The Commercial and Design Departments, then internalize the market demands within the company. Thus the Design Department develops the product project, preparing it for production. After the production phase, the Commercial Area participates once again, making contact with the customer, collaborating to launch and to promote the product. It is important to note that this company used to imitate competitor's products, once it still had no support to develop original products lines. Over time, nevertheless, the company has started to invest in its own creation and including design on this, looking for references in international events and catalogs. Nowadays, the partnership with external designers to create some product lines is a common practice.

In Company B, references are similar to those of Company A, constituted basically by materials collected from international fairs. Comparing to Company A, in this company external designers are not usually contracted, focusing internally throughout the process of product development, from the initial conception to the final product. The new product collections follow customer demands with deadlines set by the company. The process of new product projects begins with an information research from the commercial area and the Design Department. So the designers generate alternatives and then they selected alternatives to build the prototypes. The product is then developed and launched to the market through the commercial staff.

3.4 Design Management Within Companies

The design is present in the product concept, and is seen as a relevant resource for the generation of competitive advantage, in a positive relationship between investment and performance [35], although it was observed that in both companies there is still a lack of formalization in the new products development process. Companies A and B tend to use the international quality standards, without having a clear structure, which would include the processes of creative steps of generating and selecting ideas. The presence of trained professionals in the area and the investments made to have these professionals in the company have shown interest of the companies about design. So it is possible to say that the Design Management concept is not completely applied as advocated by Borja de Mozota [11] and Neumeier [36] in these companies.

It is also noticed that the design can not be managed appropriately in these companies because of not having clearly defined boundaries with areas like Marketing, Research and Development (R&D) and Engineering Departments. Furthermore, design is not part of the corporate strategic planning, which ultimately compromises its real importance in achieving goals at the organizational level. Another point that is directly reflected in the Design Management is the lack of structured functions and competencies regarding to the concern of the professional designer and design manager roles, hindering the understanding of who are professionals involved in the Design Management as well as what are the roles they have in the processes of both companies.

3.5 The Role of the Design Professional

Concerning to sharing information and knowledge among professionals and sectors involved in a certain project, this does not happen so often in the companies surveyed. This is due to organizational structures and excessive staff division and activities with rigid and specific functions. As a result there are teams working with little exchange of information with sectors participating in a project.

An intervening factor listed by respondents was the lack of autonomy and freedom to do their jobs and make decisions. Respondents were allocated in the areas of project management or product development and the projects were approved or disapproved by the senior managers. As stated by Libânio [37], design may be understood as a strategic element, and it must be connected directly to the senior managers, at a strategic level, and taking an active part in the products decisions. As reviewed in literature, Borja de Mozota [11, 12] considered that the design activity must be planned and formalized, with the coordination of the design features in all activity levels of the organization.

Such relationships were highlighted by Gorb [14], arguing that the Design Management aims to employ effectively the design according to the company's strategic objectives. This is corroborated by Borja de Mozota [11, 12], who has emphasized that the Design Management searches for achieve corporate goals.

Thus, it is clear that the integration of the teams involved in a project is progressive, but should be encouraged, both by professionals involved in projects as the company's top management in an ongoing dialogue between design professionals, teams and network of suppliers, also very important in the design process, as identified by Twigg [38], including tools and systems that can facilitate such processes [39].

4 Conclusion

Based on the set of information collected it was concluded that the Design Management is increasingly understood in a multidisciplinary way, encouraging an exchange of knowledge and strengthening a pluralistic view. It is still possible to observe an increasing volume of publications as well as a gradual evolution in the understanding about the theme internationally. It was found out that Design Management is an important research area, with multidisciplinary research centers that study the subject. However, there is discussion of certain aspects of research first abroad and later in Brazil.

The case studies allowed to think about the importance of integration of design teams with other areas and coworkers who participate in the Design Management process. As presented in this paper, this integration is hindered by some intervening factors such as lack of incentives for the development of Design Management in these studied companies, as well as the lack of design professionals and strategic partnerships. Considering the field of design research, the bibliometric analysis provides an overview of theoretical concepts related to everyday life experienced by traditional markets. Therefore, it is hoped that designers or design professionals with competencies in design can work together with managers, top managers and other partners in the projects, encouraging collaboration among teams. The research has the limitation to be applied in only two cases studies, so it is not possible to generalize the results and conclusions obtained in the metal chain as a whole. Consequently, it is suggested further research studies alike that may show industrial patterns in the metallurgical market in Brazil and abroad.

References

1. Design Management Institute (DMI) (2011) Available at <http://www.dmi.org>. Accessed on Aug 2011
2. International Council of Societies of Industrial Design (ICSID) (2011) Available at <www.icsid.org>. Accessed on 05 Sept
3. Centro Português de Design (CPD) Manual de Gestão do Design. Porto, Portugal

4. Instituto Europeu de Design (IED) (2011) Available at <http://www.ied.edu/>. Accessed on Aug 2011
5. Walsh V (1996) Design, innovation and the boundaries of the firm. Res Policy 25:509–529
6. Libânio CS, Amaral FG (2011) Aspectos da gestão de design abordados em dissertações e teses no Brasil: uma revisão sistemática. Revista Produção Online, Florianópolis 11(2):565–594
7. Lorenzini GC, Libânio CS, Wolff F, Amaral FG (2011) Design management with innovation: a case study in the furniture chain of Brazil. In: Proceedings of Tsinghua-DMI international design management symposium, Hong Kong, SAR, China
8. Kotler P, Rath GA (1984) Design: a powerful but neglected strategic tool. J Bus Strat 5(2):16–21
9. Roy R, Riedel JCKH (1997) Design and innovation in successful product competition. Technovation 17(10):537–594
10. Lojacono G, Zacai G (2005) The evolution of the design-inspired enterprise. Rotman Mag, Winter, pp 10–15
11. Borja de Mozota B (2003) Design management: using design to build brand value and corporate innovation. Allworth Press and D.M.I., New York
12. Borja de Mozota B (2006) The four powers of design: a value model in design management. Des Manage Rev 17(2):44–53
13. Maldonado T (1977) El diseño industrial reconsiderado. Gustavo Gili, Barcelona
14. Gorb P (1990) Design Management. Van Nostrand Reinhold, New York
15. Rodrigues RB (2005) A atividade de gestão do design nas organizações: um estudo no polo moveleiro de Santa Catarina", Master dissertation, Universidade do Vale do Itajaí
16. McBride M (2007) Design management: future forward. Design Manage Rev 18(3):18–22
17. Bertola P, Teixeira JC (2003) Design as a knowledge agent: how design as a knowledge process is embedded into organizations to foster innovation. Des Stud 24:181–194
18. Dell'Era C, Verganti R (2011) Diffusion processes of product meanings in design-intensive industries: determinants and dynamics. J Prod Innov Manage 28(6):881–895
19. Libânio CS (2011) O papel do profissional de design e suas interfaces na gestão de design: Um estudo de caso. Master dissertation, Porto Alegre: UFRGS
20. Fascioni L (2008) Considerações sobre a formação dos gestores de design no Brasil. Anais do P&D Design, São Paulo
21. Avendaño LEC (2002) Resgate do Protagonismo do Desenhista Industrial Através da Gestão do Design. In: 5° Congresso Internacional de Pesquisa em Design, Anais…, Rio de Janeiro
22. Spinak E (1996) Diccionario enciclopédico de bibliometría, cienciometría e informetría. Montevideo
23. Vanti NAP (2002) Da bibliometria à webometria: uma exploração conceitual dos mecanismos utilizados para medir o registro da informação e a difusão do conhecimento. Ciência da Informação 31(2):152–162
24. Borja de Mozota B, Klöpsch C, Costa FC, Da X (2011) Gestão de design: usando o design para construir valor de marca e inovação corporativa. Bookman, Porto Alegre
25. Chai K, Xiao X (2012) Understanding design research: a bibliometric analysis of design studies (1996–2010). Des Stud 33(1):24–43
26. Garcia R, Cantalone R (2002) A critical look at technological innovation typology and innovativeness terminology: a literature review. J Product Innov Manage 19:110–132
27. Becheikh N, Landry R, Amara N (2006) Lessons from innovation empirical studies in the manufacturing sector: a systematic review of literature from 1993 to 2003. Technovation 26:644–664
28. Dangayach GS, Deshmukh SG (2001) Manufacturing strategy: literature review and some issues. Int J Oper Prod Manage 21(7):884–932
29. Malhotra N (2001) Pesquisa de marketing: uma orientação aplicada, 3rd edn. Bookman, Porto Alegre
30. Bardin L (2005) Análise de conteúdo, ed. rev. e atual, Lisboa: Edições 70

31. Ahmadi R, Roemer TA, Wang RH (2001) Structuring product development processes. Eur J Oper Res 130(3):539–558
32. Roy R, Potter S (1996) Managing engineering design in complex supply chains. Int J Technol Manage 12(4):403–419
33. Lauche K (2005) Job design for good design practice. Design Stud 26(2):191–213
34. O'donnell FJ, Duffy AHB (2002) Modeling design development performance. Int J Oper Prod Manage 22(11):1198–1221
35. Chiva R, Alegre J (2009) Investment in design and firm performance: the mediating role of design management. J Prod Innov Manage 26(4):424–440
36. Neumeier M (2008) The designful company. Des Manage Rev 19(2):10–15
37. Libânio CS (2009) "Design como Elemento Estratégico para a Melhoria da Competitividade das Empresas da Cadeia Moveleira de Bento Gonçalves", Final Postgraduate Work. UniRitter, Porto Alegre
38. Twigg D (1998) Managing product development within a design chain. Int J Oper Prod Manage 18(5–6):508–524
39. Whitfield RI, Duffy AHB, Coates G, Hills W (2002) Distributed design coordination. Res Eng Design 13(4):243–252
40. Brereton P, Kitchenham BA, Budgen D, Turner M, Khalil M (2007) Lessons from applying the systematic literature review process within the software engineering domain. J Sys Soft 80(4):571–583

Analysis of Management and Employee Involvement During the Introduction of Lean Development

Katharina Helten and Udo Lindemann

Abstract The introduction of Lean Development (LD) requires change efforts within the organisation. People need to be convinced and motivated, development processes are questioned and adapted, eventually structures are changed. This paper compares the LD introduction processes within three SME with respect to three aspects: the top management involvement, the Lean leadership, and the employee involvement. Within those dimensions, main patterns are identified and interpreted to allow the derivation of implications for a successful introduction of LD.

Keywords Lean development · Organisational change · Management involvement · Employee involvement

1 Introduction

In order to improve product development processes and to manage them more efficiently, the idea of Lean Thinking [1] is applied to product development. The Lean philosophy focuses on the customer value, and therefore the elimination of any form of waste. Companies which introduce the Lean philosophy and Lean Development (LD) undergo a significant organisational change. This change process needs to be well managed to allow for a long-lasting implementation of LD and an improvement of engineering processes.

K. Helten (✉) · U. Lindemann
Institute of Product Development, Technische Universität München,
Boltzmannstraße 15 D-85748 Garching, Germany
e-mail: helten@pe.mw.tum.de

U. Lindemann
e-mail: lindemann@pe.mw.tum.de

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_71, © Springer India 2013

This paper therefore investigates the change processes during the LD introduction in detail. The aim is to identify relevant patterns and mechanisms to derive appropriate management models in the future. The findings base on empirical data gained during a project in three small and medium-sized entreprises (SME). The projects within each company ran between 12 and 18 months.

The authors analysed three main dimensions of management and employee involvement—top management involvement, Lean leadership and employee involvement. The identified patterns are compared based on an evaluation of the success of the introductory process in each company. Thus, relevant aspects and their impact are derived which are crucial for the management of organisational change during the LD introduction.

2 Background

2.1 Lean Development

The idea of Lean Thinking as defined by Womack and Jones [2] has attracted many engineering companies. Lean in general strives for the creation of customer value while eliminating wasteful tasks. After Womack et al. [1] had described the strengths of the Toyota Production System, and thus defined main ideas of Lean production, Womack and Jones derived five main principles of Lean: value, value stream, flow, pull and perfection [2].

Applying findings from Lean production to product development has proven to be difficult. Whereas the manufacturing process creates a tangible product or artifact, Lean development (LD) is mainly characterised by the transformation of information [3]. Siyamet al. claim that a deeper investigation on information value and waste will lead to more successes in LD, and define a guideline that relates information waste types to appropriate value methods [4]. However, several authors propose different frameworks to differentiate types of waste in LD. Oehmen and Rebentisch come up with a condensed overview of several authors' findings and derive eight types of waste: over production of information, over processing of information, miscommunication of information, stockpiling of information, generating defective information, correcting information, waiting of people, and unnecessary movement of people [3].

2.2 Change Management and Change Models

Change management in general can be described as "the process of continually renewing an organization's direction, structure, and capabilities to serve the ever-changing needs of external and internal customers" [5]. Change in an organisation can be based on three different aspects. According to Todnem By who refers to previous work of Senior [6] the main categories to characterise change are the rate of occurrence (e.g., (dis) continuous or incremental), how it comes about (e.g., planned, emergent) and the scale. Numerous authors have tried to describe or enhance change processes [7]. Often literature refers to the change model of Kotter to plan the main phases of change processes. Kotter's model consists of eight steps [(1) Establishing a sense of urgency, (2) Forming a powerful guiding coalition, (3) Creating a vision, (4) Communicating the vision, (5) Empowering others to act on the vision, (6) Planning for and creating short-term wins, (7) Consolidating improvements and producing still more change, (8) Institutionalizing new approaches] [8].

2.3 Lean Product Development as a Change Process Through Management and Employee Involvement

Moran and Bright man emphasise that people in general wish to have a dialogue about the coming change, and that management avoids such a dialogue. It means for management to commit publicly and to lead the change. Furthermore, the change within the organisation needs to be pushed from both directions, top-down and bottom-up. The authors depict the "Leadership paradox". Anticipating tomorrow's stage, leaders must promote the change and ensure stability at the same time. Effective change leaders act as role models and interact as much as possible with people to communicate the why, how, when etc. [5]. Emiliani and Stec list eleven errors of senior management during the Lean transformation. Among others, leaders do not show sufficient personal engagement. Moreover, senior management behaves inconsistently, exhibiting wasteful behaviour and asking the elimination of waste at the same time [9].

Nightingale and Srinivasan define seven principles of enterprise transformation. One principle specifically addresses leadership commitment. The authors emphasise the need to drive the transformation from the highest levels, i.e., senior management. Other principles address for example a holistic approach and organizational learning. The Enterprise Transformation Roadmap addresses among others the following aspects which are of relevance for this paper. The element "Engage Leadership in Transformation" (Strategic Cycle) includes a step to obtain executive buy-in, and to establish an executive transformation council. Later, change agents need to be empowered (Planning Cycle), as well as the transformation plan needs to be communicated (Execution Cycle). While implementing and coordinating the transformation plan, employees are provided with education and training. Important learnings are then diffused within the enterprise [10].

In a survey from 2010, participants were asked for the importance of different aspects regarding the expectations from leaders during change processes. Among the top answers was the ability of leaders to drive employees, to communicate actively the change was, and to initialise and shape the change process. The three most relevant success factors for successful change initiatives are to ensure mobilisation and commitment, to analyse and understand the environment, and to support leadership [11].

Taking the model of Kotter, in this regard especially the creation of a guiding coalition, the communication of the vision as well as the empowerment of people to react according to the change are of utmost importance [8].

Graebsch et al. have shown in their study that even though the idea of LD attracts lots of people, its introduction is perceived to be rather difficult. Participants of their study therefore agreed on the positive impact of pilot projects, followed by the use of a bottom-up approach [12]. As stated by Helten and Lindemann, literature doesn't provide a framework for conducting such pilot projects. Such a framework needs to indicate the necessary involvement of people as well as the definition of responsibilities. In their paper, they present a pilot scheme that includes four important phases (analysis, synthesis, realisation, and implementation), as well as important levers to lead the introduction. One of their relevant levers is "persons", thus the involvement of people. The modelling approach presented in the paper underlines the importance of the involvement of people by integrating a domain "People/Person" and two sub-domains (Management level, Department). Also lots of the proposed relations indicate the interaction of people, such as "is responsible for", "takes part in", or "knows about". Literature mentions the importance of leadership and employee involvement, but does not show specific patterns, their comparison and implications for the LD introduction [13].

3 Research Approach

The structures that are depicted and analysed in this paper are based on experiences during a research project with industrial participation. The aim of the project was the first-time introduction of LD into SME. Three companies are supported and monitored over the run of twelve to 18 months. Researchers and industry partners were in contact by means of meetings (approx. monthly), and calls and emails (approx. weekly). Some companies had experiences with Lean production. They differ among others in their product type (consumer vs. capital goods), the number of engineers in PD (about 5 to about 80) and management structure (owner vs. managing directors). It needs to be emphasised that due to the specific setting of SME and the first-time introduction of LD, the change process was characterised by the engagement of single persons or small groups, and the implementation of specifically defined actions, e.g., the creation of a knowledge database or new forms for the requirements management. In some cases more extensive actions followed after gaining some experience in LD.

Each company defined a core team, consisting of three or four persons of different hierarchical levels. The research team supports the introduction by delivering academic and literature input, participating and moderating relevant meetings, and supporting important steps such as the waste analysis or the action definition. Therefore, the research method follows the action research approach. The underlying thesis is that complex social processes can be investigated best, if changes are introduced into the system and their effects are observed [14]. The researcher is therefore both observing and participating. Susman and Evered add an aspect that is relevant in the context of the overall goal of this research to support the self-help approach during LD introduction. The authors state that action research aims "to develop the self-help competencies of people facing problems". They propose a cyclic approach that consists of five phases (Diagnosing, Action planning, Action taking, Evaluating, Specifying learning) [15].

Over the run of the project, the researchers monitored all activities in a monitoring sheet to allow for a detailed analysis. Therefore, in addition to the activities, the date and the involved persons are noted. The sheet differentiates activities that were project logical and those that solved problems. Finally, any feedback from industry during the introduction was documented. Of importance were e.g., activities between project meetings, whether the procedure is clear, or which suggestions the companies had to continue and to adapt the process to their specific internal conditions. In addition, the core teams of all participating companies were asked for their overall assessment in an interview. Based on this feedback and the evaluation by authors the success of the LD introduction can be identified. Success refers to the introduction process itself, not to the (financial) success of the LD actions.

4 Results

Based on a literature review, the analysis of the monitoring sheet with respect to management and employee involvement leads to the identification of three main dimensions and several sub-dimensions, as shown in Table 1. As described above, the involvement of top management as well as employees is essential for the success of the change. Furthermore, one category concentrates specifically on the Lean leadership.

Due to the limitations of the qualitative research, the differences are assessed more in a relative manner. In case of companies A and C the pilot project focused on product development in one business unit, in case of company B on all business units. The successes can be described as follows:

Table 1 Relevant dimensions for management and employee involvement during LD change processes

Dimension and sub-dimensions		
Top management involvement	Lean leadership	Employee involvement
• Initialisation	• Composition of core team	• Waste analysis
• Awareness		• Action definition
• Communication	• Responsibility for Lean pilot project	• Information/ Communication
	• Action taking	
	• Internalisation	

Company A and *Company B* : Based on a comprehensive waste analysis, actions were defined, detailed, and to large parts already implemented. Several employees were directly involved, most/all development engineers are at least informed. In the following of the pilot phase, the company develops further actions and follows continually the realisation of previously defined actions. The evaluating interview showed that the term LD is used within the company, in one case is also part of the company goals. The state after the pilot phase with respect to LD is to be qualified assuccessful and promising.

Company C: Based on a comprehensive waste analysis, actions were defined, detailed, and some are implemented. For those ones future steps were defined. After being involved in a questionnaire during the waste analysis, employees besides the core team are involved in the specific implemented actions, not in other initially defined actions. The core team members feel to be much more sensitised towards processes. The LD pilot project enabled several continuous improvement efforts. The term LD is not specifically used as a term throughout the entire company. Nevertheless, the company is striving for success.

Table 2 shows the patterns of relevant dimensions. The interpretation refers to the overall assessment of the LD introduction as described above. Those elements and relations are chosen that represent the situation the best according to the authors. The challenge is to find the right level of abstraction that allows a comparison of the three companies. Therefore, e.g., the descriptions of the positions of each person are slightly adapted to allow a comparison. By means of a qualitative comparison of the companies and their results, the relevance of a single sub-dimension as well as the implications for a general pilot scheme for introduction are derived.

Table 2 Models of LD change situations, their interpretation and implications for a pilot scheme

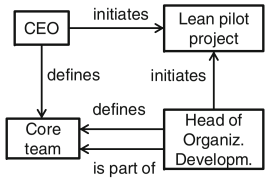
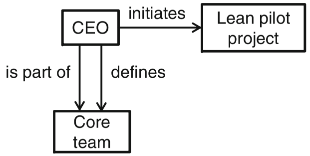
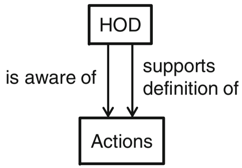
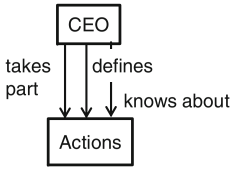
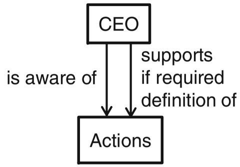
Top management (TM) involvement		
Initialisation		
Company A		**Interpretation**: In all companies the Lean pilot project is initialised by the TM. Since the CEO is part of the core teams in companies B and C, which differ slightly in their success of introduction, the CEO's participation seems not to be crucial. The Head of Organizational Development (HOD) participates in the core team of company A. Since the projects run over a period of a year or longer after the initialisation and showed the implementation of actions, any form of TM's initialisation seems to have a positive impact. **Implications**: The initialisation by TM ensures at minimum management attention, and thus a positive start into the Lean journey.
Company B and company C		
Awareness		
Company A		**Interpretation**: Even though TM has initialised the project and takes part in the core team, its awareness of ongoing actions to eliminate waste differs. The awareness scale varies from a continuous participation in as well as definition of actions (B) to awareness of the current state and support of the actions' definition (A), to an awareness and support if required (C). In TM's awareness the continuity seems to be important. Company A and B are rated the same in the success of the introduction. Even though they show slightly different pattern, they ensure the necessary continuity. Similar patterns can be found with focus on the participation. **Implications**: A continuous awareness and support of TM is required, the depth can vary.
Company B		

Table 2 (continued)

Top management (TM) involvement

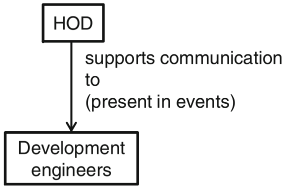
Awareness

Company C

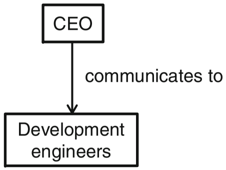


Communication

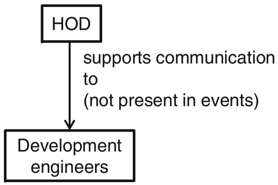
Company A



Company B



Company C



Interpretation: The communication of the LD goals, findings and actions allows the diffusion down to the level of individuals' objectives. In companies A and B, TM supports the communication. In company A the HOD is moreover present in events with employee participation. The CEO of company B directly addresses the development engineers. In all companies actions are executed by the engineers. Thus the communication needs to be ensured, but not executed necessarily by the TM.

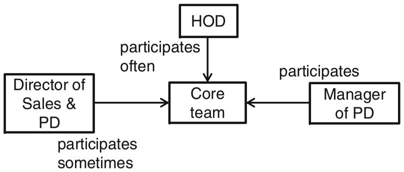
Implications: TM needs to support at least the communication on LD. It could be assumed that the presence (passive or active) shows a higher commitment, and leads to a higher success to introduce Lean Development as an overall philosophy.

Table 2 (continued)

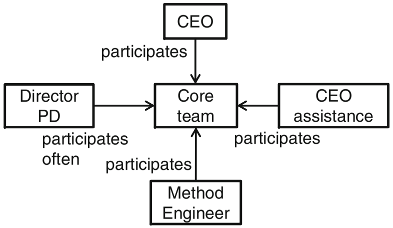
Lean leadership

Composition of core team

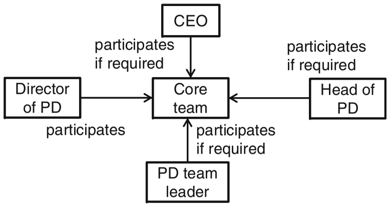
Company A



Company B



Company C

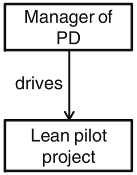
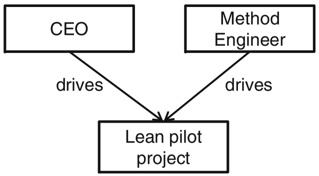
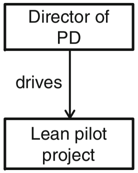


Interpretation: All companies include three to four members in the Lean core team from different management levels. The difference in the overall success of the introduction seems not to be related to the composition of the team itself, but more to the indicated relations (i.e. level of participation). In all companies the main driving person participates continuously (see "Responsibility for Lean pilot project"). In company A two main characters participate continuously, the HOD and the Manager of PD. In companies A and B most people participate always or often. In company C the responsible persons participate if required. This constellation allows the implementation of specific actions, whereas the other companies focus more on the LD philosophy as a whole.

Implications: The composition of the core team is of minor relevance as long as (selected) engineers are integrated in the overall process and relevant levels are represented. A high participation rate has a positive effect.

(continued)

Table 2 (continued)

Lean leadership		
Responsibility for Lean pilot project		
Company A		**Interpretation**: Even though the projects are initialized in all cases by the CEO, the CEO drives only in company B the ongoing process. In the other cases, responsible persons in the line organisation like the Head of PD and the Manager of PD drive the pilot project. Companies B and C have approx. the same number of PD engineers. Since they differ in their success, the number of responsible persons seems to depend on the size of the PD department. **Implications**: The number of responsible persons should be aligned with the size of the PD department. Probably, new dimensions such as no. of PD team members, the organisational structure and the involvement on tactile levels need to be considered in future work.
Company B		
Company C		

(continued)

Table 2 (continued)

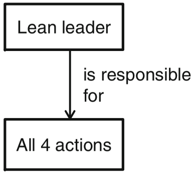
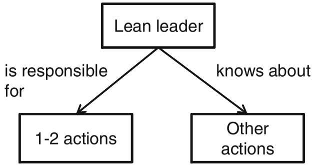
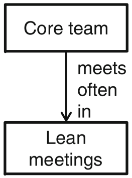
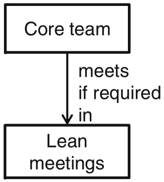
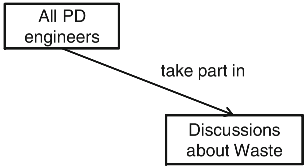
Lean leadership		
Action taking		
Company A		**Interpretation**: The Lean leaders of company A is responsible for all four actions, and thus automatically informed. In company B and C the Lean leader(s) is(are) responsible for 1–2 actions and know about the other actions. The general structure doesn't seem to be relevant for the success. Companies B and C show the same structure, but vary in their overall success. The difference is addressed to some extent in the previous factor, since two persons are leading the pilot project in company B. Again the size of the PD department in company C seems to allow for one strong Lean leader who is responsible for all actions. **Implications**: The size of the PD department seems to necessitate a certain number of responsible persons. Since all companies show a certain success after the pilot project, it could be assumed that this is due to the fact that the Lean leaders themselves are in every company responsible for at least one action.
Company B and company C		
Internalisation		
Company A and company B		**Interpretation**: This factor describes to what extent the internal team embraces the Lean initiative and drives it without external push (i.e. the research team). Companies A and B show the same frequency, and the same success. Company C meets internally if required during the pilot project. The frequency of meetings seems to correlate with the level of outcome—from the implementation of specific actions to the LD philosophy. The companies focussing more on LD need to meet often internally. **Implications**: The more often core team members meet internally, the higher the probability that the company introduces Lean as a philosophy instead of a part of the continous improvement process. The frequency of meetings seem to be an indicator for the depth of embracing the LD approach.
Company C		

Table 2 (continued)

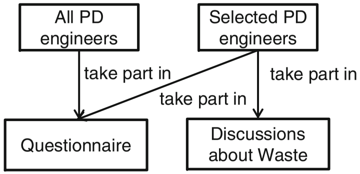
Employee involvement

Waste analysis

Company A



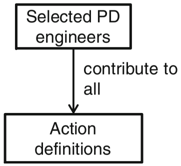
Company B and company C



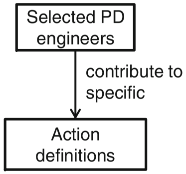
Interpretation: All companies integrate several engineers during the analysis phase. The larger companies B and C use questionnaires in addition to discussions. To allow for an identification with the LD idea and success of the introduction, engineers need to be integrated after taking part in the analysis. In company B e.g. employees are informed in an event about the results and further steps, in company C there is not such an event. Company C focuses more on the communication of results whereas company B presents also preliminary results to enhance the internal discussion. Company A seems to be successful by having a continuously intensive discussion about waste within the whole team.
Implications: The integration during the waste analysis has a positive impact. It is essential to understand the waste causes to participate in the following Lean change. Thus information about the results is advisable.

Action definition

Company A and company B



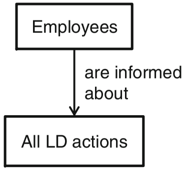
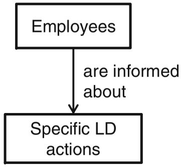
Company C



Interpretation: Whereas companies A and B involve selected engineers in the definition of all actions, specific actions are defined with the support of selected engineers in company C. The PD engineers give a feedback on a tactile level and allow for a higher applicability and more tangible improvements.
Implications: The definition (in detail) of all actions should involve PD engineers to allow feedback and suggestions from all hierarchical levels. It is assumed that a higher rate of involvement leads to a more visible commitment of the company to LD and higher success in terms of LD during the introduction.

(continued)

Table 2 (continued)

Employee involvement		
Information/Communication		
Company A and company B		**Interpretation**: All companies inform the employees about the actions. In contrast to companies A and B, company C focuses more on the information about specific actions. In companies A and B all defined actions are presented. Employees have the chance to understand the current project state and to ask questions. The companies allow thereby the participation in the Lean journey for everybody, ensure transparency and show commitment to the Lean effort. **Implications**: Employees are to be informed to ensure an open and constructive attitude towards LD. Such a public commitment drives the internal expectations to succeed.
Company C		

5 Conclusion and Outlook

The analysis of the LD introduction in three SME identifies three dimensions of utmost importance to understand management and employee involvement during the change process. These categories are top management (TM) involvement, Lean leadership, and employee involvement. The in-depth analysis of these qualitative cases allows the identification of several main factors and implications. Regarding the TM involvement, continuity seems to be the most important aspect, e.g., of awareness. In addition, it is assumed that the communication must be at least supported by the TM. Thereby the management commits publicly the need for change and paves the way for employee engagement.

With respect to the Lean leadership, it seems to be important that the core team and its members take over the Lean initiative as early as possible to embrace the idea, e.g., by driving themselves some actions. A specific composition of the core team is less important than the representation of different levels and a high rate of participation. It is assumed that the size of the PD department has some influence, e.g., on the number of responsible persons for LD. But a further investigation is needed.

If it comes to employee engagement, it seems to be of utmost relevance for the success that employees get the chance of involvement. Once involved, people need to get feedback during the whole process. Furthermore the constructive feedback of the PD engineers allow for a high understanding and applicability of the Lean actions.

The further research will investigate on further factors such as the complexity of actions and the extension of LD within the company to allow for an overall view on the LD introduction. Thus also the characterization of the companies will be considered. Moreover, the success needs a more detailed discussion. Aspects such as the fact that different numbers of business units were involved require further inquiry.

The identified alternative patterns need a deeper discussion with industrial partners. Their feedback on the patterns allows an evaluated overview and the derivation of a descriptive model. Other companies could be interviewed to gain insights into the relevance and impact of the presented dimensions.

References

1. Womack JP, Jones D, Roos D (1991) The machine that changed the world—the story of lean production. Harper Perennial, New York
2. Womack JP, Jones DT (2003) Lean Thinking. Banish waste and create wealth in your corporation. Simon & Schuster, New York
3. Oehmen J, Rebentisch E (2010) Waste in product development. In: LAI Paper Series Lean Product Development for Practitioners, Massachusetts Institute of Technology, Cambridge

4. Siyam GI, Kirner K, Wynn DC, Lindemann U, Clarkson PJ (2012) Relating value methods to waste types in lean product development. In: Proceedings of International Design Conference—Design 2012, Dubrovnik, 21–24 May 2012
5. Moran JW, Brightman BK (2001) Leading organizational change. Career Dev Int 6(2):111–118
6. Senior B (2002) Organizational change, 2nd edn. Prentice Hall, London
7. Todnem R (2005) Organisational change management: a critical review. J Change Manage 4(5):369–380
8. Kotter JP (1995) Leading change: Why transformation efforts fail. In: Harvard Business Review, Vol 73(2)
9. Emiliani ML, Stec DJ (2005) Leaders lost in transformation. Leadersh Organ Dev J 26(5)
10. Nightingale DJ, Srinivasan J (2011) Beyond the lean revolution: achieving successful and sustainable enterprise transformation. AMACOM, New York
11. Capgemini Consulting (2010) Change Management Studie 2010: Business Transformation—Veränderungen erfolgreich gestalten, Munich
12. Graebsch M, Lindemann U, Weiß S (2007) Lean Development in Deutschland—Eine Studie über Begriffe, Verschwendung und Wirkung. Dr. Hut, Munich
13. Helten K, Lindemann U (2012) Structural modelling and analysis of organizational change during lean development implementation. In: Proceedings of International Design Conference—Design 2012, Dubrovnik, 21–24 May 2012
14. Baskerville RL (1997) Distinguishing action research from participative case studies. J Syst Inf Technol 1(1):24–43
15. Susman GI, Evered RD (1978) An assessment of the scientific merits of action research. Adm Sci Q 23:582–603

ICT for Design and Manufacturing: A Strategic Vision for Technology Maturity Assessment

Mourad Messaadia, Hadrien Szigeti, Magali Bosch-Mauchand, Matthieu Bricogne, Benoît Eynard and Anirban Majumdar

Abstract Based on the EU-FP7, ActionPlanT project aims at assessing and ranking Information and Communication Technology (ICT) that will have the most impact on European competitiveness. One of the outcomes is a classification of ICT for design and manufacturing. ICT, used inside companies, can be classified in different levels according to company's organization. The paper describes layered software architecture for design management and manufacturing execution of company which intensively uses ICT. The ICT classification can link two perspectives which are developed industrial strategy and used design and manufacturing technology. Results of this work were used in the FP7 project for integrating strategy with design and manufacturing levels.

Keywords ICT · Manufacturing systems · Product development process · Information systems · Industrial strategy

M. Messaadia · M. Bosch-Mauchand · M. Bricogne · B. Eynard (✉)
Université de Technologie de Compiègne, Compiègne, France
e-mail: benoit.eynard@utc.fr

M. Messaadia
e-mail: mourad.messaadia@utc.fr

M. Bosch-Mauchand
e-mail: magali.bosch@utc.fr

M. Bricogne
e-mail: matieu.bricogne@utc.fr

H. Szigeti
Dassault Systèmes, Delmia, Vélizy-Villacoublay, France
e-mail: Hadrien.SZIGETI@3ds.com

A. Majumdar
SAP, Dresden, Germany
e-mail: anirban.majumdar@sap.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_72, © Springer India 2013

1 Introduction

The contribution of Information and Communication Technology (ICT) to the manufacturing industry has become unquestionable over the 20 years. ICT will be increasingly merged with future manufacturing processes and support the development of efficient business processes. To ensure the sustainable competitiveness of European manufacturing industry, a continuous improvement of the use of R&D expertise as well as of manufacturing and technology resources is required. The proposed analysis will consider technology and business trends as well as politics, environmental, and society needs [1].

The Lisbon Strategy adopted in March 2000 set the European Union the goal of becoming the knowledge economy the most competitive and most economy in the world. Consequently, the EU has adopted plans for Use of ICT in European industrial companies (first "e-Europe 2002" in June 2000, second "e-Europe 2005" in June 2002, and finally the strategy "i2010") [2]. The ActionPlanT project is co-funded by the European Commission under the Private–Public Partnership (PPP) "Factories of the Future" within the Seventh Framework Programme (FP7) [3]. ActionPlanT aims to develop a vision on the short, medium, and long term role of Information and Communication Technology (ICT) in the European manufacturing industry [4].

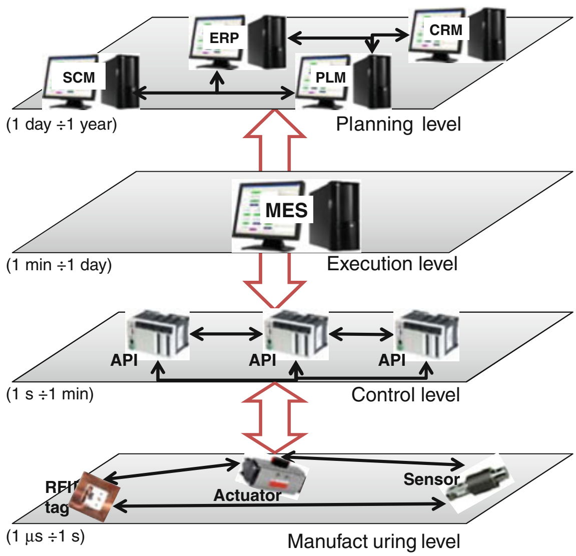
Advanced systems such as Product Lifecycle Management (PLM) Enterprise Resource Planning (ERP) or Customer Resource Management (CRM) systems are nowadays unquestionable in the strategic, tactical and operation management of the company. Based on a single database, ERP allows managing the business processes of a company and sharing information among its teams for sales and purchases, and also with the departments of "finance", "planning", "marketing", etc. CRM allows managing all customer relationships in a same process: collecting and distributing information to other services and customer analysis for marketing (pricing, promotional sales organization, choice of distribution channels).

The following section presents a literature survey concerning the growing of ICT part in the enterprise activities which is summarized on Fig. 1. Section 3 introduces the ICT classification based on outcomes proposed on Sect. 2. Section 4 is the deployment of the classification on ActionPlanT project. The conclusion discusses results of the project.

2 ICT Evolution: From the Plant to Enterprise

For over three decades, it has been seen the unquestionable increasing of ERP implementation in manufacturing industry. The use of ICT started long before, production management systems have evolved from Material Requirements Planning (MRP) systems in the 1970s and Manufacturing Resource Planning (MRP II) systems in the 1980s, to ERP systems in the 1990s, which is based on a

Fig. 1 Levels ICT areas source



single source of data for internal processing of financial assets, production planning and control, human resource management, raw materials management as well as traditional manufacturing process planning. In the 1990s, other functions began to be integrated to ERP, such as and customer relationship management (CRM) [5] and supply chain management (SCM) [6]. These "extended enterprise systems" expanded the scope of enterprise information system beyond the boundary of the company covering relationships with suppliers, partners and customers [7].

For another example, although Computer-Aided Design (CAD) systems have made it easy to create and modify drawings, these powerful systems also often create new problems with uncontrolled proliferation of technical documents and their versions. Then, PDM systems have been used by manufacturing companies to manage the data and documents accumulated in the design of their products [8]. Those systems are intended to support product data structuring and management throughout the product development process. They manage information through document management and especially product data evolution using predefined workflows [9, 10]. As an extension, Product Lifecycle Management (PLM) systems introduce new functionalities such as project management or requirements engineering [11]. Current PLM systems integrate Internet-based technologies and offer groupware-like functionalities) for proactive collaboration between project team members. One of the first definitions of engineering data management was in 1980s by Konstantinov, his work was situated in the design management area, and the vision of PLM has hugely changed since then [12]. Currently, PLM system manages all contributions and information exchange of global team members, like to business partners, suppliers and customers [13].

The management system of company usually consists of an Enterprise Resource Planning (ERP) and a Computer Aided Management program (CAM); the monitoring system providing real-time control of production. The Manufacturing Execution System (MES) is born of a lack of communication between the computer and functional layer. It therefore contributes to the data integration for Computer Integrated Manufacturing (CIM). The MES system bridges the gap between the production planning system and the control and supervision system using on-line data to manage the current application of manufacturing resources: people, equipment and inventory (Fig. 1).

The MES is an information system specified and implemented for the control of manufacturing systems. Nowadays, most manufacturing enterprises use production planning based on ERP/ERP II [14, 15] to define what and when products have to be manufactured but they have no close control and supervision of executed operations.

For many industrial companies, information systems encountered, consist of multiple levels architecture as presented on Fig. 1. They are able to carry out the products manufacture and assembly with several variations in performing operations on multiple workstations, automated or not. The physical flow are controlled, monitored and plotted based on the multiple levels and the integration of ICT.

Manufacturing level is classically split up into: (1) an operating sub-system, which ensures material processing (space, time or shape) for producing the desired added value; (2) a control sub-system, able to supervise a planed processes e and to control the operating sub-system according desired objectives [16].

Input data of the information system can be broken down into instructions sent by the human operators and messages sent from other components of the ICT architecture (MES, etc.).

The shop floor is connected with MES, which has a number of functions (supervision, launch and track work orders, performance analysis, traceability, etc.) and allows the integration to the upper ICT levels (including order processing and scheduling of manufacturing and assembly orders). The MES is implemented based on web services, allowing a remote access to all functionalities and in particular the control of the production lines and operations. In this way, it is possible to access archived production data for use as current operating data, for example, validate models. Gradual extension towards the upper level (ERP, PLM, etc.) is ensured, as well as the integration or interoperability with specific systems [17].

3 ICT Classification

According to ICT survey and their application areas, it has been identified a four levels architecture (Manufacturing, Control, Executive and Planning) see Fig. 1.

Based on these levels and the survey, ICT's for manufacturing have been classified according to Fig. 2. The proposed classification aims to link the low level of the company, which is composed of machine-tools, conveyors, sensors, actuators and controllers with the highest level which is a suppliers and customers

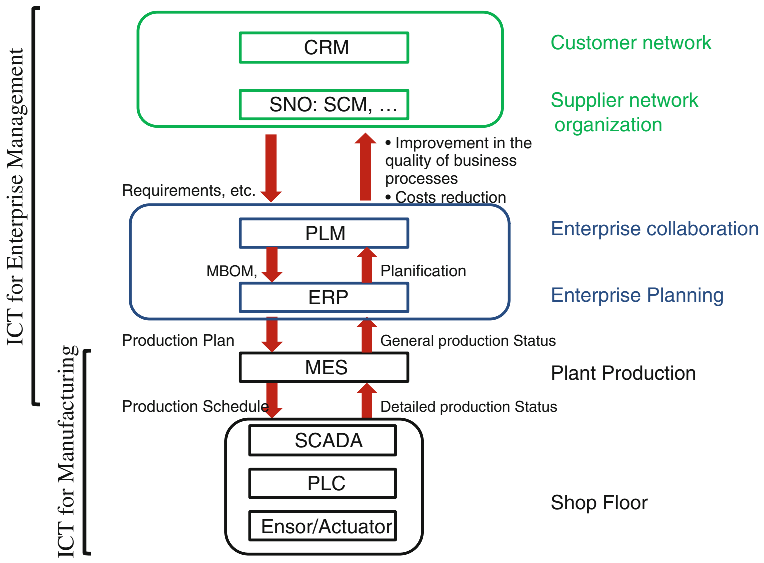


Fig. 2 ICT classifications according to enterprise architecture

oriented management strategy. Figure 3 shows a detailed view of ICT layer in an automated production system.

ICTs are classified according to their scope of application. The classification starts from the small part of enterprise, shop floor, the first level of monitoring system is the Supervisor Control and Data Acquisition (SCADA) that supervises the working productive area [18]. MAS (Machines, Automation, and SCADA) includes sensors/actuator, PLC and SCADA. MES is the bridge between the production plant—shop floor and the whole Enterprise. It coordinates and synchronizes manufacturing processes, the information flow between ERP/PLM and production plant/shop floor (PLC, Robots…). It also distributes operations and tasks to other sub-level of information system. MES receives information from ERP/PLM (process planning, operations sequence) and sends process scheduling as machine commands for manufacturing sequences. MES gives the visibility on what happens in the production and operation area. ERP system manages information on values and costs for manufacture and assembly of products [19].

ID	Optimisation	On Demand	Innovation	Green	Better Plant	Improvement Goal
RT10	2	0	0	0	1	**3**
RT11	0	1	0	0	0	**1**
RT12	0	0	0	1	0	**1**
RT13	2	0	0	0	0	**2**
RT14	0	0	0	0	0	**0**

Fig. 3 Research topics (RT) weighting

PLM an ERP are at the highest enterprise level (Strategic planning). ERP manages and controls information of the whole enterprise. It includes several modules supporting a large range of business functions such as finance, administration, logistics, manufacturing, marketing and so on [13]. ERP exchanges data and information with other systems of CAx family (CAD, CAE and CAM) or Supply Chain Management (SCM) to Customer Relationship Management (CRM) via Product Lifecycle Management (PLM).

PLM manages all documents and information exchange from all project team members, like to suppliers (via SCM) and customers (via CRM). PLM increases communication, coordination and collaboration with partners of an "extended enterprise" [20]. PLM makes the link with the highest level of management, from enterprise to extended enterprise, by providing collaborative and interoperable share space where suppliers/clients/OEM can access and share, in real time, product lifecycle information.

CRM enables us to collect many types of data. For example, it can be known about the customer's interaction history with us, when the customer lodged a complaint, when we reply, etc. Overall, CRM leads to better insights about customers, which help to see how it can be improved and planed for services that are of added value to customers [21].

4 Case Study

ActionPlanT project aims at defining an agenda for leveraging "ICT in Manufacturing" in the next ten to 15 years by creation of a vision and roadmap [1]. The ActionPlanT vision will serve as a precursor to the ActionPlanT roadmap. The former will focus on highlighting the key manufacturing challenges and their corresponding ICT enabling production technologies. This is reflected by the establishment of effective link between the strategic approach (Ambitions) and technologies deployment in the manufactory (Technology Readiness Level: TRL[1]).

Westkämper identified several "inefficiencies" in the use of ICT in the "practice of manufacturing". The risk of disrupting a functional production line by adopting a disruptive technology is the foremost. Second is the issue of obsolescence whereby systems and middleware of varying maturity deployed at the levels of shop floor (plant connectivity), plant/site (MES, PLM), and enterprise (ERP) do not seamlessly interact with one another thereby forcing system landscapes to be inflexible. The third is the issue of prohibitive cost of developing in-house systems or purchasing off-the-shelf systems. Modern day enterprises, especially SMEs,

[1] TRLs are a set of management metrics that enable the assessment of the maturity of a particular technology and the consistent comparison of maturity between different types of technology [22].

require low-cost solutions [23], open systems with standard interfaces, and those that are easily configurable.

4.1 Ambitions

The European Environment State and Outlook Report 2010 (SOER 2010) outlined a cross-cutting assessment of how key global megatrends are going to impact European denizens in the near to mid-term future. The premise for the ActionPlanT Vision is based on these multidimensional changes which are taking place socially, technologically, economically, ecologically and politically. In the project we cluster the eleven global megatrends in SOER 2010 into three prominent European Megatrends relevant for European industries: (1) Impact of demographics (people) on consumption and employment; (2) Global competition and push for innovation; (3) Increasing importance of sustainability issues.

Based on the list of clusters of R&D topics provided by state-of-the-art analysis of over 35 roadmaps, we first identified which/how different factors impacted the R&D topics in a positive or a negative way. These identified factors were further streamlined and grouped into a set of 25 STEEP Factors, each taxonomized into distinct Factor Clusters (Social, Technological, Environmental, Economical, and Political/Legal). The final step of the analysis consisted of mapping these factors to ICT topics (distinguished by their topic codes) which were presented to the ActionPlanT experts in the form of scenarios for evaluation and ranking. Based on STEEP analysis approach [4], the first axis identifies five ambitions: Optimization, On Demand, Innovation, Green and Better Plant. These ambitions also relate to the strategies outlined implicitly or explicitly in all roadmaps analyzed under the inventory analysis work of ActionPlanT.

- ON-DEMAND: to deliver on-demand custom products faster than competitors through a network of manufacturing partners
- OPTIMIZED: to provide optimal product quality, safety, durability and additional services for a given cost
- INNOVATIVE: to industrialize new product/process technologies faster than competition
- GREEN: to track and reduce the environmental footprint for products and processes
- BETTER PLANTS: to provide workers a better place to work, adapted to them, safer and compliant with all regulations.

Second axis based on TRL approach, identifies the maturity of technologies in different topics of the roadmap. This work aims to give a maturity level to each RT in order to evaluate the technologies maturity used in the RT. Results are evaluated by experts (Industrial and scientists) during workshops.

4.2 Research Topics

The international experts involved in the workshops organized by the ActionPlanT Consortium suggested more than 130 specific Research Topics (RTs); all capable of significantly impacting the European manufacturing industry through ICT focused research.

In order to evaluate the impact in a more structured way, each RT has been evaluated against the five ambitions (On-demand, Optimized, Innovative, Green, Better Plants), using a mapping approach with an index of a scale of the number of "sub-ambitions" impacting the RT.

Improvement goal is the result of RTs weighting. Improvement goal is an indicator that will allow us to evaluate the RT and compare it to other RT. This will allow us to assess its maturity and develop a strategy (future) of improvement.

4.3 ICT Classification

The ICT classification by levels will be used for linking the two project axis i.e. "ambitions" and "technologies maturity". The deployment of the approach started with mapping topics according to the ICT levels (column) and different other axis (line). As an example it can be mentioned case of 5 M axis (lean manufacturing) line, which is specific to the manufacturing workshop environment [4]. As result it is obtained an ICT distribution according to their field of use in the workshop.

Once ambitions are defined, each one was detailed on different "sub-ambitions". Initially we assign weights to sub-goals which corresponded to the average weight of ambition. Thus, we could have a qualitative assessment. A second work was to give weight to the ambitions for the number of sub-goals. Finally we compared these two approaches and found that they converged. However, deployment should be done in order to have more accurate weight (Table 1).

Table 1 Ambitions and their "sub-ambitions"

Optimization	On-demand	Innovation	Green	Better plants
Yield	Reusability	Supplier integration	Waste	Work environment
Quality	Quick development	Time information	Recycle	Stress
Reliability	Scalability	User innovation	Resource usage	Human intervention
Cost	Adaptive		Safety	
	Small size batches customization		Energy	

	Measure	Machine	Method	Worksapce	Material	Man
CRM	0	0	4	0	1	2
SNO	1	2	6	0	1	2
PLM	4	7	14	5	3	3
ERP	3	7	12	4	1	4
MES	4	10	16	4	1	4
M.A.S	4	10	15	4	1	4

Fig. 4 ICT concentrations in the production plant

During the mapping, we have chosen the weight of the ambition equal to the sum of "sub ambition" impacting the RT. Once the weight of the RT defined, we made a mapping of RTs according to their application field in manufacturing.

All RTs were regrouped and evaluated according to five ambitions (Fig. 4). The aim is to link these den RT and manufacturing, especially the application in

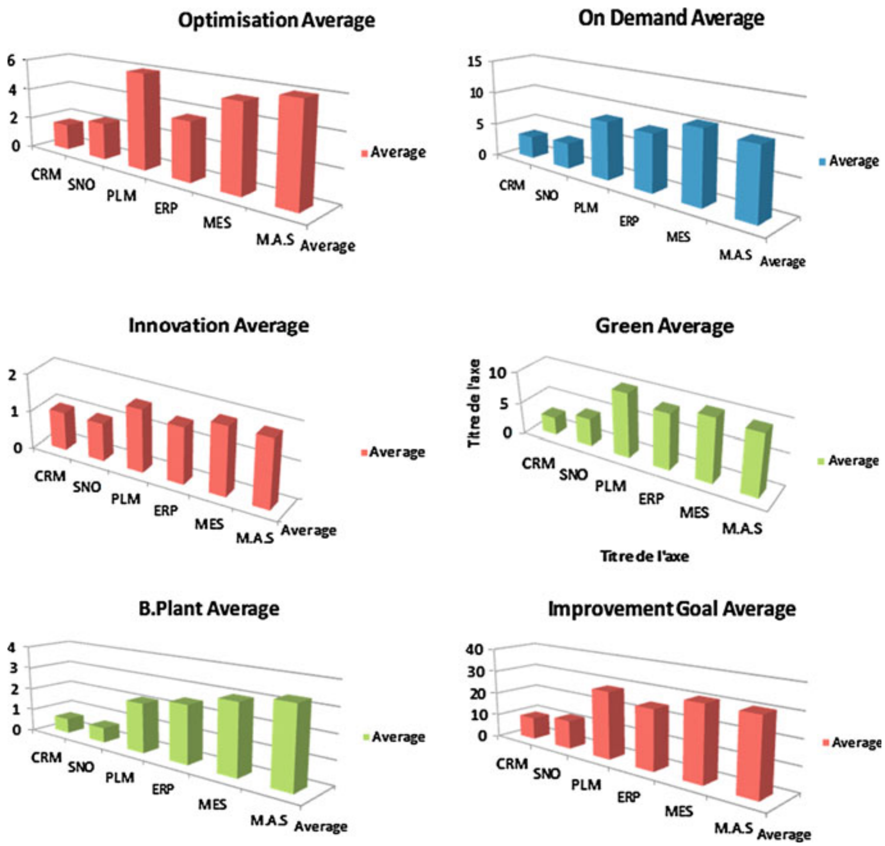


Fig. 5 ICT levels applied to ICT projects roadmap according to the five ambitions

	Measure	Machine	Method	Worksapce	Material	Man		Average
CRM	0	0	5	0	1	4	CRM	1,66666667
SNO	0	2	7	0	1	4	SNO	2,33333333
PLM	2	7	15	5	2	5	PLM	6
ERP	2	5	8	2	0	5	ERP	3,66666667
MES	3	8	14	2	0	5	MES	5,33333333
M.A.S	3	8	16	4	0	5	M.A.S	6

Fig. 6 ICTs averaging approach

manufacturing. For this, we identified different approach that we present the 5 M (standard in Lean Manufacturing).

On Fig. 4, dark red areas underline field where the density is huge, those lighter red areas are less of density, etc.: CRM, SNO (supplier network organization), are less important in the Research Topics (RT). The first conclusion is that Organization and Human Services (CRM, SNO) are less treated in Research Topic (RTs). Considering Fig. 4, it can be found that the highest density is that Methods in the interval [MAS, PLM]. This outcome is explained by the limitations of ICT (or rather their current maturity). Indeed the "Challenge histogram Technologies Standards" according to ambitions is presented on Fig. 5.

It is worth noticing that the above described components, the Ambition axis, Average Factor, and TRL, are not dependent on each other, but combined they give a significant overall. For example, a low TRL level does not necessarily mean that the RT should be researched at later stages of the Horizon 2020 timeframe while on the other hand a high TRL level does not indicate that the RT should be researched immediately in the future (Fig. 6).

Summarized it can be said that the TRL measures the current technological maturity of the RT, the ambitions, especially their "sub-ambitions", are the potential impact of a successfully researched RT, and the average factor can be used as a base for an indication of the proposed time for carrying out research activities.

5 Conclusion

In a global and competitive context it is important to have a link between strategic vision and technologies used in the manufacturing industry. The work presented in this paper aims to link the two stages of the ActionplanT project. Hence ICT are classified according to their area of use for data and information management, from the manufacturing cell in the production plant until the whole extended and collaborative enterprise based on PLM. It provides a synthesis view of limitations of these information systems and a clarification of the link between technology maturity and strategic targets of development (Ambitions).

Future work will focus on the development of new prospects, and more complete deployment of the proposed approach by integrating ICT standards survey and not only systems and applications.

References

1. ActionPlanT (2012) Roadmap and vision for manufacturing 2.0. http://www.actionplant-project.eu/index.php?option=com_content&view=article&id=51&Itemid=56. Accessed 30 Apr 2012
2. Eurostat (2012) http://epp.eurostat.ec.europa.eu. Accessed 30 Apr 2012
3. ActionPlanT (2012) Project. http://www.actionplant-project.eu. Accessed 30 Apr 2012
4. Szigeti H, Messaadia M, Majumdar A, Eynard B (2011) STEEP analysis as a tool for building technology roadmaps. In: Internationale challenges e-2011 conference, Florence, 26–28 Oct 2011
5. OECD (2012) http://www.oecd-lirary.org. Accessed 30 Apr 2012
6. Choy KL, Lee WB, Lo V (2003) Design of an intelligent supplier relationship management system: a hybrid case based neural network approach. Expert Syst Appl 24:225–237
7. Møller C (2005) ERP II: a conceptual framework for next-generation enterprise systems? J Enterp Inf Manag 18(4):483–497
8. Kovacs Z, Le Goti JM, McClatchey M (1998) Support for product data from design to production. Comput Integr Manufact Syst 11(4):285–290
9. Liu DT, Xu XW (2001) A review of web-based product data management systems. Comput Ind 44:251–262
10. Eynard B, Gallet T, Nowak P, Roucoules L (2004) UML based specifications of PDM product structure and workflow. Comput Ind 55(3):301–316
11. Terzi S, Bouras A, Dutta D, Garetti M, Kiritsis D (2010) Product lifecycle management: from its history to its new role. Int J Prod Lifecycle Manag 4(4):360–389
12. Guerra-Zubiaga DA, Ramon-Raygoza ED, Rios-Solter EF, Tomovic M, Molina A (2009) A PLM tools taxonomy to support product realisation process: a solar racing car case study. In: Tomovic M, Wang S (eds) Product realization a comprehensive approach. Springer, London
13. Consoli D (2011) A layered software architecture for the management of a manufacturing company. Informatica Economică 15(2):5–15
14. Botta-Genoulaz V, Millet PA, Grabot B (2005) A survey on the recent research literature on ERP systems. Comput Ind 56(6):510–522
15. Bond B, Genovese Y, Miklovic D, Wood N, Zrimsek B, Rayner N (2000) ERP is dead—long live ERP II. Gartner Group, New York
16. Khedher AB, Henry S, Bouras A (2010) An analysis of the interaction among design, industrialization and production. In: 7th IFIP international conference on product lifecycle management, Bremen, 12–14 July 2010
17. Tursi A, Panetto H, Morel G, Dassisti M (2009) Ontological approach for products-centric information system interoperability in networked manufacturing enterprises. Ann Rev Control 33:238–245
18. Kilpatrick T, Gonzalez J, Chandia R, Papa M, Shenoi S (2008) Forensic analysis of SCADA systems and networks. Int J Secure Netw 3(2):95–102
19. Lalsingh D, Raut N (2012) Data management among PLM-ERP application: an integrated PLM–ERP technique. In: AIMS international conference on technology and business management. Dubai, 26–28 Mar 2012
20. Eynard B, Troussier N, Carratt B (2010) PLM based certification process in aeronautics extended enterprise. Int J Manuf Technol Manag 19(3–4):312–329

21. Thompson SHT, Devadoss P, Pan SL (2006) Towards a holistic perspective of customer relationship management (CRM) implementation: a case study of the housing and development board, Singapore. Decis Support Syst 42:1613–1627
22. TEC-SHS (2008) Technology readiness levels handbook for space applications
23. Bosscha P, Coetzee R, Terblanche P, Gazendam A, Isaac S (2006) SmartFactory: the challenges of open and low-cost ICT in the small manufacturing industry. S Afr J Sci 102(7–8):335–338

Part VIII
Enabling Technologies and Tools (Computer Aided Conceptual Design, Virtual Reality, Haptics, etc.)

Approaches in Conceptual Shape Generation: Clay and CAD Modeling Compared

Tjamme Wiegers and Joris S. M. Vergeest

Abstract We compared the methods of modelers who modeled in clay and those who modeled in CAD. We gave special attention to the size and shape characteristics of the model, and to the differences in approach between individual modelers. Four modelers made three different objects in clay and four other modelers made the same three objects in CAD. As a measure of success of the modeling method, we used the quality of the generated model, based on a set of criteria. Generally, the overall appearance of the clay models was better than that of the CAD models. Individual modelers applied different approaches for the same shape, not only when using clay, but also during CAD modeling. The quality of the models varied greatly. We conclude that the most appropriate modeling method depends on the size and shape character of the model, and also of the preferences and skills of the subjects.

Keywords Shape ideation · Conceptual design · CAD · Clay modeling

1 Introduction

For designers in the phase of idea generation, different tools and methods are available for shape exploration. New shapes can be sketched, modeled in clay, foam or card board, or generated with Computer-Aided Design (CAD) systems.

T. Wiegers (✉) · J. S. M. Vergeest
Department of Design Engineering, Delft University of Techno.ogy, Delft, The Netherlands
e-mail: t.wiegers@tudelft.nl

J. S. M. Vergeest
e-mail: j.s.m.vergeest@tudelft.nl

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_73, © Springer India 2013

For many shapes, one can deliberately choose one of these methods. However, it can be expected that particular shapes can best be made by one method and other shapes by other methods. Conceptual modeling can be considered as early prototyping, in the sense of Lim's definition [1]. Lim defines prototyping as creating a manifestation that, in its simplest form, filters the qualities in which designers are interested, without distorting the understanding of the whole. As purposes, Lim mentions evaluation and testing; understanding of user experience, needs, and values; idea generation; and communication among designers. Her Economic principle of prototyping tells that the best prototype is one that, in the simplest and the most efficient way, makes the possibilities and limitations of a design idea visible and measurable. Additionally, Grady [2] shows that quick and inexpensive prototypes make designers less defensive and users freer to criticize. Therefore, the economic principle of prototyping can function as a criterion to decide between different shape modeling methods in the ideation phase of design. For one modeling method may be more appropriate for a particular strategy than another one. And the same shape may be modeled more satisfactory with one method than with another one. Robertson and Radcliffe [3], for example, found that CAD is often not applicable for the creative phase of design. The complexity of CAD systems is a challenge for the design of interaction. Issues in this area are, for example, visibility, feedback, size of workspace, direct manipulation and context recognition [4]. Many of these are not big issues in physical modeling. Direct manipulation, for example, is obvious when modeling in clay or foam, and visibility is just a matter of turning the object in the hands, or moving around it. Elkaer [5] advocates the use of physical models, because their ambiguity makes them well suited for early discussions, whereas the digital models often close down the creative process if used from day one. The focus of this study is on idea generation, the creative phase of shape generation, in which many alternative shapes are explored in a short time. In this phase, I have often seen design students making small clay models within a few minutes, to make their ideas tacit. Such models are good examples of the economic principle of prototypes. Clay has as advantages that modelers can feel the model they are working with and can see it from different viewpoints. But there are drawbacks, too: for large models this craft is time consuming, and tiny parts may collapse. We compared the modeling processes of subjects that modeled in clay and subjects that modeled in CAD. We gave special attention to the size and the shape character of the model, and to the differences in approach between individual modelers. In this paper, we will indicate clay modeling and CAD modeling as modeling *methods*. When applying one of these modeling methods, different sequences of activities can be performed to achieve a particular shape modification. We will mention such an activity sequence an *approach*. So, subjects using the same modeling method (e.g. clay modeling), can still use different approaches (e.g. hitting and cutting are possible approaches for making a flat surface).

About the sizes and shape character of the models, it is believed that clay modeling will be more appropriate if the model is small, or has double curved faces, and CAD modeling will be more appropriate for large models and models that have geometrically well-defined shapes (e.g. blocks and cylinders). To verify this, in our tests we used multiple objects that differ in size and shape characteristics.

About the modeling approaches, students often believe that, for generating a particular shape in CAD, there is one best approach they should apply. On the other hand, when clay modeling, they often just start to knead the clay, without thinking a particular strategy is required. Because of this, we want to verify whether CAD modeling subjects indeed apply the same strategy if they model the same shape. And if a variety of approaches can be observed among clay modelers who generate the same shape. To investigate these issues, we formulate the following research questions:

- Do different modeling methods differ in appropriateness if they are used to model the same shape?
- Do subjects use different approaches if they use different modeling methods for the same shape?

Which modeling approaches can be expected? For CAD modelers, important factors are the available tools and functions offered by the CAD system. In general, CAD systems offer a multitude of tools, much more than a modeler will use for generating the rather simple objects that are used in this test. Therefore, we will not list all possible functions of the CAD system used, but only mention a subset. Functions that are frequently used by design student are: sketch, extrude, transfer, scale, rotate, cut, trim, and also functions that support viewing and evaluating the model-under-construction, such as zooming, panning and rotating the view.

For clay modeling, the situation is different. Which activities are applied, depends mainly on the preferences and skills of the user. van Dijk and van Veldhoven [6] observed clay modelers and identified ten clay modeling activities (Fig. 1). We used this categorization for our analysis. Apart from this, the type of clay plays a role. Water based clay behaves different from oil based clay. From the latter, the softness at room temperature is important. Styling clay is hard at room temperature, so modelers can apply sand paper and files. For molding styling clay, it should first be heated. We will use plasticine that is soft enough at room temperature to deform it by hand, without tools. However, the subjects are allowed to use tools, because they can be useful to make sharp cuts and edges and to flatten surfaces and make transitions smoother.

Fig. 1 Some of the identified clay modeling activities

2 Method

To answer the research questions, we designed an experiment. In this experiment, subjects will model shapes using different methods. As methods we choose clay modeling and CAD modeling. During the experiment, subjects have to model an object. Some subject will use clay for the modeling, others will use CAD. Different objects will be used, to be able to test the influences of size and shape characteristics. We choose objects from which we think they can be modeled in clay and in CAD. However, we also want to verify this. For this reason, students are asked which modeling method they would prefer to model the object. However, if this question is asked to the subjects that actually have to model the object in clay or in CAD, the results can be biased. Therefore, this question is asked to students that do not participate in the test as modelers. The modeling subjects had to finish their task in 15 min. They filled pre and post experimental questionnaires.

2.1 Subjects

Subjects were 24 students Industrial Design Engineering (IDE). Twelve subjects modeled objects in clay. These subjects had at least 1 year experience in clay modeling. Twelve other subjects modeled in CAD. The applied CAD software was Solid Works. The subjects had at least 2 year experience with Solid Works. Three objects were modeled. Each object was modeled by eight subjects. Four of them modeled the object in clay; the other four modeled the object in CAD. Eight more IDE students participated in the test. Their task was to evaluate the quality of the modeled shapes. They were also asked which modeling method they would prefer if they had to model the particular object, as described above. The assessment was based on a list of criteria. These criteria concerned the recognizability of the form of the model, the proper volume impression, the perceived quality of the model, the recognizability of characteristic details and in how far the model could serve to estimate if the product can easy be used (user friendliness). The latter is important for designers that generate a quick model to get a first feedback on their generated ideas. Figure 2 shows the question list for the evaluators.

2.2 Objects

Because the appropriateness of the modeling method may depend on whether a shape is large or small, organic or geometric, and tiny or solid, we selected objects that differ in these qualities, see Fig. 3. The mobile phone is small and the stool is large. The hand set of an old telephone has an organic shape. In contrast to this, the stool has geometric shapes. And the stool has tiny parts, but the hand set is rather

Which method do you prefer for Modeling this object in 15 minutes?	CAD / Clay / Hard foam / Drawing / Other						
In what level do you recognize the form of the phone/horn/stool?	Bad	1	2	3	4	5	Good
In what level do you get an impression of the volume of the object?	Bad	1	2	3	4	5	Good
What do you think about the quality of the object?	Bad	1	2	3	4	5	Good
In what level do you recognize the details of the phone/horn/stool?	Bad	1	2	3	4	5	Good
In what level can you test the user friendliness of the model?	Bad	1	2	3	4	5	Good

Fig. 2 Questions for the evaluators

Fig. 3 The three objects for the experiment

compact. We expect the hand set will best be modeled with clay, but the stool with CAD. The small size of the mobile phone is an advantage for clay modeling; however, its buttons can easy be copied and pasted in CAD. Therefore, we expect that the approaches in clay and in CAD will be different, but the quality of the results will differ less than those of the other objects.

We choose a method in which multiple subjects model the same shape, because we want to be able to compare individual results. This method, however, has also a disadvantage. In fact, we ask subjects to copy a shape, not to design it. In this aspect, the test differs from the real design situation. Therefore, we should be aware that there can be other factors that play a role if a designer is creating new shape. For example, the skills of the designer and the ease of use of the applied CAD software may influence the ease of working, and, implicitly, the creativity of the designer.

2.3 Interviews

The subjects were asked questions before and after the experiment. The pre experimental questions were about their CAD experience and about their expectations of the modeling task. They are shown in Fig. 4. The post experimental questions are about the result of the modeling task (Fig. 5).

Which method do you prefer for modeling this object?	Clay	CAD
How much time do you expect you need to model this object in:	Clay?	…… (min)
	CAD?	…… (min)
Which difficulties do you expect when you model this object in clay?		
Which difficulties do you expect when you model this object in CAD?		
How experienced are you in working with SolidWorks?	Bad/Average/Good/Excellent	

Fig. 4 Pre experimental interview

Name:		
Start year at IDE:		
What were the difficulties in the modeling of the object?		
Afterwards, would you prefer modeling this object in clay or in CAD?	Clay	CAD
What do you think about the quality of your own model?	(Bad) 1 2 3 4 5 (Good)	
What do you think about the details of your object?	(Bad) 1 2 3 4 5 (Good)	

Fig. 5 Post experimental interview

3 Results

The mobile phone was completed very fast by all subjects. Most time was spent on the detailing. In general, the evaluators found the overall impression of the clay models better than that of the CAD models (Fig. 6). According to the averages of the grades given by the evaluators, the clay models were better on Volume Impression and Testability of user friendliness, however, the CAD models are better on Recognizability and Quality of the shape, see Table 1. The averages for Recognizablity of Details hardly differs between clay and CAD models.

For the telephone hand set, some clay modeling subjects first created both ends and the midsection separately, and then assembled them into a hand set. Others molded the hand set as one whole. Some CAD modelers used extrudes, sweeps and fillets, others worked with lofts and assemblies. The differences in approaches are obvious in Fig. 7. Within the time limit of 15 min, the CAD subjects were not able to blend and bend the different part sufficiently to resemble the hand set properly. For all aspects that were assessed by the evaluators, the average grades for the clay models were higher than those of the CAD models.

The stool was quite a challenge for the clay modelers. They all made a small scale model and exaggerated the diameters of the thin profiles. Yet their models were not strong enough for testing. The CAD modelers had fewer problems. They had enough time left to make a render with realistic materials. Figure 8 shows the

Fig. 6 The results of the mobile phone

results. For all aspects that were assessed by the evaluators, the average grades for the CAD models were higher than those of the clay models.

We also compared the scores of all clay models to those of all CAD models. On average, clay models score higher on Volume Impression and Testability of user friendliness; CAD models score better on Recognizability and Quality of the global shape. The Recognizability of details does not differ very much between clay and CAD models. This is exactly what we found for the results of the mobile phone. The results of the hand set and of the stool, however, slightly differed from the overall results.

From the questions asked to the evaluators, we found the following frequencies of preferred modeling methods:

- 10 times CAD;
- 5 times clay;
- 5 times foam;
- 3 times drawing;
- 1 time no preference was expressed.

Apparently, CAD is the preferred modeling method in most cases. Nevertheless, the subjects estimated the required modeling time for CAD 5 times higher than the modeling time for clay modeling. Remarkably, the subjects who modeled in clay expected long times for CAD modeling, while the subjects who used CAD estimate long times for clay modeling. Subjects with more than average experience with Solid Works expected longer modeling times. Those with 2 years experience actually needed those times, however, those with 3 years experience were quicker than they expected. The subjects who have more experience with SW scored better on Recognizability of details and on Testability of user friendliness.

Table 1 Results of the questionnaires

Subject	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Cell phone								Hand		Set						Stool							
Applied method[a]	1	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2
Observers																								
Pref. method[a]	3	3	2	2	2	3	.	3	1	1	4	2	1	1	3	1	2	4	2	2	2	4	2	2
Recognizability	5	4	2	3	5	5	5	5	5	5	5	4	4	2	3	3	2	4	1	3	4	5	5	5
Volume impr.	5	4	1	5	1	1	2	2	2	4	4	4	2	1	1	1	1	2	1	1	1	2	3	3
Quality	4	4	1	2	3	4	4	3	2	4	4	2	3	3	2	2	3	3	2	3	3	4	4	5
Details recogn.	5	3	3	3	2	4	5	2	3	4	3	3	1	3	1	1	1	3	2	1	1	5	4	4
Testability	3	4	2	4	1	2	1	1	2	2	4	2	1	1	1	1	1	1	1	1	1	2	1	1
Average grade	4	3, 8	1, 8	3, 4	2, 4	3, 2	3, 4	2, 6	2, 8	3, 8	4	3	2, 2	2	1, 6	1, 6	1, 6	2, 6	1, 4	1, 8	2	3, 6	3, 4	3, 6
Modelers																								
Cohort (+2000)	2	1	2	1	1	1	1	1	4	3	4	1	1	2	1	1	1	1	3	4	1	1	1	1
Average grade	4	2, 5	2, 5	2, 5	4	3, 5	4	2	4	1, 5	3	2	3	3	1, 5	1	1	3	2, 5	3	1, 5	3	3, 5	2, 5
SW experience	2	3	3	3	2	2	3	1	2	1	3	2	3	3	2	2	1	3	3	1	2	2	3	3
Exp. clay time ′	15	8	10	10	10	10	10	15	10	10	10	10	45	20	20	30	10	.	2	10	15	10	20	30
Exp.CAD time ′	240	15	100	3	30	20	20	30	300	60	90	90	75	240	30	60	60	30	45	60	10	10	10	90
Actual time ′	12	10	10	6	15	15	15	15	15	15	13	12	15	15	15	15	6	5	4	4	15	15	15	15

[a] 1 = clay, 2 = CAD, 3 = foam, 4 = drawing

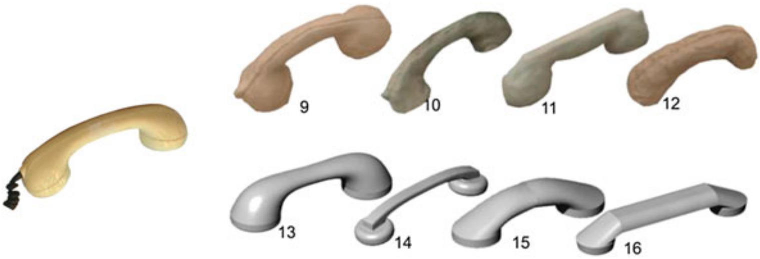


Fig. 7 The results of the hand set

Fig. 8 The results of the stool

Subjects with scores below 2 had short modeling times; they scored in particular low on Volume impression and Recognizability of details. Many of them had no realistic expectations of the required modeling time. They estimated the modeling time either too high or too low.

Which activities were performed? Typically, a clay modeling process started with pressing a volume of clay for making the global shape of the object. Next, the activities differed among subjects. Some started detailing the global shape, others first check if the volume and its ratios are correct. The following step is the modeling of the smaller shape elements. Pinching is often used for that, and tools are applied to make sharp details. Individual subjects performed different activities, such as hitting, pounding, pressing and cutting. Several subjects rolled clay into small cylinders. After the modeling of the smaller shape elements, the global shape was optimized. Also fir this purpose, individual subjects differed in the activities they performed for that. We observed smoothening, hitting, adding clay, detailing with the help of a tool, etc. Summarizing, subjects did not much in the modeling of the global shape. However, for the finishing touch, we observed different strategies, in particular for the modeling of flat surfaces and for the fine tuning of the global shape.

For CAD modelers, extrusion of a sketch was the typical activity for generating the global shape. Some subjects followed with making cut extrudes for particular local shape elements. Next, fillets were made. Some subjects applied other functions, such as chamfering, line patterns and the dome function. Also the mirror function was used by several subjects.

From the above, we see clear differences in approach between clay modeling and CAD modeling subjects. We mention a few. Generally, clay modelers start from a volume and press it into the right shape. Solid Works modelers, however, sketch a cross section and extrude it. They also make fillets, because otherwise the edges will be too sharp. In contrast, clay modelers sometimes use tools to sharpen the edges, because the shapes they generate are often too smooth. However, we did not only see different approaches between clay modelers and CAD modelers, also subjects who used the same modeling method differed in their strategies.

Comparing the results of the clay modeling subjects to those of the CAD modeling subjects, we can summarize that the clay modeling subjects delivered better handsets, and the CAD modeling subjects delivered better stools. For the mobile phones, the outcome is less simple. Some aspects of the mobile phones were better in the clay models, while other aspects were better in the CAD model.

From the hand sets, the clay models had better global shape and gave a better impression of the volume distribution. Also, the separate parts were more realistic, and they were more smoothly connected to each other. Furthermore, the clay models contained more details. The assessors found the clay models of the hand sets, compared to the CAD models, were more appropriate to test the user friendliness of the product.

The stools were much better when modeled in CAD. Although the global shapes of the clay models were appropriate to indicate a stool, the details were far less convincing than those of the CAD models. None of the clay models, for example, contained the telescopic shape of the pole, nor the caps at the ends of the legs. The legs did not have clear profiles, where the CAD models had oblong cross sections, just as the stool that served as the example for the modeling task. On the other hand, the seat of most clay models was slightly hollow, while the CAD models neglected this shape aspect and just contained a flat disk.

These results give us qualitative insights into the appropriateness of different modeling methods. However, the numbers of subjects and objects in the test are too low to do quantitate claims. Another restriction is caused by the applied modeling software. Solid Works was used, because nearly every design student is familiar with it. However, a wide variety of modeling software exists, from which several are more appropriate for modeling organic shapes, e.g. because they contain better functions for surface modeling. In addition, for designers who are more experienced in computer modeling will have fewer problems with modeling organic shapes.

4 Conclusions

Revisiting the research questions, we can conclude that different modeling methods do differ in appropriateness for modeling the same shape. Secondly, the approach a modeling subject applies depends on the modeling method the subject is using. Different methods have their own pros and cons. With clay modeling, for example, it is possible to give a good overall impression of an organic shape in short time, in particular if the detailing does not need to be very precise. In such cases, clay modeling is a good choice according to Lim's Economic principle of prototyping [1]. If CAD is used for the same modeling task, the modeler might either spend more time or end up with a model that has some aspects worked out in a very detailed way, while other shape aspects are missing. In the latter case, the model does not tell a consistent story and may confuse the observer. Other types of shapes, however, may be easier to model in CAD, for example if they consist of thin elements with simple geometric cross sections. It is difficult to work with such elements in clay, because they easily bend or break, sometimes already because of their own weight. CAD models don't have such problems, because they have no mass at all.

Summarizing, we conclude that the best modeling approach to be applied does indeed depend on the size and shape characteristics of the model. Furthermore, individual modelers apply different approaches for modeling the same shape, not only when using clay, but also during CAD modeling.

Acknowledgments The authors like to thank Stephan Maaskant and Koen Vorst for performing the experiments and gathering the data.

References

1. Lim Y-K, Stolterman E, Tenenberg J (2008) The anatomy of prototypes: prototypes as filters, prototypes as manifestations of design ideas, ACM transactions on computer-human interaction, Vol. 15(2), pp 1–27
2. Grady HM (2000) Web site design: a case study in usability testing using paper prototypes. In: Proceedings of IEEE professional communication society international professional communication conference and proceedings of the 18th annual acm international conference on computer documentation: Technology & Teamwork, IEEE, Cambridge pp 39–45
3. Robertson BF, Radcliffe DF (2009) Impact of CAD tools on creative problem solving in engineering design. Comput Aided Des 41:136–146
4. Ghang Lee G, Eastman CM, Taunk T, Ho C-H (2010) Usability principles and best practices for the user interface design of complex 3D architectural design and engineering tools. Int J Hum Comput Studies 68:90–104
5. Elkær TN (2009) Using computers to aid creativity in the early stages of design—or not! http://www.salle.url.edu/sdr/info/ ©ARC, Enginyeria i Arquitectura La Salle, Universitat Ramon Llull. In: Computation the new realm of architectural design 27th eCAADe conference Proceedings, 1st edn. Cenkler Printing, Istanbul, pp 761–768
6. van Dijk O, van Veldhoven E (2003) Research on clay modeling, advanced modification analysis. Dynash research report, Delft University of Tecnology, Faculty of Industrial Design Engineering

Optimization of the Force Feedback of a Dishwasher Door Putting the Human in the Design Loop

Guilherme Phillips Furtado, Francesco Ferrise, Serena Graziosi and Monica Bordegoni

Abstract The aim of the research work described in the paper is to enable designers to optimize the force feedback of a dishwasher door, in order to improve the user experience with the product at the moment of purchase. This is obtained by allowing the user to test the product since the beginning of the design process through the use of interactive Virtual Prototypes based on haptic technologies. A commercially available dishwasher is used as case study. The mechanical system producing the force feedback is modeled in a multi-domain simulation environment, and in parallel a parameterized simplified simulation is made available to the user through a force feedback haptic device. That feedback can be easily modified on user's requests and the desired behavior can be sent back to the multi-domain simulation, which optimizes the system to behave in the desired way. How to correctly involve humans into the proposed design framework is also discussed, highlighting their key role in determining product characteristics.

Keywords Virtual prototyping · Product virtualization · Human in the loop · Product design

1 Introduction

It is known that what makes consumers like and buy a product has not a simple answer. Anyway it can be assumed that the most successful product appeals on both the rational and the emotional levels [1, 2].

G. P. Furtado (✉) · F. Ferrise · S. Graziosi · M. Bordegoni
Dipartimento di Meccanica, Politecnico di Milano, Milan, Italy
e-mail: francesco.ferrise@polimi.it

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_74, © Springer India 2013

Most of the emotions, which are part of the user experience, rise during interaction with the products. All the human senses concur to create the final estimate, even if the buyer is not aware of this at the moment of purchase [3]. Consequently from a design perspective, there is a big issue in designing appropriately those product features that consumers will interact with at the point of sale: good design can make pleasant and efficient the consumers' interaction with the product as well as the buying experience [4].

Therefore, it is now strategic for a company to understand which are the multisensory characteristics of the products that mainly influence customers' delight. This is mainly the job of marketing experts who have to collect information from or about customers' likes/dislikes. That job is not a trivial task to perform, for: (1) on one hand, it is mandatory to create a valid context for collecting information so as to avoid "unduly discouraging" and useless innovation [5], conversely, (2) it is fundamental to find an effective way to transform such "fuzzy" product attributes into engineering technical specifications. In order to be useful these specifications should be quantitatively measurable criteria that the product design is expected to satisfy [6]; unclear targets can determine longer time to market and increase the probability of not correctly meeting the customers' expectations.

In a previous work [7], authors have put efforts in addressing the first challenge, proposing a methodology, based on the use of mixed prototypes and multisensory interaction models, to build a valid context for collecting product information related to users' experience with the product. That approach enables the creation of high fidelity and flexible representations of the product without the need of developing costly and time-consuming physical prototypes, and allowing us to evaluate several multisensory product variants (e.g. different sounds, touch and visual effects) [3]. In that work it has been used a fridge freezer as case study, which has been used to analyse the perception that users have of the frontal doors and subsequently of the internal elements of the products [8]. Using such a multisensory product representation it is then possible to rapidly change and tune the combined stimuli (e.g. the sound produced when opening a door and the force required to perform the opening action) until the user perceives an optimum condition. The final outcome is a virtual representation of the "ideal" product characterized by the desired behavior and the preferred appearance.

In this paper, the second challenge is discussed, which is how to transform such virtual representation of the ideal product, or better its "meta" characteristics, into technical specifications necessary for starting the design phase. To reach such purpose the methodology has been additionally developed by integrating an initial phase of advanced modeling of the physics at the basis of the haptic interaction modality by using the LMS-AMES im simulation environment [9]. Then the resulting outcome consists of a double but totally integrated view of the product: one view is technical and expressed in terms of physical laws, and the other one is experiential and expressed as a perceptual model. A change in the perceptual model should correspond to a change in its physics model. This new methodology has been tested on a case study provided by the Indesit Company (www.indesitcompany.com), a company operating in the field of domestic appliances. The research work consists in the optimization and re-design of the haptic feedback of a dishwasher door with a particular attention to the user experience.

2 Related Work

Especially for market-driven innovation projects, the role of marketing experts is to capture and interpret customers' expectations (i.e. what the product should do and how), but also to transfer that knowledge to the company, mainly to designers, who will have to develop the new product. Performing such interpretation is not a trivial task since customers' requirements are often expressed through imprecise, non-technical terms [10]. Even if up to now a great effort has been put to define mechanisms to enhance communication between marketing and engineering teams [11, 12] difficulties are still present since their working domains, control variables and product representation models are completely different [13].

Thus, the complex work of designers is to make use of their experience and intuition to translate such qualitative requirements into product features: the final result is however a product capable of satisfying their interpretation of the customer needs, rather than the real ones. Furthermore, several levels of costly and time-consuming refinements are necessary: during design review sessions, specifications have to be verified usually by means of testing sessions on physical prototypes. These ones work as the experimental set-up of end users' response evaluation tests, enabling them to physically see, touch and interact with the product. However, mainly due to costs and time saving targets, these artefacts are not always made with the same material that will be selected for the final product, and neither they usually implement the final construction solutions. For this reason it is not guaranteed that visual and sounds effects will be the same of the final product.

Due to the cost of the physical prototypes, one of the recent trends in the Product Development Process (PDP) is to substitute these ones with their virtual replica (Virtual Prototypes—VP), which should at best look like, work like and behave like as the final product or at least as the physical prototypes; VPs are flexible to changes, especially during design review sessions, and less expensive than the physical ones [14, 15]: intermediate versions of the new product concept can be verified.

Interaction with Virtual Prototypes happens through Virtual Reality (VR) technologies. Visualization VR technologies have now reached a high rendering quality and in some cases cost reduction [16]. Thanks to the interest they attracted within the research community for decades they have been studied, developed and applied more than haptics [17]. However, the evaluation of the physical interaction by means of "non-physical" components is definitely poor and does not provide useful results: visual prototypes, i.e. prototypes based on pure visualization technology, are mainly aesthetic in the sense that they enable people to see in a realistic manner how the final product will look like.

Simple haptic control devices, such as knobs and buttons, have been developed for testing user interaction with the interface components of consumer products [18, 19]. The fidelity of the representation of the haptic behavior of the knob is high, but the test of the user interaction with the product is limited only to these elements. Other custom 1-Degrees of Freedom (DOF) haptic devices have been developed to help engineers to design and evaluate the haptic feedback of doors of refrigerators [20] and car doors [21] during the design activity.

However, a method is lacking on how to correctly translate the haptic interaction results into technical specifications useful to optimize the complex initial mechanical system (that is the one responsible for the interaction). Effort has been put to overcome this lack for what concerns the sound stimuli since studies [22, 23] have concentrated on correlating them with specific product features, and then with engineering specifications.

In [24] an attempt has been made to merge haptic, sound and visualization stimuli: a multimodal VR system has been designed to test and reproduce the human multisensory experience through interactive Virtual Prototypes (iVPs, i.e. prototypes made to test human-product interaction features [7]). The haptic feedback is returned through a 6DOF haptic device equipped with a generic handle, and a single sound for each colliding component is recorded and played. This pilot study has driven the research activity described in [7] where the analysis performed on the real product is more accurate.

In this paper authors add a detail to the design of the multisensory experience, i.e. an approach to help in translating marketing qualitative requirements into engineering specifications. The final output should bea multi-domain representation of the system under analysis, equipped with appropriate optimization algorithms. In particular, even if the paper is focused on describing the optimization procedure for the force feedback stimulus (i.e. the haptic stimulus), it takes into account that this feedback is always part of a multisensory experience, which the user will test through an interactive Virtual Prototype (iVP) as described in [7]. The intent of focusing the work only on the force feedback is justified by the fact that, as previously said, while for vision and sounds methods are available on how to correctly translate the interaction results into technical specifications, for the haptic feedbacks these methods are not present in literature.

3 Designing the Multisensory User Experience: A Design Framework

The term *User Experience*s defined by the ISO 9241-210 [25] as the user perception of the use of a system. It represents what the user feels interacting with the system and how that interaction affects his/her personal perception of it. In order to make that perception as much pleasant as possible objective methods are necessary to enable the quantification of user's preferences and then the translation of these into clear design specifications.

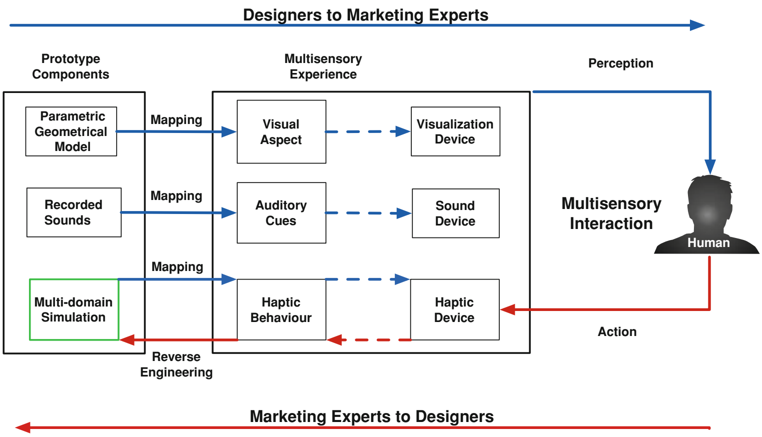


Fig. 1 The proposed design framework: how translating user experiences into measurable parameters to use in the product design

To address this need a design methodology has been defined. The idea behind the methodology is to make use of iVP which, even if the product does not exist physically, can however model its effects and functions. As shown in Fig. 1 the multisensory experience of the product is realized mixing three different sensory stimuli: (1) *vision*, using a rendering device which reproduces the appearance of the product; (2) *audio*, involving a sound device able to generate auditory cues; (3) *haptic*, by means of a device which reproduces the haptic behavior of the product. That mix generates a perception on the user that will react interacting with the virtual product itself: the final result is then an action-perception loop.

A new loop will be generated once changes are implemented on the virtual prototypes thus creating a new multisensory experience to explore. However, since the research purpose is to quantitatively monitor the feeling that users can get by interacting with and observing the virtual replica of the product, the multisensory interaction loop alone is not sufficient. To completely address the research purpose, another loop (i.e. mapping-reverse) has been inserted in the proposed design framework. This loop is based on linking each sensorial stimulus of the iVP to the specific functional representation or technical source that generates it. The intent is to let users interact with the virtual prototype, express their preferences and ask for changes to be applied to the interactive Virtual Prototype. Knowing the physical laws and the dimensional characteristics that are behind the iVP, is then possible to perform a reverse engineering of these preferences in order to update the technical models in accordance with users' insights. The final resulting framework is itself a loop between two different perspectives, the technical and the marketing one.

The proposed methodology is then able to support the experience creation and modification: the interaction with the virtual prototype is parameterized so that needs and preferences can be translated into something measurable. Furthermore, in case of technology push projects, where the implementation into the product of a new technology is the driving innovation force, the methodology enables designers to virtualized their technical solutions or their product variants, and then ask market experts to choose the most appealing.

In this paper the discussion will be focused on demonstrating the potentials of correlating the haptic behaviour of the virtual product with its functional model (i.e. the multi-domain simulation indicated in Fig. 1) since the other elements of the framework have been already tested and discussed in previous papers (see [7] for the multisensory interaction loop, and [22, 23] for the sound feedback).

4 Case Study: Force Feedback Optimization of a Dishwasher Door

The physics of the dishwasher door opening highly influences the user's first perception of the product since it is the first element the user interacts with, at the point of sale.

Depending on how the door and its opening mechanism have been designed, the force required to open it can vary. To open the door, typically, the user has to pull hard enough to un-lock a spring-loaded mechanism. A traditional qualitative rule states that the door should close and lock without heavy pressure, to prevent the user has to force the dishwasher to shut. The critical point is how to correctly translate the qualitative indication of "avoiding heavy pressure" into a quantitative force/pressure value to consider as input when designing the door lock mechanism. The dishwasher door force feedback optimization has been considered as an interesting case study to test the proposed design framework and in particular, the haptic loop (see level 3 of Fig. 1).

4.1 Interaction Problem Analysis

The primary aspect that a designer takes into account when designing the opening system of a dishwasher door is to be compliant with the technical requirements defined by reliability issues and normative validation analysis.

In a dishwasher the door is attached to the front side of the cabinet by means of a hinge placed at the bottom part of the door (Fig. 2). The hinge provides an appropriate balancing force, generated by the cumulative effects of the spring and of the frictions, in order to guarantee the stability of the doors during its movement from the vertical to the horizontal position. The latch mechanism used to lock the door, and specifically the component that clips into the locking mechanisms, can be represented as a leaf spring. From the user interaction point of view, the haptic feedback of the door opening is the combination of the initial leaf spring (i.e. the

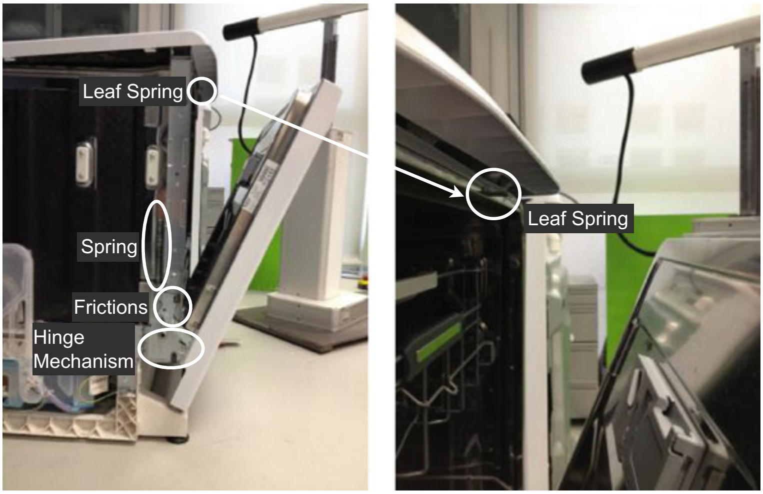


Fig. 2 Mechanical components that contribute to the creation of force feedback on user's hand

click effect perceived at the beginning of the opening) plus the inertia of the door together with frictions plus a compression spring.

To merge technical requirements with customer's needs the first step is to build the dynamical model of the door opening system. The model is necessary to simulate how the different parameters that compose the mechanisms affect the overall behaviour of the door opening system. It can be described by a set of differential equations, whose constants are the parameters that mostly affect users' perception: these ones can then be used to tune the mechanical behaviour of the system.

The model has been designed by using the LMS-AMESim suite. Figure 3 illustrates the sketch of the system with highlighted the main parts that contribute to the interaction (i.e. frictions, spring and door collisions). The dishwasher door has been modeled as a bar mechanism, while the friction devices present in the system were considered as producing dry friction. The latch mechanism was modeled as a linear spring able to work only on a narrow range, when opening and closing the door. The effects of air compression and circulation (when opening and closing the dishwasher) were considered as not influent. The human force (i.e. the input force, Fig. 3) exerted to open the door, has been also inserted in order to simulate the human behaviour. That behaviour is based on the results described in the work of Jain et al. [26], and on the experimental acquisitions performed on the door of the fridge described in [7]. The effect can be effectively treated as a ramp function.

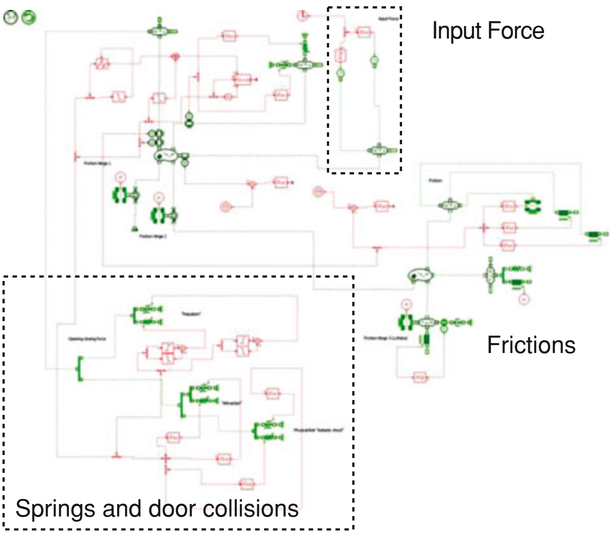


Fig. 3 The main contributions to the force exerted on user's hand highlighted in the sketch of the door mechanism

4.2 *Making the Simulation Interactive: The Use of the Haptics*

The next step of the proposed design framework (Fig. 3) consists of mapping the model built with the multi-domain simulation into functions that control the haptic device in order to make the user able to test the model.

In reality, the behaviour reproduced by the haptic device might not be necessarily described using the same mathematical model selected to represent the system in the multi-domain simulation environment. This might occur for several reasons, among them undesired vibrations on the device caused by a high stiffness, or by the fact that it might be simpler to program the device using a different approach, like creating a magnetic surface to constrain the movement of the end-effector instead of reproducing mathematically the effect of a reversed pendulum.

Before developing the application, a typical scenario of use has been figured out (Fig. 4) in order to guarantee that the test is performed in a realistic condition: the dimensions of the visual and of the haptic models should be the same of the dimensions of the real product.

Specifically, to control the haptic manipulation and then propose to the user different opening behaviours, the scripting language Python integrated with H3DAPI (www.h3dapi.org) has been used for developing the interaction model and for retrieving the values necessary to quantitatively describe the interaction phase in terms of displacement, acceleration and velocity. The dishwasher door trajectory has been reproduced faithfully in the haptic device by creating a cylindrical magnetic surface with high attraction force. The device is then only able to follow a semi-

Fig. 4 User interacting with the real door and the simulated one

circumference trajectory. The tuneable opposing force F_h, generated by the haptic device, is composed by a dry friction component and a viscous damping, both acting on the direction of the trajectory. The coordinate θ describes the angular position of the end-effector with respect to the horizontal plane, while R is the length of the door. The dry friction component can be modeled as $D * \mathrm{sgn}(\dot{\theta})$, D being the magnitude of the force, and $\mathrm{sgn}\,(\dot{\theta})$ the sign function, a discontinuous function that can be approximated by a continuous hyperbolic tangent, $\tanh\left(v\dot{\theta}\right)$, when $v \gg 1$. The viscous damping is considered proportional to the velocity of the door. Therefore, the equation describing the magnitude of the force acting tangent to the trajectory, opposing the force F_u applied by the user, is:

$$F_h = D\tanh\left(v\dot{\theta}\right) + c\dot{\theta} \tag{1}$$

The latch mechanism that acts when opening and closing the door can be modeled as a spring, where both the stiffness and the direction of the force depends whether the user is closing or opening the door. The equation that computes the magnitude of the force from the action of opening the door is:

$$F_o = k_o(\theta - \alpha) + F_h \tag{2}$$

where α and k_o are heuristically chosen to tune the resistant force when trying to open the door.

The magnitude of the force from the action of closing the door is computed by a similar equation:

$$F_c = k_c(\theta - \beta) + F_h + c_c\dot{\theta} \tag{3}$$

The main difference between (2) and (3) is the addition of a damping effect. The use of the damping force is to avoid the end-effector from bouncing back when closing the door. Additional terms could also be added to the force equations to express additional effects.

All the parameters can be changed in real time: they can be increased or decreased while the user is testing, accordingly to his/her preferences. Once the parameters are chosen, the force applied by the user together with the position of the haptic device end-effector is extracted (in function of time). The force F_u applied by the user is used as the input for the AMESim model (Fig. 3). Then, the position $\theta(t)$ obtained from the haptic device is compared with the position $\theta^*(t)$ obtained from the simulation. The comparison is described as the maximum square difference between the two values:

$$\varepsilon = \max(\theta^*(t) - \theta(t))^2, t \in \{0, T\} \tag{4}$$

The objective is to find the parameters on the differential equation that minimizes ε. LMS-AMESim offers tools that can be used to solve this optimization problem. If the result of the optimization is adequate, a physical prototype can then be constructed for validation.

5 Conclusions

The design of the emotional response is one of the key factors of a company's success because it influences consumers' purchasing behaviour. Starting from this consciousness, the work described in this paper aims at proposing a new design framework able to objectify the interaction aspects that determine consumers' choices, and to make easier the translation of qualitative customers' expectation into quantifiable design specifications.

To reach such purpose the haptic feedback, coming from the interaction of the user with the Virtual Product (by means of an haptic device), has been correlated with the physics and then the equations of those specific mechanical systems or sub-systems of the product involved in the interaction. The LMS-AMESim environment has been chosen to define the dynamical/mathematical model used to represent the system behaviour. The algorithms used to control the haptic device have been shaped according to the previously defined model. Correlations between these two mathematical representations have been identified in order to come out with a mapping-reverse design loop: a change in the algorithms that control the haptic device, and then in the interaction of users with the Virtual Prototype, can be translated into a change of the mechanical system responsible for the interaction. An optimization activity of the emotional response of a product can then be planned so as to make easier and more effective the collaboration of designers with product final users (or company marketing experts).

The proposed framework has been tested on a case study provided by the Indesit Company.

Acknowledgments The authors would like to thank the Indesit Company, and in particular Eng. Dino Bongini, for providing the case study and the feedback during the development of the case study.

References

1. Norman DA (2003) Emotional design: why we love (or hate) everyday things. Basic Books
2. Neff J (2000) Product scents hide absence of true innovation. Advertising Age 7:22
3. Spence C, Gallace A (2001) Multisensory design: reaching out to touch the consumer. Psychol Mark 28(3):267–308
4. Meyer C, Schwager A (2007) Understanding customer experience. Harvard Bus Rev 117–126
5. Veryzer RW (2005) The roles of marketing and industrial design in discontinuous new product development. J Prod Innov Manage 22(1):22–41
6. Otto KN, Wood KL (2001) Product design: techniques in reverse engineering and new product development. Prentice-Hall, Upper Saddle River
7. Ferrise F, Bordegoni M, Graziosi S, (2012) A method for designing users' experience with industrial products based on a multimodal environment and mixed prototypes. Comput-Aided Des Appl (in press)
8. Bordegoni M, Ferrise F, Cugini U (2012) Development of virtual prototypes based on visuo/tactile interaction for the preliminary evaluation of consumer products usage. CIRP Design Conference, Bangalore
9. Marquis-Favre W, Bideaux E, Scavarda S (2006) A planar mechanical library in the AMESim simulation software. Part II: library composition and illustrative example. Simul Model Pract Theor 14(2):95–111
10. Harding JA, Popplewell K, Fung YK, Omar AR (2001) An intelligent information framework relating customer requirements and product characteristics. Comput Ind 44(1):51–65
11. Griffin A, Hauser JR (1996) Integrating R&D and marketing: a review and analysis of the literature. J Prod Innov Manage 13(3):191–215
12. Leenders M, Wierenga B (2002) The effectiveness of different mechanisms for integrating marketing and R&D. J Prod Innov Manage 19(4):305–317
13. Michalek JJ, Feinberg FM, Papalambros PY (2005) Linking marketing and engineering product design decisions via analytical target cascading. J Prod Innov Manage 22(1):42–62
14. Buchenau M, Fulton J (2000) Experience prototyping symposium on designing interactive systems 2000, ACM Press, Brooklyn, pp 424–433
15. Zorriassatine F et al (2003) A survey of virtual prototyping techniques for mechanical product development. Proc Instit Mech Eng, Part B: J Eng Manuf 217(4):513–530
16. Hainich RR, Bimber O (2011) Displays: fundamentals and applications. A K Peters/CRC Press
17. Hayward V, Astley OR, Cruz-Hernandez M, Grant D, Robles-De-La-Torre G (2004) Haptic interfaces and devices. Sens Rev 24(1):16–29
18. Bordegoni M, Colombo G, Formentini L (2006) Haptic technologies for the conceptual and validation phases of product design. Comput Graph 30(3):377–390
19. Kim L et al (2008) A haptic dial system for multimodal prototyping. In: 18th international conference on artificial reality and telexistence (ICAT 2008)
20. Sunghwan S et al (2012) Haptic simulation of refrigerator door, Haptics Symposium (HAPTICS), 2012 IEEE, pp 147–154

21. Strolz M, Groten R, Peer A, Buss M (2011) Development and evaluation of a device for the haptic rendering of rotatory car doors. Ind Electron IEEE Trans Impact Factor 58(8): 3133–3140
22. Parizet E, Guyader E, Nosulenko V (2008) Analysis of car door closing sound quality. Appl Acoust 69(1):12–22
23. Van der Auweraer H, Wyckaert K, Hendricx W (1997) From sound quality to the engineering of solutions for NVH problems: case studies. Acta Acustica Unit Acustica 83(5):796–804
24. Ferrise F, Bordegoni M, Lizaranzu J, (2010) Product design review application based on a vision-sound- haptic interface. In: Haptic and audio interaction design, vol 6306. Nordahl R, Serafin S, Fontana F, Brewster S (eds) Lecture notes in computer science. Springer, Berlin/ Heidelberg, pp 169–178
25. ISO DIS 9241-210:2008. Ergonomics of human system interaction—part 210: human-centred design for interactive systems. International Organization for Standardization (ISO), Switzerland
26. Jain A et al (2010) The complex structure of simple devices: a survey of trajectories and forces that open doors and drawers. In: 2010 3rd IEEE RAS and EMBS international conference on biomedical robotics and biomechatronics, pp 184–190

Cellular Building Envelopes

Yasha Jacob Grobman

Abstract The paper argues that the digital revolution in architectural design and manufacturing, particularly the new possibilities offered for the design and manufacture of complex geometry, calls for a re-examination of the traditional concept of the layer-based building envelope which serves only as a barrier. The paper presents a framework for developing building envelopes based on a complex cellular or sponge-like geometry and preliminary design experiments that examine various tectonic approaches to cellular envelopes. The new envelope types, inspired by both cellular/spongy envelopes in nature and monocoque structures in the aviation, automotive and naval industries, are based on simple materials that can be manipulated to generate a complex geometry. The complex geometry of the cellular grid and the cells is developed using parametric digital modeling.

Keywords Cellular envelope · Parametric design · Freeform · Biomimetics

1 Introduction

The building envelope has changed significantly from ancient times to the modern era. It has shifted from being made of massive elements, which were used both for climate control and for structural purposes, into thin elements occasionally made of state-of-the-art materials that do not necessarily have a structural role.

Y. J. Grobman (✉)
Faculty of Architecture and Town Planning,
Technion Israeli Institute of Technology, Haifa, Israel
e-mail: yasha@technion.ac.il

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_75, © Springer India 2013

However, during the entire history of construction, the basic structure of the building envelope, a laminated entity made of different layers that are used as a barrier, has remained unchanged.

Today, the building envelope must cope with increasing demands for performance. The common solution is changing the dimension (mainly thickness) and/or the material of one or more layers that constitute the envelope. This often involves adding advanced high-tech—and thus, usually costly—materials, which pushes up the cost of the entire building. Moreover, the envelopes of contemporary buildings are treated mainly as a threshold that must dispose of rainwater as quickly as possible and avoid vegetation growth (green wall or roof) within the envelope itself. When a green wall or roof is designed, it is added as yet another external layer to the envelope, further increasing the envelope's cost.

The paper argues that the digital revolution in architectural design and manufacturing, and particularly the new possibilities offered for the design and manufacture of complex geometry, calls for a re-examination of the traditional concept of layer-based building envelopes that are used only as a barrier. The paper presents the preliminary results of a research study that develops a building envelope based on complex cellular or sponge geometry. The suggested cellular envelope type, inspired by envelopes in nature, is made from state-of-the-practice simple materials (such as concrete), which can easily manipulated to construct complex form. The final aim of the research is both to develop prototypes for cellular building envelopes and to show that a high-performance façade can be produced by the joint effect of the envelope's material properties and the micro-climate that is being created close to the envelope's surface due to the complex form.

2 Free-Form Design and Manufacturing in Architecture

There is a strong connection between the ability to design a form and the ability to fabricate it. In fact, according to William J. Mitchell, "[a]rchitects draw what they can build and build what they can draw" [1]. Free-form design has been widely used by architects since the end of the 1990s with the introduction of commercial design tools that allow design and manipulation of surfaces based on Non Uniform Rational B-splines (Nurbs). The current decade is witnessing the assimilation of parametric design and Building Information Modeling (BIM) tools and concepts that expand ever further the designer's ability not only to manipulate complex form but also to fabricate it. One can clearly argue that architects today have very few (if any) limitations in formal or geometrical design and manipulation.

One of the most salient advances of the use of parametric design and BIM is the direct connection to fabrication. This allows direct information exchange between architectural design and manufacturing without the need for mediators (construction drawings made by consultants or contractors) [2]. The use of CNC milling machines and other computer-controlled manufacturing machines is being increasingly assimilated into the building industry's standard manufacturing process. Moreover, even 3D additive manufacturing machines have reached the size and material capacities of building scale elements and end products.

Indeed, the cost of fabricating a complex form in general and a complex geometry façade in particular is still far more expensive than a traditional orthogonal-layer-based façade. Moreover, the building industry is still oriented toward mass production of standardized elements, and the shift to mass customization, not to mention customized construction, will clearly take some time.

However, it seems safe to argue that the shift toward computer manufacturing and especially large-scale CNC milling and 3D printing will continually reduce this gap. Therefore, given the understanding that the cost of computer-based manufacturing will drop in the near future and the difference between orthogonal form and freeform computer-based manufacturing will diminish if not totally disappear, there is both an opportunity and a need to examine the performance potential of freeform envelopes in architectural buildings.

3 Inspiration from Nature

Building envelopes have numerous distinct functions. Hutcheon [3] organized these functions into two groups with a total of 11 functional requirements.

The first group consists of the items that relate to the facade as a barrier for the control of heat flow; air flow; water vapor flow; rain penetration; light, solar and other radiation; noise; and fire. The second group consists of overall requirements, such as providing strength and rigidity; being durable; being esthetically pleasing; and being economical.

Similar functional requirements exist in the natural world. During evolution, living organisms developed various approaches and strategies to fulfill these requirements. Architecture has a long history of looking at nature for inspiration. Some approaches concentrated on the rather formal aspects of nature or natural form. These approaches include, among others, art nouveau architecture [4], organic architecture [5] and zoomorphic architecture [6]. The focus of this research is a different approach, generally called biomimicry, which examines the performative aspects of natural form and tries to extract insights for creation of architectural form and processes [7, 8]. More specifically, this research examines skins and envelopes in flora and fauna as a possible inspiration for the performance of a building façade.

A recent review by Gruber and Gosztonyi [9] presented a summary of the sparse existing academic research and studies related to biometric façade and compared the functions of skins of organisms and their analogy in architecture. A more specific study by Badarnah et al. [10] examined various strategies for thermoregulation based on insights from nature and shading strategy based on organizational feature in leaves [11]. Laver et al. suggested a cellular structure for a high-performance masonry wall system based on insight from termites and barrel cacti [12]. None of the above described research suggested an overall framework or an argument for a shift to a cellular approach in building envelopes.

4 Why Cellular or Spongy Envelopes?

Ever since the modernist separation between the structure and the building envelope, the development of building envelopes has concentrated mainly on finding new materials, combining materials, or shear optimization of the performance of the building envelope's various layers and their combined performance.

Knippers and Speck [13] argue that traditional architecture and civil engineering define construction in two separate categories: material and structure. They claim that this separation is impossible in natural world structures, which could be divided into five to twelve interconnected hierarchical levels in different scales/levels (biochemical level, microscopic level and up to the ultra-structural level). They define an important characteristic of natural system as being multilayered and having a "finely tuned and differentiated combination of basic components which lead to structures that feature multiple networked functions."

Comparing building envelopes and natural envelopes or skins, one can clearly see that one of the main differences between the two has to do with the cellular-based structure. Natural skins or envelopes—and in fact, a large percentage of natural tissues—are based on cellular units [14]. These cells are characterized by complex 3D freeform (as opposed to the flat envelopes of buildings), which is based on geometric and material logic; multi-functionality; structural and formal heterogeneity; and multilevel hierarchical structure that consists of both isotropic and anisotropic structure according to local needs (the characteristics are based on Knippers and Speck's design principles of natural systems).

As opposed to the complex cellular structure of natural skins, traditional building envelopes are typically based on flat (extruded 2D) orthogonal geometry, repetition, limited functions (usually as a barrier) and structural homogeneity (frequently the envelope does not have a structural role). Developing cellular building envelopes that are based on a number of natural cellular skins principles and cellular/sponge-like geometry [15] could facilitate a multifunctional envelope system that could offer the following advantages:

- A single spatial structure—This could function as a barrier, water collector, shading mechanism and green wall. This represents a shift into more efficient building structure based on ideas implemented in monocoque structures, which are currently used in the naval, aviation and automotive industries.
- More than a threshold—The suggested envelope changes the narrow perception of the building envelope, which is currently regarded almost exclusively as a threshold. It challenges the perception that rainwater must be avoided and/or

disposed of rapidly in building envelopes by allowing a certain amount of water to be collected inside the cavities, where it will be used for cultivation of plants. Thus, the envelope itself also turns into a green wall (as opposed to the current need to construct a special layer for plants). Previous research has shown that green walls offer considerable benefits by reducing heat islands, helping to conserve animal habitats and saving on infrastructure costs (by retaining some of the water and reducing demands, especially in extremely rainy conditions) [16].
- Microclimate—There is a possibility of using the air flow close to the envelope's surface to create a microclimate. As opposed to the traditional layering approach, a parametric complex geometry approach to the building envelope is fundamentally based on a cellular or perforated surface in which the spatial relationship between the filled spaces and the hollow spaces is controlled parametrically and is used to create a microclimate. The microclimate can be optimized for insulation, ventilation, light, draft, water conservation and the cultivation of vegetation (green wall) according to the demands [17, 18].
- Form heterogeneity—There is a possibility of creating a variation of envelope cells that would be customized to deal with changing local conditions within the building envelope.
- Simple materials—In terms of materials, the suggested approach suggests a shift to building envelopes based on a small number of simple, widely used materials, such as concrete. This could have significant ramifications, since the creation of high-performance, low-cost envelopes could considerably decrease the buildings' energy consumption.
- Decrease of the environmental impact/footprint of building—This would occur due to the increase in performance and the possibility of embedding green walls and using storm water collection [19].

A shift to building envelopes based on freeform cellular geometry and logic also entails some challenges or disadvantages. One of the main challenges has to do with the programmatic flexibility of customized complex forms. As it is suggested that the envelope would be tailored to fit both the external and internal needs of a specific program, one can assume that during the buildings' lifetime the internal program is liable to change. This might change the demands, for example, for natural illumination. In traditional buildings where all openings are similar, this would not be a problem, but in customized buildings, the opening demands of one programmatic function might not well serve other functions.

Another disadvantage is cost. Although it is expected that the cost of fabricating complex geometry will be reduced substantially when computer-based fabrication becomes widespread, it is logical to expect that there would be a cost difference as compared with manufacturing an envelope based on repetitive elements.

Other possible challenges have to do with the fact the living envelope has to be carefully maintained and that complex form might not be well accepted by the client that who is accustomed to traditional orthogonal buildings.

5 Precedents for Cellular or Spongy Building Envelopes

Although freeform architectural design in general and freeform cellular or spongy form in particular demands computer-based manufacturing for its realization, the notion of cellular buildings and building envelopes is not a new one. The following sections will briefly describe precedents for cellular or freeform envelopes.

While freeform architecture was not common in the post-industrial revolution period, architects such as Antoni Gaudi, Eladio Dieste and others were able to design and build highly articulate building forms and building envelopes. However, even though the entire form of some of their buildings was complex, the envelopes of these buildings were still based on traditional building methods and did not try to postulate better performance as a result of the form.

At first glance, one might consider Gaudi's well-known Casa Mila project (La Pedrera in Barcelona, Spain, 1910) as an example of a complex cellular façade due to the formal complexity of the envelopes. Nonetheless, a deeper examination reveals that the façade design is driven by solely formal aspects and that no argument was suggested by the designer for the performative aspects of this type of envelope.

Erwin Hauer's work and research on complex 3D wall systems (mainly for interiors) can be considered one of the early examples of cellular complex 3D logic in building walls [20]. He developed and implemented complex 3D repetitive units, mainly from concrete, back in the 1950s (see Fig. 1). His walls are principally orthogonal, but the units or cells that populate the grid he creates within the wall are formally complex. His work has been an inspiration to later research that tried to use parametric design tools to examine possibilities of creating both complex wall systems (as oppose to Hauer's orthogonal walls) and replacing the repetitive grid and tile with parametrically modified ones [21].

A different perspective on cellular approach to building envelopes is derived from Leatherbarrow and Mostafavi's idea [22] of the "denial of the frontality of the façade" in relation to Le Corbusier's introduction of the *brise-soleil*. The façade's frontality and flatness is replaced in this case with a space that acts as a light control mechanism but also challenges the notion of the flat building envelope. A more general perspective regarding this notion could refer to kinetic building

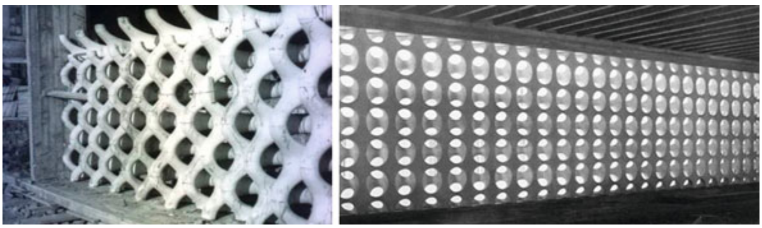


Fig. 1 Erwin Hauer—church in Liesing, Vienna, Austria, 1952 (*left*). Church in Erdberg, Vienna, Austria, 1954 (*right*). *Source* www.erwinhauer.com

envelopes. A well-known example in this realm is Jean Nouvel's Arab World Institute (Paris, France, 1987). An earlier but comprehensive discussion on kinetic building and envelopes can be found Zuk's book on kinetic architecture [23].

The introduction of computers to architectural design and particularly the use of parametric design "offers a high degree of geometric control combined with ability to rapidly generate variations" [24]. According to some researchers, the assimilation of parametric design methods and tools in architectural design and manufacturing has introduced a new "style" called Parametricism to architectural design and stimulated experiments in both urban and building (mainly envelope) scales [25, 26]. Parametric tools such as ParaCloud generative modeler (GEM) and Grasshopper (generative modeling tool for Rhino) have made it possible to generate complex geometry and to connect the architectural form to simulation software [27]. Parallel to research that concentrated on the geometric aspects of building envelopes, a considerable amount of research has been dedicated to the idea of performance in architectural [28, 29] and computational material [30, 31]. The new direct data exchange between these ideas and tools and computer-aided manufacturing tools, such as CNC milling machines and laser cutters, has fostered a flurry of parametrically designed and computer-manufactured structures, mainly in pavilion or installation scale, over the last 5 years [32, 33].

At the outset of the computer's assimilation to architectural design and manufacturing in the late 1980s, design experiments initially concentrated on creating new types of building layers, such as inflated materials (for example, the Beijing Olympic swimming pool by PTW Architects (Fig. 2) [34], Allianz Arena by Herzog and De Meuron architects [35] and the Eden Project by Grimshaw-Architects [36]. Subsequent experiments with complex geometry façades concentrated on the new potential for manipulating complex forms that required almost no attention to the envelope's performative aspects [37]. See also, for example, Migrating Formations wall by Contemporary Architecture Practice (Fig. 3) [28], KOL/MAC Architecture's INVERSAbrane building envelope [28], Greg Lynn's Blobwall [28] and Gramazio Kohler's The Dissolved Wall/Screens projects [37].

Fig. 2 PTW architects—watercube—Beijing National Aquatics Center, Beijing, China, 2003. *Sources* http://www.ptw.com.au, http://www.terrywier.com/, http://www.flickr.com/photos/xiaming/484446352/lightbox/

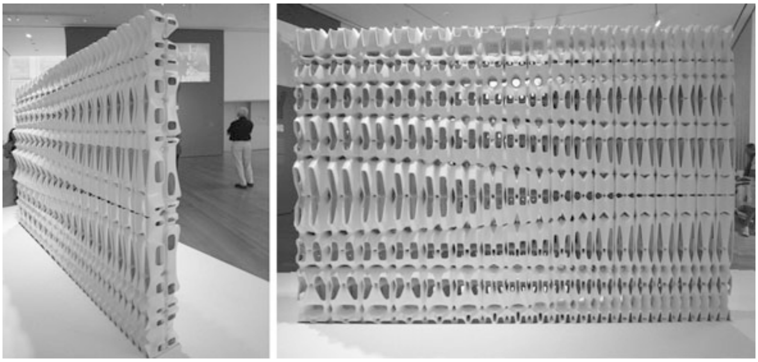


Fig. 3 Contemporary architecture practice (CAP)—migrating formations, New York, USA, 2008. *Source* Grobman and Neuman [28], p. 97

6 Cellular Envelope Design Experiments

The following section presents preliminary design experiments that examine the potential and trajectories in the design of cellular building envelopes. The method used in the design process of these projects combines digital form-finding methods with more traditional formal design methods. It thus combines ideas from research by design approach [38, 39] and digital and non-digital form-finding [27]. The design method used for these experiments is based on "populating" cellular elements on the cells of a grid that was generated for each of the experiment's envelopes. The rather complex grid that is used in each of the experiment is developed from initial regular grid that was modified according to performance criteria such as orientation, program (of the spaces behind the façade) and function of the specific areas of the facade. For example, an area which is intended for utility equipment does not usually needs a similar amount illumination as areas which are used for offices. Each of the final cells in the grid was populated by a different cellular element according to its location and function (type of space served by the specific cell of the envelope).

Each one of the three different experiments examines a different approach to cellular envelopes. In the first approach, the grid is used as a structural element and the cellular elements are inserted in the spaces created by the grid. As opposed to the duality characterizing structure and cells suggested in the first experiments, in the second and third experiments the grid serves as both a structure and a barrier.

6.1 Experiment No. 1

A cellular unit is populated inside a Voronoi based geometry grid (Fig. 4). Each unit is unique and made to fit a specific position in terms of size and performance.

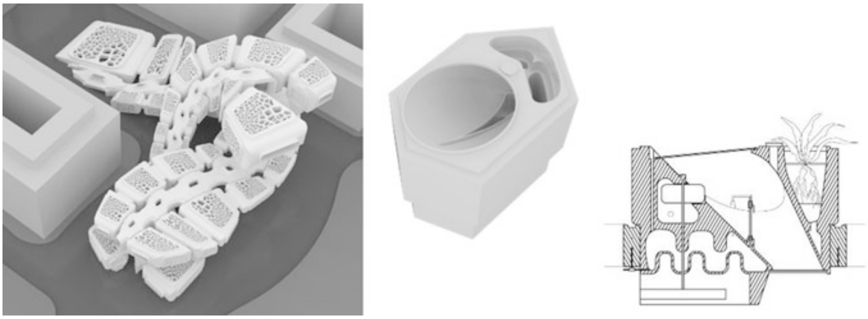


Fig. 4 Experiment no. 1 envelope with a structural cellular grid based on Voronoi algorithm geometry (*left*). Isometric view of a cell unit (*middle*). Section of a cell unit (*right*)

The unit presented in Fig. 4 contains the following elements: a place for a plant; a solar radiation system based on heating water by means of focusing the solar radiation using a circular surface; and a ventilation heat-exchange system based on a turbine. A cell unit can contain these entire features or any a combination of them, based on local need.

6.2 Experiment No. 2

The envelope is created from a family of cellular units, which are used both as a structure and as an infrastructure for functions such as shading, growing plants and isolation. The envelope's front view in Fig. 5 shows an example of the parametric approach to populating the cells in which the designer can choose a specific member from a unit family for every position in the envelope. The units' function can vary; it can serve as a passage, a room/space or a balcony.

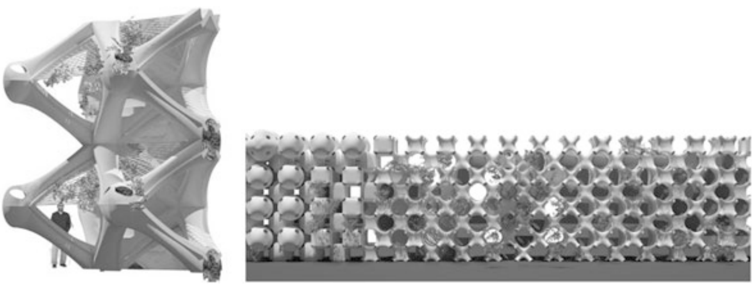


Fig. 5 Experiment no.2—Isometric view of an envelope unit (*left*) and a front view of an envelope (*right*)

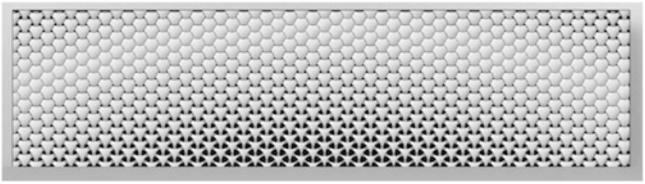


Fig. 6 Experiment no.3—envelope, front view

6.3 Experiment No. 3

This experiment presents a similar system to the one developed for the previous experiment in terms of the parametric population of the cells within the grid and the multifunctionality of the cellular unit. The main difference between the two experiments is that the current cell system is based on a singular unit that allows a gradual change in its dimensions. This allows the creation of a continuous variation in the envelope units, which in turn gives the envelope a more organic formal expression (see Fig. 6). The system is built from a structure of fiberglass and metal, which create the structure for Ethylene Tetrafluoroethylene (ETFE) air cells that are used both for thermal isolation and for transferring natural light (see Fig. 7).

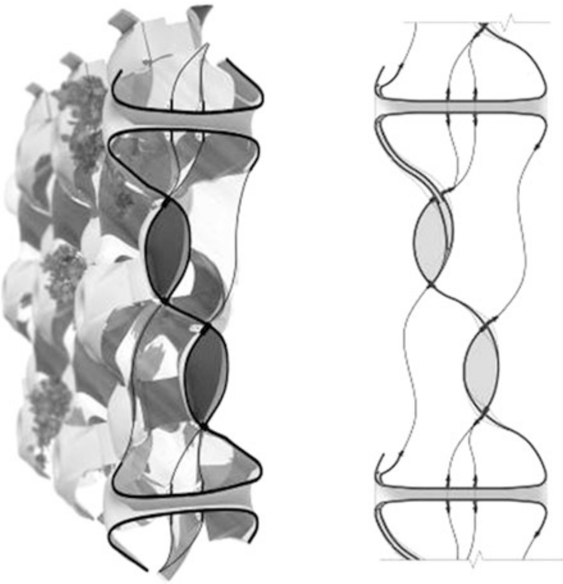


Fig. 7 Experiment no.3—section (*left*) and isometric rendered section in the envelope (*right*)

7 Conclusion and Future Research

The approach and the design experiments described above present the initial framework and possible trajectories for developing cellular building envelopes. Although several design directions have been developed and the concept seems plausible from the design and manufacturing viewpoints, the next stages of the research has yet to prove the possibility to reach similar performance in various environmental criteria as in traditional envelopes.

The significance of the proposed approach lies in the centrality of the building envelope to the design, manufacturing and performance of buildings. The resulting shift in the traditional concept of building envelopes could potentially improve the building's overall energetic performance, decrease urban heat islands by allowing vegetation to grow over the envelope and reduce the infrastructure needed for handling rainwater. Moreover, the new possibility of creating low-cost complex geometry envelopes that embed vegetation as an integral part of the envelope itself could trigger a dramatic change in the way our built environment looks and behaves. From the current strict division between built and green areas, our built environment would become—to a certain extent, at least—all green.

Acknowledgments The design experiments were developed during a design studio by the students Itay Blaistain (experiment no. 1), Asaf Nevo (experiment no. 2), and Michael Weizmann (experiment no. 3). Their contribution is hereby acknowledged.

References

1. Mitchell WJ (2001) Roll over Euclid: how Frank Gehry designs and builds. In: Gehry FO, Colomina B, Friedman M, Ragheb JF, Cohen J-L (eds) Frank Gehry architect, hardcover. Guggenheim Museum Publications, New York, pp 352–363
2. Eastman C, Teicholz P, Sacks R, Liston K (2011) BIM handbook: a guide to building information modeling for owners, managers, designers, engineers and contractors, 2nd edn. Wiley, New Jersey
3. Hutcheon N (1963) Requirements for exterior walls-IRC-NRC-CNRC. Canadian Building Digest, CBD-48
4. Russell F (1979) Art nouveau architecture. Academy Editions, London
5. Pearson D (2001) New organic architecture: the breaking wave, 1st edn. University of California Press, California
6. Aldersey-Williams H, Victoria AM (2003) Zoomorphic: new animal architecture. Laurence King Publishing in Association with Harper Design International, London
7. Benyus JM (2002) Biomimicry: innovation inspired by nature. William Morrow Paperbacks, New York
8. Gruber P (2010) Biomimetics in architecture: architecture of life and buildings, 1st edn. Springer, New York
9. Gruber P, Gosztonyi S (2010) Skin in architecture: towards bioinspired facades, pp 503–513
10. Badarnah L, Nachman Farchi Y, Knaack U (2010) Solutions from nature for building envelope thermoregulation. pp 251–262

11. Badarnah L, Knaack U (2008) Organizational features in leaves for application in shading systems for building envelopes, vol I. pp 87–96
12. Laver J, Clifford D, Vollen J (2008) High performance masonry wall systems: principles derived from natural analogues, vol I. pp 243–252
13. Knippers J, Speck T (2012) Design and construction principles in nature and architecture. Bioinspiration Biomimetics 7(1):015002
14. Gibson LJ, Ashby MF, Harley BA (2010) Cellular materials in nature and medicine, 1st edn. Cambridge University Press, Cambridge
15. Burt M (2011) The periodic table of the polyhedral universe. Int J Space Struct 26(2):75–94
16. Oberndorfer E, Lundholm J, Bass B, Coffman RR, Dunnett N, Gaffin S, Kohler M, Liu KKY, Rowe B (2007) Green roofs as urban ecosystems: ecological structures, functions, and services. Bioscience 57(10):823–833
17. Laver J, Clifford D, Vollen J (2008) High performance masonry wall systems: principles derived from natural analogues, vol I. pp 243–252
18. Yannas S (2004) Adaptive skins and microclimates, in built environments and environmental buildings. pp 615–621
19. Kats G (2009) Greening our built World: costs, benefits, and strategies. Island Press, Island
20. Hauer E (2007) Continua-architectural screen and walls. Princeton Architectural Press, Princeton
21. Hensel M, Menges A, Weinstock M (2010) Emergent technologies and design: towards a biological paradigm for architecture. Routledge, London
22. Leatherbarrow D, Mostafavi M (2005) Surface architecture. The MIT Press, Cambridge
23. Zuk W (1970) Kinetic Architecture. Van Nostrand Reinhold, New York
24. Schumacher PS (2011) The autopoiesis of architecture: a new framework for architecture, 1st edn. Wiley, London
25. Kolarevic B, Klinger K (2008) Manufacturing material effects: rethinking design and making in architecture, 1st edn. Routledge, London
26. Meredith M (2008) From control to design: parametric/algorithmic architecture. Actar, Barcelona
27. Grobman YJ, Ron R (2011) Digital form finding—generative use of simulation processes by architects in the early stages of the design process. In: Proceedings of eCAADe 2011 respecting Fragile spaces, Ljubljana, pp 107 115
28. Grobman YJ, Neuman E (2011) Performalism: form and performance in digital architecture, 1st edn. Routledge, London
29. Kolarevic B, Malkawi A (2005) Performative architecture: beyond instrumentality. Routledge, London
30. Sass L, Oxman R (2006) Materializing design: the implications of rapid prototyping in digital design. Des Stud 27(3):325–355
31. Menges A (2010) Instrumental Geometry. In: Corser R (ed) Fabricating architecture: selected readings in digital design and manufacturing. Princeton Architectural Press, New York, pp 22–41
32. Iwamoto L (2009) Digital fabrications: architectural and material techniques. Princeton Architectural Press, New York, p 144
33. Krauel J (2010) Contemporary digital architecture: design and techniques. Links International, Ceg
34. PTW [Online] (2011) Available http://www.ptw.com.au/ptw.php. Accessed 17 Oct 2011
35. Grimshaw-Architects [Online] (2011) Available http://www.grimshaw-architects.com/base.php?in_projectid=. Accessed 17 Oct 2011
36. Herzog and de Meuron Architects [Online] (2012) Available http://www.herzogdemeuron.com/index/projects/complete-works/201-225/205-allianz-arena.html. Accessed 4 Oct 2012
37. Gramazio F, Kohler M (2008) Towards a digital materiality. In: Kolarevic B, Klinger K (eds) Manufacturing material effects: rethinking design and making in architecture, 1st edn. Routledge, Londo, pp 103–118

38. Schumacher P (2011) Architecture schools as design research laboratories. In: Hadid ZM, Schumacher PS (eds) Total fluidity: studio Zaha Hadid projects 2000–2010 University of Applied Arts Vienna, 1st edn. Springer, New York
39. Sevaldson B (2010) Discussions and movements in design research. FORMakademisk 3(1):8–35

Development and Characterization of Foam Filled Tubular Sections for Automotive Applications

Raghu V. Prakash and K. Ram Babu

Abstract Crash safety requirement without much penalty in structural weight of automotive structures has provided scope to fill hollow sections with foams. Different classes of foams are used for this purpose—polymer foams and metal foams. Metal foams are prepared out of light metals such as aluminum, magnesium, though occasionally steel foams are also suggested in the literature. This paper presents the results of crushing, bending and damping characteristics of steel extrusions with and without foam filling. Polymeric foam and aluminum foam are considered for this study. Based on the experimental study, the following observations are made: (a) The force verses displacement characteristics of aluminum foam filled tubes show large resistance (at higher loading rates) during axial crush; polymeric foam filling did not show such a marked improvement in energy absorption characteristics, (b) The bending resistance of aluminum foam filled sections shows an improvement in bending by 60–200 % during 3-point bend testing, and (c) Vibration levels are found to be reduced in lateral direction for foam filled sections. This foam filled section was tried on typical section of a two-wheeler component.

Keywords Foam filled sections · Vibration · Crushing capability · Aluminum foam · Polymer foam

R. V. Prakash (✉)
Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600 036, India
e-mail: raghuprakash@iitm.ac.in

K. R. Babu
TVS-Motor Company, Hosur, India

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_76, © Springer India 2013

1 Introduction

Occupant safety is a prime concern in case of modern automobiles, and assessment of crashworthiness is an important stage in structural design. Crashworthiness represents a measure of the vehicle's structural ability to plastically deform and yet maintain a sufficient survival space for its occupants in crashes involving reasonable deceleration loads. In this context, use of appropriate materials, design of safe crush zones and other methods such as passenger restraint systems, occupant packaging provide additional protection to reduce severe injuries and fatalities.

To meet the requirements for improved safety, sometimes, thicker steel sheets or additional reinforcements are usually provided, which leads to a heavier body-in-white. Therefore, it is necessary to improve crash safety while at the same time reducing the weight of vehicles for better performance. In order to achieve a safe automobile body in the event of a collision, deformation of the cabin structure should be minimized to protect the occupants, and the collision energy should be absorbed in a short deformation length within the crushable zones. However, the reaction force generally exceeds a certain value when a material with higher strength is used to build a car; new structures and materials are required for building the ideal car body that can absorb the collision energy in a short span and with a constant reaction force. Towards this, in the recent times, foam filled structures are considered to design programed crush zones in automotive structures. Polymeric foams and metallic foams are considered as candidate materials for improving the energy absorption characteristics. This paper presents the results of mechanical property evaluation of metallic as well as polymeric foam filled steel sections subjected to compression, bending and crushing experiments.

2 Literature Review

Foams and other highly porous materials with a cellular structure are known to have interesting combinations of physical and mechanical properties, such as high stiffness in conjunction with very low specific weight or high gas permeability combined with high thermal conductivity. A typical stress–strain curve of metal foams in several stages is shown in Fig. 1; the graph consists of an initial, almost linear deformation, plastic collapse and final densification. It can be seen from the comparison between the stress–strain curve of an aluminum foam and the corresponding curve of an plastic foam, that the two loading curves are similar except that an approximate thirty times higher stress amplitude was found for the aluminum foam as compared with the plastic foam.

In the case of bending, tensile stresses produce fracture in the tensile zone. Consequently, the behavior of the foam alone (with or without skin) is in agreement with the results of tensile tests, which leads to very low energy absorption. The combination of the foam with the tube allows having a composite structure

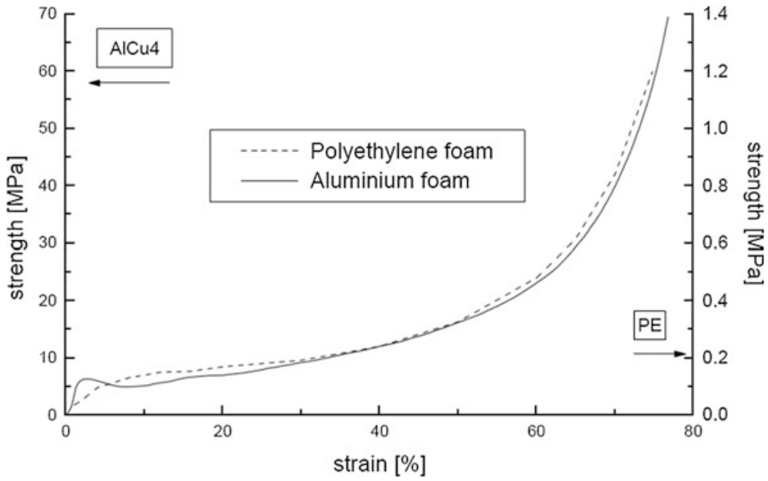


Fig. 1 Stress-strain response of polymeric and metallic foam. *Source* [1]

with high energetic absorption and collapse load, if compared with the basic elements. The foam presence produces a substantial change in the tube collapse mechanism. Even if the foam fractures, the effect of internal constraint of the tube gives some benefits for the energetic absorption thus, avoiding the formation of the well known bending collapse mechanism (with consequent decrease of the resistant load). However, the new collapse mechanism increases the tensile stresses in the tube walls: with higher rotations. This causes the fracture of the tube, with consequent sudden decrease of the load and of the capacity of further energy absorption. This situation is made worse by the reduced fracture deformations of the aluminum alloys for extrusion. Figure 2 shows the bending behavior of different tubular sections.

The aim of this work is to evaluate the crushing characteristics of steel extruded sections with and without foam filling, as well as bend and vibration characterization of foam filled sections. Aluminum foam and polymer foam filled structures are considered for this study.

3 Manufacturing of Metallic Foams

Aluminum foam was developed in-house at the Metallurgy and Materials Engineering Department of IIT Madras as per schematic shown in Fig. 3. Pure aluminum ingots of required quantity are placed in graphite crucible, which was placed inside a resistance melting furnace. About 1.5 wt.% calcium (Ca) (in metal form) was added to the aluminum melt at 680 °C. The melt is stirred for 6–10 min during which the melt viscosity continuously increases by a factor of up to 5 owing to the formation of calcium oxide (CaO), calcium aluminum oxide ($CaAl_2O_4$) and

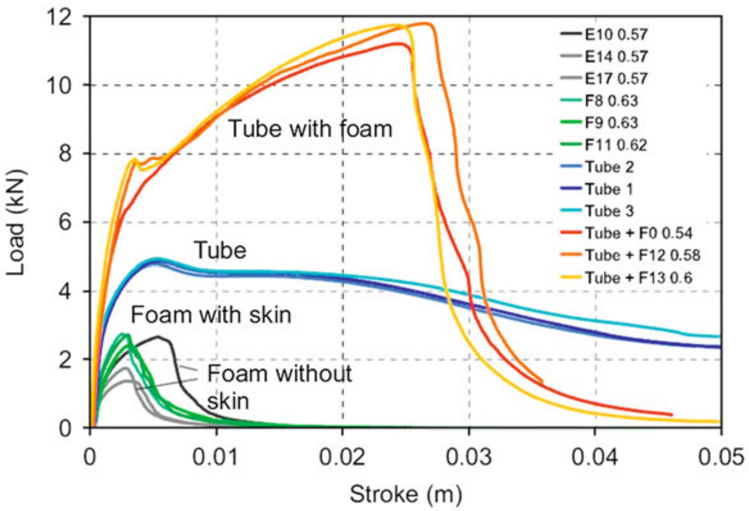


Fig. 2 Bending characteristics of extruded sections with and without foam. *Source* [2]

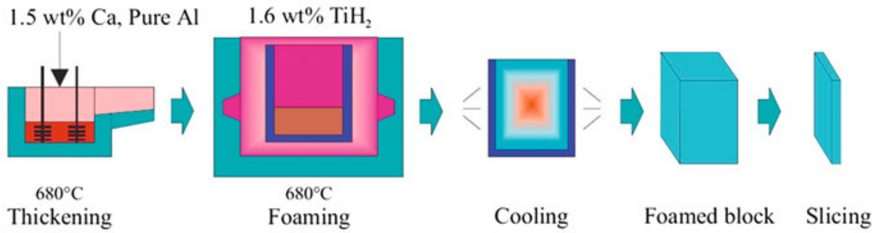


Fig. 3 Schematic of aluminum foam manufacturing in laboratory

in some cases Al_4Ca inter-metallics which thicken the liquid metal, according to the following reactions:

$$2Ca + O_2 \rightarrow 2CaO,\ 2Al + Ca + 2O_2 \rightarrow CaAl_2O_4$$
$$4Al + Ca \rightarrow Al_4Ca$$

Figure 4 shows the effect of stirring time on the viscosity of aluminum melts with various quantities of calcium addition. While the pure molten aluminum does not increase in viscosity on stirring, stirring with the addition of Ca increases the viscosity remarkably. After the viscosity has reached the desired value, a blowing agent is added to the melt. The blowing agent decomposes under the influence of heat and releases gas which then propels the foaming process. In this study titanium hydride (TiH_2) is added (typically 1.6 wt.%) which serves as a blowing agent by releasing hydrogen gas in the hot viscous liquid, according to the following reactions:

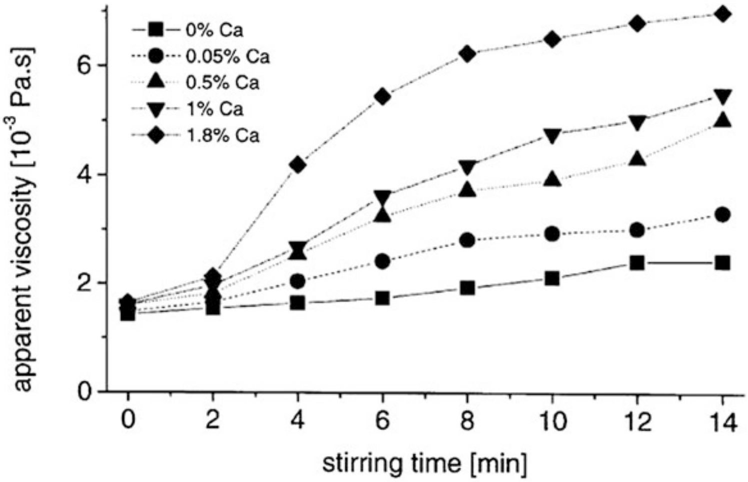


Fig. 4 Effect of stirring time and percentage Ca addition on viscosity of molten aluminum. *Source* [3]

$$TiH_2 \rightarrow Ti + H_2$$

The melt starts to expand slowly and gradually fills the foaming vessel. The foaming takes place at constant atmospheric pressure. After cooling the vessel below the melting point of the alloy, the liquid foam turns into solid aluminum foam and can be taken out of the mold for further processing. The entire foaming process takes along about 15 min for a typical batch of 0.6 m^3. The typical charge chosen for each melt is about 500 g. It has been found through experimental trials that a careful adjustment of process parameters leads to very homogeneous foams. Typical densities after cutting off the sides of the cast foam blocks are estimated to be between 0.18 and 0.24 g/cm^3. Table 1 shows the aluminum foam material composition by percentage weight.

It may be noted that viscosity enhancement of molten aluminum can also be obtained by bubbling oxygen, air or other gas mixtures through the melt, thus causing the formation of alumina, or, by adding powdered alumina, aluminum dross or scrap foamed aluminum or by using metallic viscosity enhancing additives. However, stabilization of process parameters by this method seems to be quite difficult and requires complicated temperature cycles and mechanical agitation.

Table 1 Aluminum foam material composition (by percentage weight)

S.No.	Raw material	Parts by weight %
1	Aluminum ingot	0.9699
2	Calcium metal (Ca)	0.0145
3	Titanium hydride (TiH_2)	0.0155

4 Processing of Polymer Foam

The preparation of polymeric foam involves the formation of gas bubbles in a liquid system, followed by the growth and stabilization of these bubbles; as the viscosity of the liquid polymer increases, solidification of the cellular resin matrix is formed. Polyurethane foam falls under the thermosetting group foams, having no thermoplastic properties.

Castor oil (polyol) and toluene di-isocyante (isocyanate) are the two basic raw materials required for the synthesis of polyurethane foam. When these raw materials are mixed in the appropriate ratio, polymerization reaction takes place resulting in polyurethane foam. Other raw materials used are DABCO® catalyst, poly (di-methylsiloxane), di-chloromethane (solvent) and water. Vigorous stirring was carried out till the creamy stage is reached. Foaming occurs by evaporation of solvent and evolution of carbon dioxide gas due to chemical reaction between excess iso-cyanate and water. Poly (di-methylsiloxane) was used as a surfactant to reduce the surface energy of generated gas bubbles and thereby foam structure was retained. No foaming reaction occurred without addition of catalyst as catalyst acts as a polymerization initiator. Polyurethane foam formation is an exothermic process and the temperature rise due to foaming was measured to be approx. 60 °C; di-chloromethane evaporated during this temperature rise. Optimal amount of solvent and water were added to control the extent of foaming reaction. Excess solvent resulted in boiling rather than foaming. Foaming reaction is given by:

$$R^1\text{-}N{=}C{=}O + R^2\text{-}O\text{-}H \longrightarrow R^1\text{-}\underset{}{\overset{H}{N}}\text{-}\overset{O}{\overset{\|}{C}}\text{-}O\text{-}R^2 \quad (1)$$

Polyol is a macro molecule of polyhydric alcohols, when reacted with isocyanate, which contains a NCO radical reacts with the OH part of the polyol in the presence of suitable catalysts to form a urethane linkages (−NC). The catalysts accelerate the reaction to the required level. The blowing agents blow the cells, increases its volume to form the light weight polyurethane foam. The surfactants promote and stabilize the polyurethane cells and helps to retain the shape into which it has been blown to. Density of foam obtained 0.35–0.45 g/cm^3. Table 2 presents the polyurethane foaming material composition by percentage weight.

Table 2 Polyurethane foaming material composition (by percentage weight)

S.No.	Raw material	Parts by weight %
1	Castor oil (polyol)	0.5305
2	Toluene di-isocynate (isocynate)	0.2599
3	Poly-dimethylsiloxane (surfactant)	0.0053
4	DABCO catalyst	0.0212
5	Water (blowing agent)	0.0239
6	Dichloromethane (solvent)	0.1592

5 Specimen Preparation

Extruded steel tubes of rectangular cross-section with dimensions of 50 (b) × 25 (d) × 100 (h) mm, and wall thickness of 1 mm is used for axial crushing characterization, specimens with dimensions of 50 (b) × 25 (d) × 160 (h) mm, having a wall thickness of 1 mm were used for 3-point bending characterization in this study. Polymer and metal foam as described in earlier section was filled inside this extruded tube section. Typical polymer foam density was estimated to be approximately 0.4–0.5 g/cm^3 and that of metal foam density was estimated to be approximately from 0.9 to 1.1 g/cm^3.

6 Material Characterization

Foams Axial crushing and 3-point bending testing of specimens have been performed on a 100-kN MTS servo-hydraulic system. Figure 5 presents the view of experimental setup for axial crushing of extruded sections. There are two rigid platens that can be gripped into the hydraulic jaws of the MTS machine and the test section is loaded in between the lower and upper platens. Crush tests were conducted under displacement control mode at a displacement rate of 5 and 100 mm/min and the specimens were compressed by 30 mm from the original height of 100 mm. For each crushing velocity, force–displacement characteristics were recorded during the test and the energy absorbed during the impact was calculated from the area underneath the curve.

Figure 6 shows the photograph of three-point bending test setup, for characterizing the bend performance of extruded sections. The fixture includes two adjustable lower support anvils and one upper center loading anvil. The support beam has graduated lengthways in metric and imperial units for accurate positioning of the anvils. The specimen is supported on machined (free to rotate or stationary) anvils of a defined radius and the bend force is applied centrally. Bending tests were conducted under displacement control mode at a displacement rate of 5 and 100 mm/min and the specimens were deformed for a vertical distance of 25 mm.

7 Results and Discussion

7.1 Axial Crush Tests

Figure 7a presents the deformed shape of empty extruded section subjected to crush test. Shown along with in Fig. 7b is the load–displacement record during crush test. One complete symmetric plastic lobe and one partial lobe are formed

Fig. 5 Photograph of crush test of foam filled extruded section

for the crushing distance of 30 mm. An excellent agreement is found in the overall shape of the deformed tube for two different loading rates (5 and 100 mm/min) and each specimen displays one complete lobe and one partial lobe. Imperfections present in the tubular sections leads to slight disturbance in lobe formation at high loading rates and the formation of first lobe can be anywhere along the length. The area under the load–displacement record is used to estimate the cumulative energy absorption during crushing. The energy dissipation is observed to be higher at higher crushing rates of 100 mm/min. The mean crush force was found to increase with the increase in the rate of loading up to certain displacements, and thereafter instability conditions cause it to be reduced.

Figure 8 presents the deformed shapes of foam filled extruded sections subjected to compression loading. Table 3 presents the energy absorption characteristics of empty, aluminum foam filled and polymer foam filled extruded sections subjected to compression loading. The number of lobes in the side walls of extruded section has increased in case of metal foam filled section compared to empty and polyurethane foam filled tubes; the two complete symmetric plastic lobes are formed with the initiation of third lobe for the crushing distance of 30 mm. At high loading rates, it is observed that aluminum foam reduces the plastic lobe formation length, thereby generating large number of plastic hinges

Fig. 6 Three point bend testing of foam filled extruded sections

compared to other conditions, which results in an increase in energy absorption capacity of structure.

Specific energy absorption rates were estimated based on the final weight of sections, and it was found that polymer foam filling results in maximum energy absorption for a given weight, which is followed by Al-metal foam filled section.

7.2 Three-Point Bend Tests

Figure 9 shows the results of 3-point bend tests of extruded sections. Each specimen was loaded at its mid span and deformed up to 25 mm (vertically), each specimen displays inward curl, which is generated by the round nose of the testing fixture and the plastic hinge is concentrated and the inward curl is slightly deeper at high loading rates. The energy absorption during bending was estimated by considering the area underneath the load–displacement curve for each specimen. Table 4 presents the results of three-point bend testing of empty, foam filled extruded sections. Specific energy absorption (energy absorbed per unit weight of extruded section) for aluminum foam filled tubular sections was found to be more than empty and polyurethane foam filled sections.

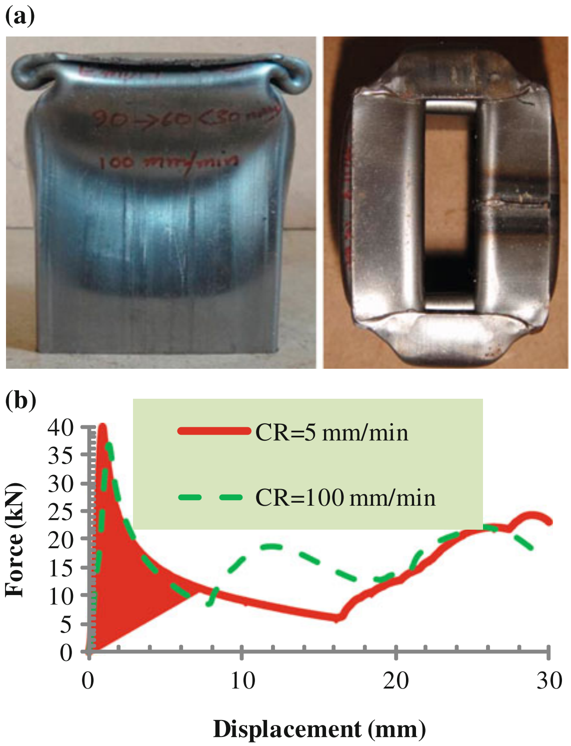


Fig. 7 **a** Deformed shapes of empty extruded sections at 100 mm/min rate of compression. **b** Load–displacement record during axial compression testing of extruded sections

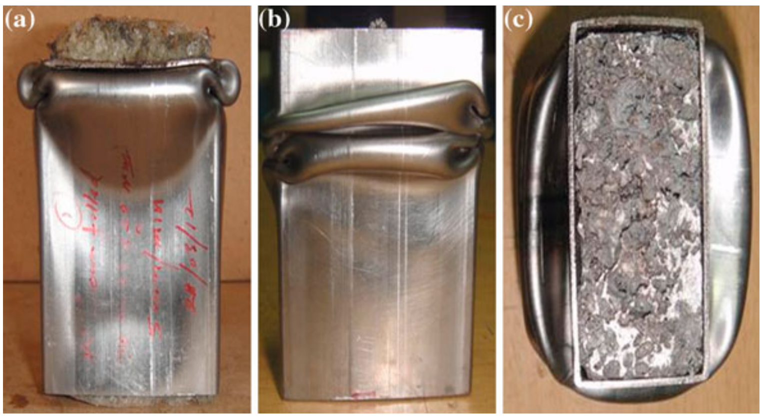


Fig. 8 **a** Crush shapes of polymer foam filled section at 5 mm/min. **b** Al-metal foam filled section at 100 mm/min. **c** Al- foam filled section at 5 mm/min rate of compression

Table 3 Crush characteristics of extruded sections at two different loading rates

S. No.	Loading rate (mm/min)	Peak force (kN)			Energy absorbed (J)		
		Empty	PU foam filled	Al foam filled	Empty	PU foam filled	Al foam filled
1	5	39.84	38.17	44.7	688.24	711.5	919.7
2	100	36.76	35.76	58.45	484.24	668.5	1691

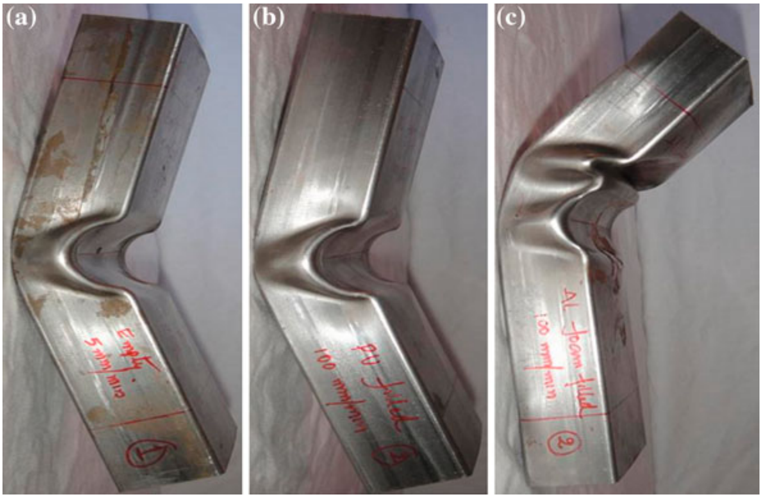


Fig. 9 Deformed shapes of 3-point bend specimens. **a** Empty extrusion, **b** PU foam filled extrusion, **c** Al-metal foam extrusion

The force–displacement response shows that in addition to initial peak force, a secondary peak force (relatively higher than the initial peak force) after 15 mm deflection was noticed, whose magnitude increases with the loading rate. The results show that the rate of loading has a significant influence on the mean crush force, initial peak force as well as energy absorbed by the extruded member.

7.3 Application of Concepts to a Motor Cycle Frame

Both poly-urethane and aluminum metal foams were filled in swing arm of a typical motor cycle and the performance of these sections was evaluated for lateral stiffness, vibration response. It was observed that there is an improvement in load bearing capacity of swing arm as yielding starts at higher loads compared to unfilled swing arm section; it was also noticed that the swing arm stiffness increased approx. 10 % in case foam filled sections. Vibration levels on handlebar measured directly on the vehicle and obtained through shake table testing suggests

Table 4 Bending characteristics of extruded sections

S. No.	Loading rate (mm/min)	Peak force (kN)			Energy absorbed (J)		
		Empty	PU foam filled	Al foam filled	Empty	PU foam filled	Al foam filled
1	5	8.75	9.55	18.82	172	203.5	440
2	100	9.2	9.35	21	177.5	206.4	321

a significant reduction in vibration levels in case of lateral direction when tested on vehicle directly. This offers the advantage of improving the structural dynamic performance.

8 Summary

This paper presented the details of axial crushing and 3-point bending behavior of the empty, polyurethane foam filled and aluminum foam filled tubular sections, and application of foam filling in motorcycle chassis structures, like swing arm. The force verses displacement characteristics of aluminum foam filled tubes shows large resistance at high loading rates during axial crushing. The bend tests of aluminum foam filled tubes shows greater resistance to deformation i.e. about 60 and 200 % improvement at two peak forces, and marginal improvement in polyurethane foam filled tubes over the empty tubes. The energy absorption characteristics improved with foam filling. Thus foam filling can be considered positively in design of automobile structural elements.

References

1. Yu C-J, Banhart J (1998) Mechanical properties of metal foams. In: Proceedings of metalfoam.net, conference paper, pp 37–48
2. Peroni L, Avalee M, Peroni M (2008) The mechanical behavior of aluminum foam structures in different loading conditions. Int J Impact Eng 35:644–658
3. Banhart J (2001) Manufacture characterization and application of cellular metals and metal foams. Int J Prog Mater Sci 46:561–608

The Current State of Open Source Hardware: The Need for an Open Source Development Platform

André Hansen and Thomas J. Howard

Abstract Open Source Hardware (OSHW) is a new paradigm attempting to emulate the Open Source Software movement. While there are several flagship OSHW projects, this product development paradigm has yet to live up to its full potential. This paper reviews the current state of OSHW and reveals the lack of a robust and simple development platform as being a major barrier to the uptake of OSHW. The authors argue that an Open Source, Cloud-based platform would be the most viable direction.

Keywords Open source hardware · Open source hardware collaboration platform · Open source software

1 Introduction

While free software is becoming as commonplace as your very own personal computer, free physical products are more of a rare phenomenon. However, it is our strong believe that this will change in the not too distant future, following the emerging paradigm of Open Source Hardware (OSHW). Free products may only be the minor benefits of OSHW as it might revolutionise the way new technologies are created and the way we interact with physical products in our everyday life.

A. Hansen (✉) · T. J. Howard
Section of Engineering Design and Product Development,
Department of Mechanical Engineering, Technical University, Copenhagen, Denmark
e-mail: mail@andrehansen.me

T. J. Howard
e-mail: thow@dtu.dk

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_77, © Springer India 2013

The Open Source movement has in recent years managed to challenge even the biggest international software companies, threatening the closed systems [1]. Open Source Software development has been able to capitalize from the development in communication technologies, enabling dispersed individuals and communities to efficiently share information. While Open Source Software (OSS) is motoring ahead and changing the realm of software development, one wonders why engineering design and the development of physical products still seems to be a mere bystander yet to embrace the full potential of the Open Source methodology.

Some obvious barriers arise when trying to transpose the paradigm of Open Source Software into the realm of physical products and engineering design, e.g. problems regarding test and validation. However, engineering design has become more and more digitalised through the use of CAE. This realization should allow a better utilization of communication technologies in engineering design and foster hope for a further adoption of the Open Source methodology in the development of physical products.

A key aspect of the future success of OSHW is the development of a robust collaboration platform. Using the words of Koch and Tumer "Why are robust collaboration tools openly available to the programmer, but not to the designer?" [1]. It seems evident that this must change if OSHW development is to counter OSS in efficiency and success. Another important realization is that, for now, OSHW communities do not work on or share partial designs [2]. If OSHW is to embrace the efficient development of more complex and meaningful products, this must also change. This paper sets out to explore the characteristics of collaboration platforms supporting OSHW development.

2 What is Open Source Hardware?

So what is Open source hardware? Before investigating the questions regarding OSHW collaboration platform, this chapter sets out to give a general overview of the OSHW Paradigm.

2.1 A Framework and Definition

Some conceptual ambiguity seems to be surrounding open source development of physical products. At the moment two terms appear online and in literature: open (source) design and open source hardware. The use of the term open design could result in confusion as it could be both a noun and a verb, which is why this paper will be using the term OSHW as convention. We propose the following Open Source Design Taxonomy (Fig. 1) emphasizing the activity of designing open source elements of all kinds. Note that mechanics also encompasses structures and architecture—these are included in the term for simplicity.

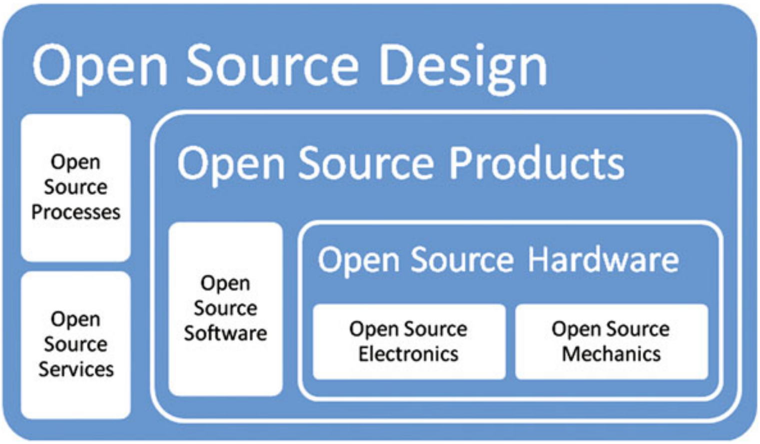


Fig. 1 The taxonomy of open source design

Although OSS has reached a stable definition, work is still being carried out to finalize an OSHW definition. The OSHW definition hosted at freedomdefined.org (definition in 2012) gives hope to this work being concluded in the near future:

> Open source hardware (OSHW) is a term for tangible artefacts—machines, devices, or other physical things—whose design has been released to the public in such a way that anyone can make, modify, distribute, and use those things.

2.2 Protecting and Profiting from Open Source Design

Reaching a stable definition is most important in respect to creating suitable licenses protecting OSHW products from unintentional exploitation. The most used licenses at the moment are variations of the Creative Commons licenses, http://creativecommons.org/. Licenses are a key element of creating sustainable OSHW business models.

According to Fjeldsted et al. [3] there are some fundamental characteristics of open design business models that apply to both OSS and OSHW. The nine building blocks of business models [4], used to describe an archetypal business model, illustrate these characteristics. There are a number of important elements that are needed for a successful implementation and operation of open design, such as attracting and retaining participants, creating a value proposition that appeals to both end-users and participants but most notably, a platform to build the open design activities upon and a strong community [3]. The platform enables, facilitates and empowers interaction and development between participants through a symbiotic relationship. The community involves the company's key resources as well as participants that co-operate through mostly a self-serviced platform, which in addition works as a channel for sales and services. The fundamental business part of the model and one which holds the biggest potentials for improvements is the identification and exploitation of revenue streams.

In this relation Fjeldsted et al. support Fitzgerald's [5] claim of trademarks and brands becoming the next IP mechanism, taking Oracle as an example, using the "unbreakable Linux" slogan. The same approach is being used by the OSHW developer Arduino that licenses their brand and logo to manufacturers for a 10 % share of their sales.

On top of licensing there are other revenue streams to be found such as incorporating manufacturing and direct sales, providing consultancy, writing books, selling merchandise, enabling subscriptions, membership fees, etc. These revenue streams affect other parts of the business model, resulting in an iterative process which may produce different versions of business models for a company to choose from and adopt.

2.3 Commons-Based Peer Production and Open Source

Following the advances in communication technologies, the phenomenon of large-scale collaborations between individuals in non-hierarchical communities is becoming commonplace. Most Open Designs seem to be taking advantage of this new mode of economic production. Commons-based peer production (*CBPP*) [6], is the collaboration among large groups of individuals who effectively provide information, knowledge or cultural goods without relying on market pricing or managerial hierarchies to coordinate their common enterprise.

Common-based peer production as a mode of socio-economic production has proven to be feasible to such an extent that it rivals other modes of economic production such as *market-based* and *managerial-firm based production*. *CBPP* differentiates itself in two core characteristics from other modes of economic production. The first being decentralization of authority. The authority to act resides with the individual and not a hierarchical based organiser. The second is the use of social cues and motivations to motivate and coordinate the actions of participating agents, rather than prices or commands [6]. Although open design projects do not necessarily need to make use of *CBPP* as a mode of economic production, there is an obvious synergy between the two paradigms. Open source elements seem to be a prerequisite for an efficient exploitation of *CBPP* and vice versa. Most Open Design collaborations take advantage of *CBPP* while you often find it implemented alongside more traditional *firm-based production* exemplified by a somewhat hierarchical structured core foundation.

2.4 OSHW Development Process

Most OSHW projects seem to be initiated by core teams which publish a more or less finished design for a community to start working on. Not having a design to start from might leave new developers too high an entry barrier to start developing. This seems to be the case with the collaborative space travel and research team, cstart.org, a promising project whose activities have now ceased. With the core team facilitating the development, a larger group of perimeter participators contributes with varying commitment. This resembles OSS set-ups where established companies, such as IBM, also undertake open designs development. In this case, the community of developers acts as a virtual development team [1]. To the knowledge of this author no big established company has yet to implement OSHW development in their product development strategy, had their initial product not started out as an open design.

Traditional product development is often guided by a somewhat well defined development process creating a framework for development and collaboration. In many cases having such a well defined process allows for a more aligned development thus heightening efficiency [7]. Many Open Design developments seem to take on a more autonomous approach where formality and standards emerge from the ongoing collaboration and where different processes can coexist within a project. In common practice there would usually be a difference between how core team members and projects perimeter participators would work. This autonomous approach might allow for more people to participate while possible misalignment could affect the projects negatively, e.g. designs made available in different formats thus harming the communication between developers.

In such non-hierarchical distributed processes the trust networks between participants becomes one of the important elements in the development. When dealing with complex products there is a particular need for groups and individuals to be able to trust the input of others to a higher degree. For individuals and groups with better reputations it will be easier for them to get their ideas implemented, while new developers might find it hard to be heard. One of the most interesting things about Open Design development is when the developer also becomes the user (see Fig. 2). The traditional lines between user and developer are being blurred in open design development, which in the end can result in very close feedback loops between usage and development [2] as it is the case in OSS projects. Being both the developer and user is also one of the reasons people contribute to OSS projects. Developers give their time and knowledge and will in return get to use the product for free as they can simply download it. Free use of the product is not always the case in OSHW as someone has to pay for the product to be produced before it can be used. Furthermore, developers using the product are in OSS projects are a key source for improvements as they will report mistakes in the code, “bug reports”. Due to the ease by with the developers can test new ideas and solutions, mistakes in the code are corrected with incredible speed while the data management systems automatically keep track of these changes. Most OSHW projects will never match OSS in this aspect as the tangible product often needs to be manufactured before it can be tested and validated. However, this is being somewhat eased through the emergence of DIY manufacturing and electronics projects such as the RepRap (3D printer) and Arduino (microcontroller).

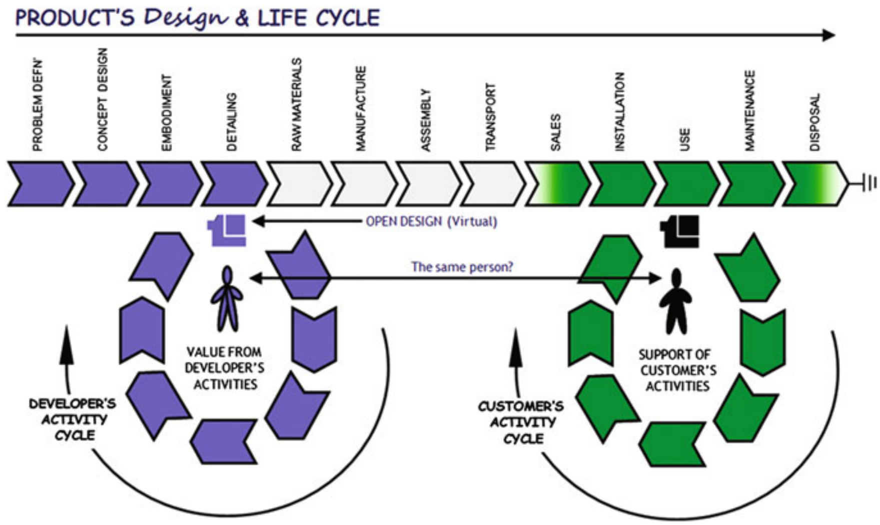


Fig. 2 The life and activity cycles for open source design [2]

2.5 Challenges Facing Open Source Hardware

Three main challenges facing OSHW are presented by Howard et al. [2] that partly explains why OSHW is yet to repeat the success of OSS. The challenges are interdependent so one needs to take a holistic view on these challenges to overcome them.

The first, and most obvious challenge, comes from the fact that OSHW entails a physical product needing allocation of physical resources to be produced. So there is a challenge of manufacturing. OSS products can be copied and distributed at a negligible cost, facilitated by the same system used for its development. OSHW products need a more complex and investment-heavy supply chain set-up to reach its end user. On one hand this can result in some OSHW products never reaching a final form, benefiting society. On the other hand, the manufacturing cost can result in a more sustainable business model for the project originators as consumers will choose to purchase the final product instead of producing it themselves [2].

The second challenge facing OSHW emerges from the need to validate designs. Again there is often a need to produce prototypes to test and validate designs properties to allow close loop iterations. Considering the complexity of common products today, this could be a major obstacle for the realization of OSHW products, not only in respect to the cost but also the know-how needed. Digital simulations are the first step to overcoming this obstacle but creating systems that support and lower the cost of testing/validating design properties is crucial if OSHW is to entail the development of complex products and efficient product development. Such a system could mirror the peer-review systems in OSS projects. Having partially open systems, which allows some parties to capitalize on closed source test documentation, as proposed by the 40 fires foundation (http://www.40fires.org/), a OSHW project focusing on developing energy efficient technology. This strategy could also be part of the answer to overcoming the challenge of validating designs. The concept of "Manufacturing as a Services" (MaaS), community based manufacturing shops which allow individuals to make use of flexible manufacturing equipment, might in time create a base for easier design validation as it allows communities to bypass large operations and manufacturing facilities [1, 8].

Finally, there lies a challenge in allowing OSHW communities to efficiently collaborate on high-tech complex products [2]. This is closely related to the validation of designs because complex products will entail more sub designs in need of validation. Benkler and Nissenbaum [6] present three structural attributes of the CBPP relations which are highly relevant with regards to overcoming the challenge of complexity in OSHW projects. These attributes are: *modularity, granularity* and *low-cost integration*.

For now OSHW communities do not work and share partial designs [2] mainly due to a lack of a suitable collaboration platform. A higher focus on attributing *modularity* to OSHW objects could allow the OSHW system to better handle partial design development and allow communities to work on more complex products. Modular design will also allow subsystem to be tested and validated independently, one of the module drivers of Erixon [9]. Focusing on modularisation will however, also result in higher requirements for the discipline in the development process as modularity will lay additional constraints on the object of development in the form of structural standards.

The *granularity* of the modules is important, as appropriate finely-grained modules allow contributors to contribute in respect to their motivation and skill [1], lowering the barriers of entry to complex projects. Defining modules with the "right" granularity can be a difficult task but several methods guiding the modularisation process are available such as the "design structure matrix" [10].

The *cost of integration* refers to the cost of integrating the modules into a whole end product. OSS benefits from low-cost integration due to efficient integration software, which allows somewhat automated integration (merge features), and established iterative peer-review practises. The latter also plays a big role in design validation and is in some cases formally integrated in the collaboration platform, e.g. sourceforge.com. Although many OSS peer-review practises could easily be adopted in OSHW development, automated integration cannot, partly due to the wide range of digital formats used in many OSHW projects. One way of dealing with a higher cost of integration in OSHW projects could be having a more formal development process, in which stricter requirements are set on the various contributions. The level of formality on OSHW projects seems to vary a lot, not only between projects but also between different participating groups within each project, e.g. as mentioned between core team members and perimeter participators. Creating an OSHW collaboration platform that supports development of designs that contain the three structural attributes is by these authors seen as an essential part of letting OSHW communities deal with the challenge of product complexity. The next chapter will go further into detail with the requirements for an OSHW collaboration platform.

3 OSHW Collaboration Platforms

OSS and OSHW platforms alike seem to have two fundamental functions; to function as a social platform and to provide tools to enable efficient collaboration. Social platform referring to a platform that creates awareness of the OSHW projects and allows projects initiators, participators and stakeholders to meet creating a base for the community. Although no studies have been done on how the size of an OSHW community affect the success of a related project, most successful OSHW projects today seem to have large and active communities.

The second fundamental function is to provide the community with the right tools, collaboration tools such as design repositories and wikis. As mentioned earlier, there is a lot of variation in how OSHW projects are structured so there is a need for the platform to be flexible. OSS platforms, such as sourceforge.com and github.com, provide a lot of flexibility. When projects are created on these platforms it is easy to activate the tools the project creators see a need for. There is no current collaboration platform specifically designed to support OSHW development. The Open design engine.net looks to be one of the only promising OSHW platform projects judging by their guiding values and potential features. The project has not yet reached a state for evaluation and unfortunately the project progress seems to have halted.

Koch and Tumer present 6 main areas that must be integrated into a collaboration platform; Project overview, Documentation and Design Repository, Communication, User Identification Standard, Funding and Licensing [1]. The following section will discuss the first 3 areas as they are the most influential in regard to creating efficient collaboration.

3.1 Project Overview

Providing a good project overview allows for several things. First of all it gives new potential users a good first impression which might result in them participating in the project [1, 11]. Project overview in this sense is very important in relation to allowing the platform to function as a social platform. The project overview also allows for an overall guiding of the project by providing information to the participators, e.g. displaying news and urgent matters. There is a question of how big a role such a collaboration platform should play in regard to the management of the projects? There are open source project management tools out there, why building on this work, implementing a suitable product data management system, seems to be a logic way forward.

More commercialized current OSHW projects e.g. makerbot.com and arduino.com, implement a product website focusing on marketing, providing product introduction and selling their products while maintaining links to the development site, which give a good current view of the project. Other OSHW products such as RepRap.com and Openeeg.sourceforge.net use a wiki as their main page, focusing more on displaying the development of the product. In general it can be said that a good project overview is something that is lacking in OSHW projects. This is especially the case with regards to documenting the development process. One comment on the open source ecology forum gives one reason for this.

> The OSE development process is intended to be completely wide open and accessible to anyone who wants to watch. However, knowing HOW to watch can be challenging. OSE activities take place in a wide variety of web sites, software applications, email, conference calls, and on-site meetings at the Factor e Farm development facility.

This case is repeated in many OSHW projects and results in a high entry barrier for new developers. Especially for widely distributed projects such as RepRap, it is hard to keep track of new derivatives and development tracks.

3.2 Documentation and Design Repository

Most, if not all, current OSHW projects collect most of the development documentation on wikis. The dynamic nature of wikis makes them the perfect tools for collaboration, making knowledge sharing in large groups easy. However, the wiki content should be standardized using page templates to make communication more efficient. Many developers might share the view that documenting your work is tedious work although important, so tools with allow for an easy documentation will most likely heighten the quality of the documentation. By utilizing the script based CAD software, Open SCAD, the RepRap communities are working on implementing automated documentation by embedding additional product documentation, such as assembly instructions into the CAD model as comment threads, making it much easier to keep up-to-date documentation. Open SCAD functionalities make it appealing to the 3D printer communities as it is script based, but will probably not be the dominant CAD software any time soon. The idea of linking CAD and additional documentation would relieve OHWS communities of a tedious and resource demanding task and is therefore very interesting.

The design documentation, e.g. schematic, CAD files etc. in larger OSHW projects, are for now often made available via design repositories on sites such as Github.com and Sourceforge.com while providing some product data management. The Design repositories on these sites are very focused on OSS development, just understanding the syntax can be an obstacle for people without knowledge about software, although the sites have easy to use functionalities.

An important aspect of design repositories is which product data management (PDM) model, or version control system (VCS) as it is called in software development, they make use of as it can have a huge impact on the development workflow. The most widely used model is the centralized. Such a system has a single master repository from where all developers check-out the documentation. However, not all developers will have write-access [12]. The centralized model therefore focuses the project control to the initiated. A decentralized model lets every check-out be a full-fledge repository with complete commit history. With no evident master repository a repository is identified by convention within a community [12]. Clarifying which model is most suitable for OSHW projects is beyond the scope of this paper as it also depends on how the projects wish to structure their product development. There exist several high quality PDM/PLM solutions on the market today although they are probably too expensive for most OSHW projects. Aras corp. provides an open source PDM solution which might be useful as it is currently being used by international companies such as Motorola. A very interesting notion is cloud PDM. Such a thing could be exactly what is missing for OSHW to undertake more complex product development. It could be the Github.com of OSHW. Solidworks n! fuze is leading the way in commercialized cloud PDM but for now no open source counterpart exist.

Thingiverse.com is a site which makes design documentation available in a more accessible form than the OSS focused repositories, and is widely used in the desktop 3D printer communities. Although it has none of the features embedded in more advanced design repositories, such as an actual version control systems, it provides an easy and visual access to the design documentation. As a design repository Thingiverse is not the best choice when dealing with complex product development as it functions more like a showroom. A combination between thingiverse's ease of access and sites such as Github's functionality would be an interesting possibility.

3.3 Communication

Kock and Tumer speak of three main forms of communication; group (forums), one-on-one (mail) and real time (Skype, chat). As communication is essential for an efficient collaboration these three forms should definitely be implemented. Furthermore, automated indirect communication on a community level would be helpful in respect to project overview. For example having voting systems that lets participators vote on promising development tracks could allow other developers anticipate which direction the project is taking so they could streamline their efforts. This is especially useful in the implementation of standards. Following a thread on the RepRap forum, a group had decided on a standard. The next step was to inform the community. Quoting one of the posts, "now it's time to scream, shout and make noise". How do you make a community aware of the "good" ideas? Voting and bidding systems seem to be obvious solutions, alongside competitions. These elements are used to a wide extent at crowd sourcing sites.

3.4 A Platform that Sources the Crowd

Looking at the collaboration system at OSHW projects today three main tools facilitates the development (not looking at the inter-collaboration between the core team members). These three tools are the wikis, forums and design repositories. Between them, these tools make a rather complex system of information which results in a development process easily lacking tractability. Although this system might, to some extent, prove sufficient for the dedicated developers it leaves a high entry barrier for new developers, as for example in the open source ecology example earlier. This results in OSHW projects not fully utilizing the possibilities of CBPP. Even for successful projects such as RepRap this is the case. Looking at the RepRap model "Prusa Mendel" which is focusing on low-cost and ease of sourcing, making it the ideal choice for new developers, only four "pull request" have been made the last year judging by the activities at github.com and only three commits a available under the Prusa improvements overview at RepRap.org. It looks as if the new improvements are not integrated into an "optimal" design. Instead, new derivatives a created which are hard to find or poorly documented. One reason for this could be the high cost of integration as the models are not modular. Another reason could be that many people actually do not share their designs. In this aspect there might be lessons learned from crowd sourcing. A crowd sourcing site like 99designs.com has 113 designs per project (contest). It is very easy to contribute to projects on such sites and it is easy to get an overview of the different contributions due to the use of "design contests". Such a concept could easily be implemented in a platform to attract more perimeter participators who just wants to give small contributions, while more complex collaboration tools should be implemented to suit the need of the more dedicated participators.

4 Conclusion

OSHW projects have definitely gained more awareness following projects such as Arduino and RepRap, but OSHW development does for now not mirror the efficiency in OSS development. This is partly due to the challengers that come from dealing with physical products and the fact that there is no collaboration platform specifically design to support OSHW development. A part of the solution to overcoming these challenges is giving OSHW products the structural attributes of CBPP, creating rightly grained modular products which will lower the cost of integration and allow for independent test and validation of designs.

Because many OSHW projects entail some OSS elements, an OSHW collaboration platform needs to provide the same service as OSS collaboration platforms today, and more, for the complete project to be run on the same platform. A platform should not only play in tact with the development process and work flows, but also support the business models and revenue streams all of which are in need of further research. Two fundamental functions of an OSHW collaboration platform are found to be: to function as a social platform and to provide the community with collaboration tools. For this to happen, better product data management systems need to be made available to the OSHW communities and workflows should be defined which will lower the entry barriers for new developers. Although, many agree that realizing a true OSHW collaboration platform is of utmost importance if OSHW is to emulate OSS in success, there is no apparent solution out there which will truly fill the void any time soon.

References

1. Koch MD, Tumer IY (2009) Towards open design: the emergent face of engineering—a position paper. In: Proceedings of ICED'09, Vol. 3(11), pp 97–108
2. Howard TJ, Achiche S, Özkil A, McAloone TC (2012) Open design and crowd sourcing: maturity, methodology and business models. In: Proceedings of the 12th international design conference
3. Fjeldsted AS, Aðalsteinsdóttir G, Howard TJ, McAloone TC (2012) Open source development of tangible products. In: Nord design 2012, Denmark, pp 22–24
4. Osterwalder A, Pigneur Y (2010) Business model generation: a handbook for visionaries. Game Changers and Challengers. Wiley
5. Fitzgerald B (2006) The transformation of open source software. MIS Q 30(3):587–598
6. Benkler Y, Nissenbaum H (2006) Commons-based peer production and virtue. J Polit Philos 14(4):394–419
7. Ulrich K, Eppinger SD (2007) Product design and development, 4th edn. McGraw Hill, New York
8. Manufacturing as a service (MaaS). Postfully yours
9. Erixon G (1998) Modular function deployment—a method for product modularization. KTH Royal Institute of Technology, Sweden
10. Steward DV (1981) The design structure system: a method for managing the design of complex systems. IEEE Trans Eng Manage (3):71–74
11. Saade RG, Otrakji CA (2007) First impression last a lifetime: effects of interface type on disorientation and cognitive load. Comput Hum Behav 23:525–535
12. De Alwis B, Sillito J (2009) Why are software project moving from centralized to decentralized version control systems? CHASE'09. In: Proceedings of the 2009 ICSE workshop on cooperative and human aspects on software engineering, IEEE, pp 36–39
13. Balka K, Raasch C, Herstatt C (2009) Open source enters the world of atoms: a statistical analysis of open design. First Monday 14(11):248–256

Part IX
Applications in Practice (Automotive, Aerospace, Biomedical-Devices, MEMS, etc.)

Drowsiness Detection System for Pilots

Gurpreet Singh and M. Manivannan

Abstract Though Pupil Diameter (PD) of the human eye has been known to be an indicator of sleep-onset, the exact quantification of the PD were not known. In this study variations of PD which are in excess of +5 % of the mean value were monitored and classified as Event A. In addition, the eye closure beyond −30 % of mean diameter were classified as Eye Blinks or Event B. The duration of eye blink was monitored if it is more than 1 s. Both Event A and Event B were used simultaneously to detect sleep-onset. The algorithm using Open CV and MS VC++ was tested with IR videos PD of subjects on a driving simulator. The Alert subject exhibited several Event As but no Event Bs and the Drowsy subject exhibited both Event As and Event Bs and was successfully classified as "Drowsy" 2 times during the test run.

Keywords Drowsiness detection · Pilot snooze · Puppillometry · Sleep-onset

1 Introduction

THE pilots work in a very demanding environment where they are expected to be alert at all times. They are supposed to monitor the health of different sub-systems of the aircraft throughout the flight. Even when the auto-pilot is engaged, pilots cannot afford to lose situational awareness. If any snag develops in a flight, it

G. Singh (✉) · M. Manivannan
Department of Applied Mechanics/Biomedical Engineering Division, Indian Institute of Technology, Chennai, Tamilnadu 60036, India
e-mail: gurpreet261@yahoo.com

M. Manivannan
e-mail: mani@iitm.ac.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_78,

requires immediate corrective measures from the pilot. Also if there is even a minor deviation in flight path of the aircraft due to loss of attentiveness, it could lead to disastrous consequences. Many instances have come to light wherein major mishaps have occurred due to pilot having fallen asleep while at the controls of the aircraft like the crash on 22 May 2010 in Mangalore, India, killing 158 people; in June 2008, an Air India aircraft headed to Mumbai flew past its destination with both pilots asleep [1]. In order to enhance flight-safety, it is imperative to ensure that the pilot does not fall asleep while at controls.

While there have been numerous studies on sleep [2–7], we have to deal with the sleep-onset and not with sleep itself. The reason is that the pilots undergo pre-flight medical examination which ensures that they are fit to fly. However, due to various reasons preceding or during the flight, the pilot may involuntarily tend to fall asleep. Once a pilot falls asleep there are very few physiological changes which can be monitored to reliably activate the alarm. But the transition from alert state to sleep state is a condition which is critical both from physiological monitoring and aircraft controlling point of view. It becomes imperative to identify sleep-onset rather than going into stages of sleep.

1.1 Constraints in Sleep-Onset Detection in Cockpit

Several parameters which can be used to detect sleep-onset are EEG, EOG, change in respiration, change in heart rate, etc. but the stringent requirements in case of pilots, limits the options available for making these measurements in cockpit. These constraints are:

1. There can be no use of intrusive electrodes on any part of pilot's body. This rules out the use of EEG, EOG, ECG, EMG, Blood Pressure monitoring, analysis of exhaled gases to predict sleep-onset.
2. The only parameter available to non-intrusive analysis is eye, using an optical measurement tool. Again the option is further narrowed as use of goggles should be avoided. The reason being that goggles would be required to be custom-fitted to each individual's face structure. Thereafter, every time a pilot flies, it would have to be calibrated. Lastly, it would not be a purely non-intrusive system and hence could be disproved of by Director General of Civil Aviation (DGCA).

1.2 Overcoming Constraints Using Optical Methods

The solution is to use a camera which can get the real-time images of the eye without pilot having to do anything. There is a possibility of using several different eye parameters for analysis. But as the purpose of this paper is to design a robust system with the least number of variables, only two variables were used and were found to be fairly accurate in describing the state of the subject.

Over the years different modalities have been used to study sleep-onset like Respiration [2], Cardiovascular function [3], Electro-Oculography [4], etc. but all these modalities present the basic difficulty of being intrusive in nature. In a cockpit environment, we need to have such a device which will not interfere with the working of the pilot in any way but would still be capable of reliably detecting the onset of sleep in pilot. One non-intrusive method of fatigue-detection has been discussed in [8], which brings out the fact that in case of an Alert subject the deviations in pupil diameter are restricted to +5 % of the mean pupil diameter whereas in case of a Drowsy subject, the variations are way beyond +5 % of the mean pupil diameter.

In the present study, effort has been made to clearly define the various characteristics of pupil diameter which need to be monitored and classified so that it results in very unambiguous criteria for declaring a subject as Alert or Drowsy. As the only physiological parameter being monitored is Eye pupil diameter, there is a need to specify the conditions of classification when the whole pupil is visible and also when only partial pupil is visible due to occlusion by eye lashes/lids.

In order to account for the changes in pupil diameter when the whole pupil was visible, a parameter called Event A was used whereas in cases where pupil was only partially visible due to eye blinks, another parameter called Event B was used, which was considered to have occurred if the pupil diameter reduced more than 30 % of mean pupil diameter.

The scope of this paper is to discuss the algorithm which was used to separate out the events which are encountered while monitoring the eye pupil of a subject. After the separation, the events are stored and the algorithm keeps a track of all the relevant data. Until the stored data meets the specified criteria for alarm activation, the algorithm continues to run through the video file without causing any alarm. However, the instant the laid down criteria for alarm activation are met, the alarm is activated and the video clip processing is halted. In order to prove the concept, two different video files in AVI format were used. Since this method uses a camera to capture the image of eye, it is totally non-intrusive and hence would be more acceptable in terms of cockpit requirements (Fig. 1).

2 Methods

The task of acquiring the pupil diameter begins by first acquiring the video of pupil and then it is subjected to various morphological operations which results in the residual image being the contour of pupil alone. Thereafter an ellipse is fitted to the pupil contour which is then used to calculate the area of the pupil. This in turn is used to calculate the pupil diameter. OpenCV ver2.1 is a very versatile tool to perform morphological operations on the image frames. Many operations like Image

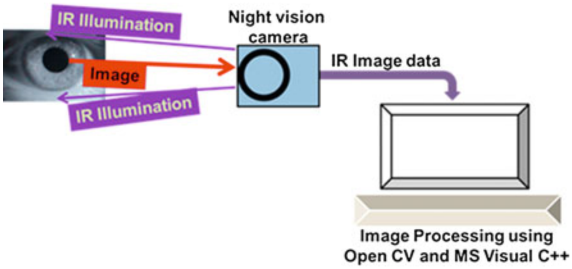


Fig. 1 Block diagram of the set-up for capturing video film for testing of alertness of the subject

Dilation, Image Erosion, Image Opening, Image Closing can be performed with very few lines of code.

Various steps involved in getting the contour of eye pupil are shown in the flowchart below (Fig. 2):

In order to convert video from colour image to grey-scale, Luminosity method has been used. However, if the video is already grey-scale or is in night-vision mode, the algorithm skips this step. Thereafter, Adaptive thresholding is applied in order to cater for illumination gradient. Thereafter, the morphological process of "Closing" is applied to each frame so as to get rid of noise and unwanted images. After all these processes have been sequentially performed, the image consists of only pupil contour and is ready for Pupil detection, as shown below (Fig. 3):

The image available at this juncture consists of only the pupil. So Open CV is used to fit an ellipse to the pupil contour. Actually Open CV provides the option of either fitting a circle to the detected contour or fitting an ellipse to it. But the manner in which Open CV fits a circle leads to introduction of large errors. If a minimum circle is fitted to the contour, then the software just draws a circle with a minimum possible diameter which includes all the points of the contour within itself. Whereas if an ellipse is fitted, Least squares method is used to determine

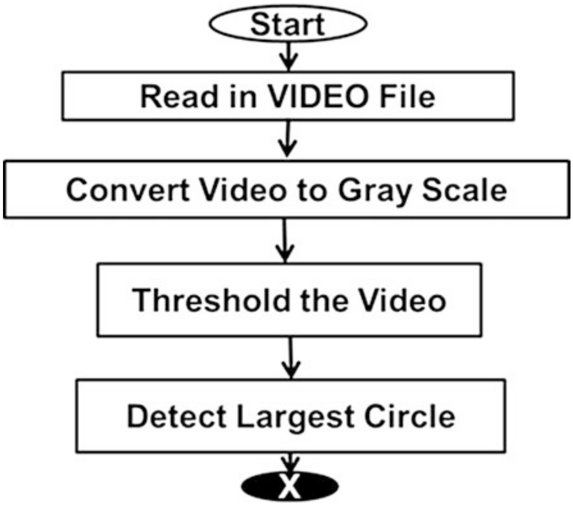


Fig. 2 Flowchart depicting sequence of steps for detecting eye pupil

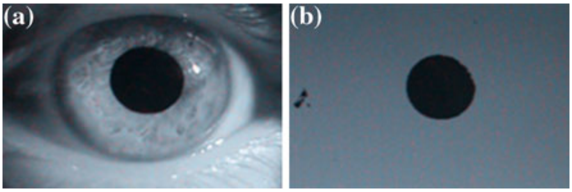


Fig. 3 **a** The input image frame, **b** the residual image after application of morphological operations, consisting of only pupil contour, ready for pupil detection

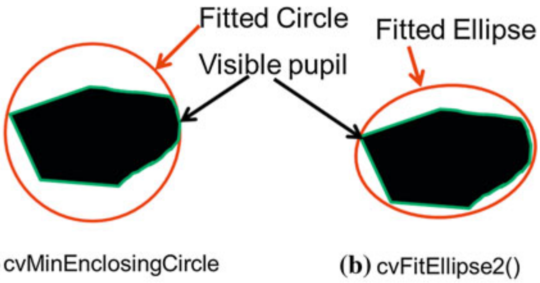


Fig. 4 The comparison of methods of (**a**) fitting a minimum enclosing circle, (**b**) an ellipse to a set of points. *Source* [9]

coordinates of an ellipse such that the ellipse is the best approximation of the detected contour [9]. This results in keeping the errors between the detected contour and the fitted shape to the minimum (Fig. 4).

Another factor of consideration here is that the pupil takes a circular shape whenever the person is looking in front. However, the shape of the pupil tends to seem elliptical only when a person is looking from the corner of his/her eyes. A point to remember here is that when a person is drowsy, the pupil automatically tends to come into the centre of the eyes. Therefore, when an ellipse is fitted to the detected pupil contour, it not only produces lesser errors than the circle but also provides better tracking of the contour and follows the pupil faithfully. Whenever the subject is drowsy, the eyes tend to come to the centre and ellipse can virtually be treated as a circle for all calculations (Fig. 5).

Once an ellipse has been fitted to the pupil contour, there is a requirement to get the diameter of the pupil. But OpenCV does not provide a direct measure of the semi-major and semi-minor axis of the ellipse. Instead, a circuitous method needs to be followed to get the dimensions of the ellipse. This involves using Contour Moments to get the area of the contour [8]. Many different characteristics of the detected contour can be calculated by Contour Moments but as we are interested only in getting the area of the contour which in turn would be used to calculate the diameter of the circle, we need to use only moment (0, 0).

Once the area of the contour has been calculated, the radius of the circle can be calculated as per the following formula:

Diameter $= ((\sqrt{}(\text{Area of Circle})/\sqrt{}\pi)*2)$.

This formula faithfully gives the diameter of the pupil till the time the person is looking straight. But if the subject is looking from the corners of the eyes, an error is introduced in diameter value. But as previously discussed, this error in pupil diameter calculation would not affect the activation of alarm as a drowsy person

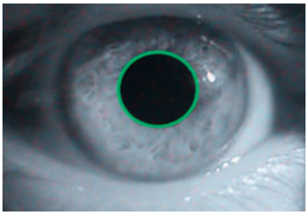


Fig. 5 The ellipse fitted to eye pupil. It is clear that when the subject is looking straight, ellipse takes the form of a circle

has a tendency to have his pupil involuntarily coming into the centre of the eyes and not at the corners. So when a person is drowsy, the pupil would be circular and there would be no error in calculation of the pupil diameter.

Availability of pupil diameter leads to the next step where constraints are set on the input in such a fashion that whenever the set criteria of drowsiness is met, the alarm is activated which alerts the pilot.

It was decided to have two defining events which need to be monitored to reliably predict sleep-onset. These are:

1. Event A: If there is +5 % change in "Pupil Diameter" w.r.t. "Mean diameter" at any instant of sampling.
2. Event B: If there is −30 % reduction in "Pupil Diameter" w.r.t. "Mean diameter".

Event A is the actual variation in the pupil diameter w.r.t. the mean pupil diameter and is calculated every clock pulse to account for different video formats working at different frame rates. However, in view of the computational requirement, only the largest value of pupil diameter detected every 1,000 ms is used for calculation of running average pupil diameter. Event B is Blink of the eye "i.e. closing of the eye-lid and opening of the eye-lid". The OpenCV® function used for fitting the best curve to detected pupil is cvFitEllipse2(). This ensures that even if pupil is partially occluded by the eye-lid, the best possible estimate of the pupil area is still available. The reason for having Event B only −30 % in pupil diameter is that blink can only lead to occlusion of eye-lid thereby leading to reduction in pupil area available for calculation. Even when eye-lid is fully retracted, it cannot have a variation which is higher than maximum pupil diameter.

The diameter of pupil is calculated in every frame. The video clips used in this project are in AVI format with a rate of 29 Frames per Second (fps). This means that each frame is available for about 34.4 ms to derive the information from it. But as OpenCV supports different video formats which may have different fps, so it was decided to sample the video every 7 ms. This ensures that a very high rate video is also processed reliably and at the same time there is no loss of data due to skipping of frames. Also 7 ms time-gap gives a feeling of continuity even though the data input changes at a rate lower than it (Figs. 6, 7).

Once the pupil diameter is available and Event As and Event Bs have been detected, a Criteria needs to be specified which, when satisfied, would lead to

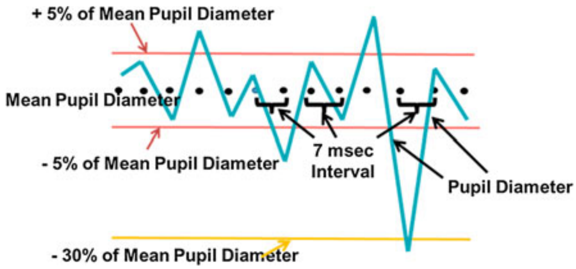


Fig. 6 Different parameters which are calculated from the available eye pupil diameter

activation of alarm. The procedure for detecting Event A and Event B are shown in the flowchart below (Fig. 8):

Once Event A and Event B have been detected, there is a need to have a timer which helps us in keeping a track of the number of Event A and Event B occurring within a specified time frame, which in this case is 5 s. Track is kept of the number of Event As and Event Bs occurring during a period of 5 s and also duration of Event B. It needs to be kept in mind that a window of 5 s is created which is reset every 5 s in case Alarm is not activated. However, it is not reset when the alarm is activated (Fig. 9).

The conditions for activation of alarm can be specified as:

1. If there are more than 3 Event As in 5 s,
2. If there are more than 1 Event B in 5 s AND the duration of any Event B is more than 1 s.

2.1 Reasoning for the Selection of Criteria

Event A can be specified as variations in Pupil Diameter due to drowsiness whereas Event B can be specified as Eye Blink. It has been observed that pupil diameter is very stable in an alert subject rarely going beyond +5 % of the mean diameter whereas for a drowsy person the variations are very frequent [8]. This study utilised two groups, a total of 30 healthy subjects (mean ±SD:28.2 ± 8.9 years old), for the experiment. One group rated themselves as alert (15 men, a normal night sleep with more than 8 h), and the other group as

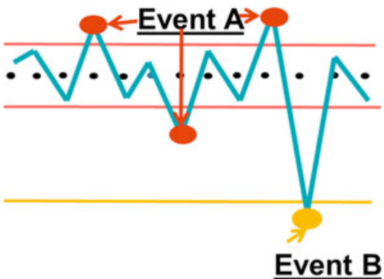


Fig. 7 Occurrence of Event A and Event B w.r.t variations in pupil diameter

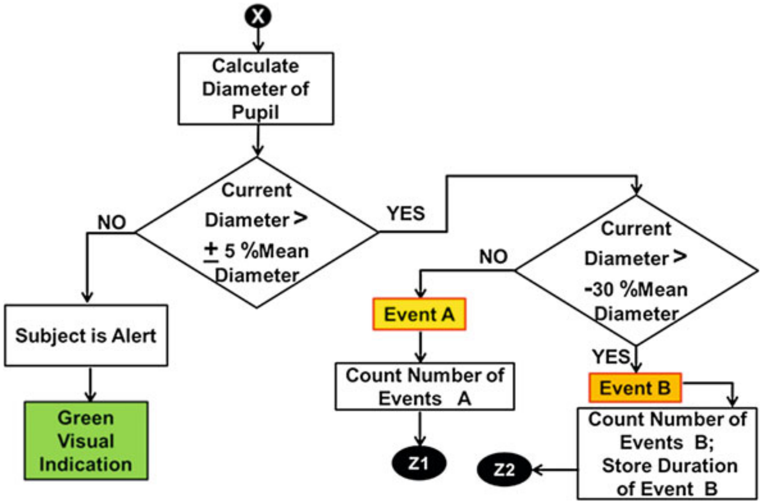


Fig. 8 Flowchart depicting conditions for detecting Event A and Event B

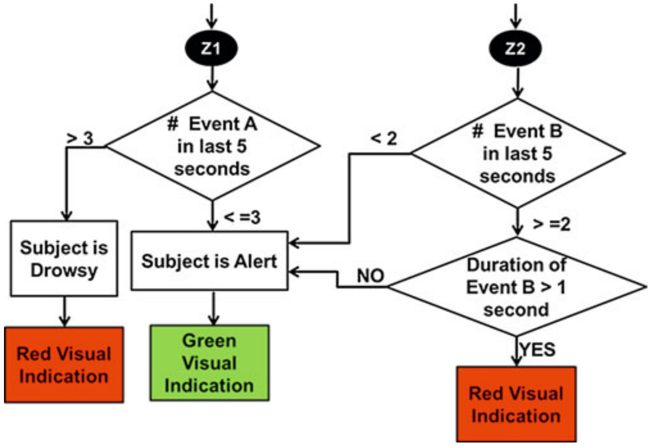


Fig. 9 Flowchart depicting classification of a subject as alert or drowsy based on conditional occurrence of event A & B

drowsy (15 men) [8]. As there is no specified number available as to how many times the pupil diameter might vary for a drowsy person, it was decided to set the threshold at 3 variations every 5 s. If the number of pupil diameter variations (Event A) during 5 s epoch is less than or equal to 3, the subject would be classified as Alert. However, if the number of Event As is higher than 3, the subject would be classified as Drowsy, leading to activation of alarm.

However, if the variation in pupil diameter is beyond the constraints of Event A, it is classified as Event B. The numbers of blinks per minute vary from individual to individual and also as per the task being performed by the individual. Usually a task which requires continuous use of cognitive function leads to reduction in number of blinks per minute to about 5 [10]. But at the same time it needs to be remembered that with increasing drowsiness, the duration of eye closure increases. For alert subject, the duration of eye blink can range from 300 to 450 ms. This duration could increase many folds during drowsiness. It was decided to set a threshold at 1,000 ms so as to avoid false alarm as well to minimise misses. So in case of Event B, the input is subjected to following checks:

1. If the number of Event Bs in 5 s epoch is less than 2, subject is alert,
2. However, if the number of Event Bs in 5 s epoch is more than or equal to 2, the duration of Event B is checked. If the duration of Event B is less than 1,000 ms, the subject is classified as alert. If however, the duration of Event B is more than 1,000 ms, the subject is drowsy which leads to the activation of the alarm. It is pertinent to mention here that Event B, also called as Blink, may also be termed as eye-lid droop which becomes a deciding factor only when the eye-lids take more than 1,000 ms to finish 1 cycle of first covering the pupil and then coming back to the default position. Event B is designed specifically to counter problems posed by blinks.

2.2 *Accounting for Occlusion of Pupil by Eye Lids/Lashes*

Eye lashes occlude the pupil only during eye blinks. So it is important to remember that Event A is not due to eye blink but due to actual variations in Pupil. On the other hand, Event B is the superficial variation in pupil diameter which is caused due to occlusion of pupil due to presence of eye lash over the pupil. We know that eye blinks usually take about 300–450 ms to complete, assuming video rate of 29 fps. This leads us to approximately 10–13 frames of the video clip to complete 1 eye blink. This means that about 5–6 frames are required to capture the closure of the eye and 5–7 frames for capturing opening of the eye. This means that each successive frame would lead to a change of about 15–20 % superficial change in pupil diameter. "Superficial" because it appears to be happening but is actually not. In order to avoid erroneous results due to occlusion, the algorithm is so designed that when the variations in pupil diameter are −30 % of the mean pupil diameter, it is automatically classified as Event B. So now the algorithm already knows that the subject is in the process of blink. Now the algorithm sets up another check for measuring the number of blinks in the 5 s epoch. As is known, if the number of blinks in the epoch is less than 2, it ensures that the subject is alert. However, if the number of blinks (Event Bs) in the epoch is equal to or more than 2, the algorithm checks for another condition i.e. whether the duration of the blink is less than 1 s or not. It has been found that with increased drowsiness the duration of blink increases. So if the duration of blink exceeds 1,000 ms, the subject is classified as drowsy else he is classified as alert.

2.3 Effect of Different Blink Rates

The rate of eye-blinking varies from individual to individual, from 300 to 450 ms. Usually people tend to overlook individuals who have slower blink rates whereas those with higher blink rates are immediately recognised. There are two issues with blink rate:

(a) The blink period is larger than 450 ms.

When a person is drowsy, the blink period increases. The blinks are still there though with reduced frequency and increased period. When a drowsy person falls asleep, blinking stops i.e. blink period becomes ∞. The result is that the blink period keeps on increasing with increased drowsiness. There does not exist any data on what is the exact value or a range of blink-periods which denote stage-I sleep. In order to design the algorithm, it was decided to arbitrarily keep the value at 1,000 ms. This provided a mid-value between a sleeping person with zero blink-rate and a normal person with a nominal blink period of 400 ms.

(b) The blink period is smaller than 300 ms.

There are individuals who are pre-disposed towards smaller blink periods. They tend to blink very frequently and thus present another challenge to the algorithm. The challenge arises due to frequent occlusion of pupil due to eye-lid cover, either partially or fully.

The essential requirement of the algorithm is to get the correct value of pupil diameter once every second. This would be sufficient to satisfy the requirements of both Event A and Event B. However, the algorithm is so designed that it calculates the "running average" of the pupil diameter every clock pulse. Assuming that the video being tested has a rate of about 25 frames per second. This means that the video provides 25 pictures of pupil per second along with its running average. This provides for a lot of redundancy in calculations. So even if the eye-lid occludes the pupil, the results are robust enough to give the correct status of the subject.

3 Results

In order to validate the hypothesis and the set criteria, two AVI format videos, one each of an alert and a drowsy person, were used to validate the algorithm. Both these videos were acquired by Hirata Y [5]. The videos were recorded when subject sat comfortably on a driving simulator equipped with a steering wheel and brake & accelerator pedals (Logicool PRC-11000) in a dark room as elaborated in [5]. The subject wore a goggle (NEWOPTO ET-60-L) with 2 CCD cameras each of which takes infrared images of each eye at the frame rate of 29.97fps (NTSC). The various characteristics of the videos used for validation of the algorithm are tabulated in the following table (Fig. 10):

The video featuring the pupil of Alert subject exhibits very few changes in pupil diameter (few Event As) and no Event Bs whereas the video featuring a drowsy subject exhibits many Event As and Event Bs. The algorithm is so designed that the program execution stops if the Drowsiness alarm gets activated. The summary of the results is given in a tabulated form below (Fig. 11):

The results obtained after subjecting the two videos to the algorithm are shown in pictorial form in Figs. 12, 13. It is clear from both the tables and graphs that Events A and B are far too frequent in a drowsy person as compared to an alert person.

In addition to the above-mentioned videos, one of the authors recorded two videos, each of about 2 min duration, of alert persons using SONY® HANDY-CAM® hand-held camera in night-vision mode. The results were found to be consistent with the hypothesis. However, as no corresponding recordings were carried out for drowsy person by the author, the mention of even the videos of alert person has been kept out of the paper.

The activation of alarm was found to be consistent with the criterion specified. If either of the two criteria as specified in Sect. 2 were satisfied, the alarm was activated.

4 Summary and Future Work

The novelty of this method is that pilot does not have to wear any goggles. The system is totally non-intrusive in nature which could help it get more acceptability in aviation community. The camera is to be fixed on an instrument panel of the aircraft which maintains pilot's face in the view. The challenge lies in ensuring

S. No.	Type of Video	Size (Mb)	Frame Rate (Frames/sec)	Clip Duration (sec)	Frame Size (Width : Height)
1.	Alert Person	1.13	29	20	320:240
2.	Drowsy Person	1.40	29	20	320:240

Fig. 10 The table showing the characteristics of the two video clips used to validate the algorithm

S. No.	Type of Video	No. of Event A detected	No. Of Event B detected	Drowsiness Alarm Activation
1.	Alert Person	5	Nil	Nil
2.	Drowsy Person	8	5	2

Fig. 11 The table showing the summary of the working of the algorithm on the two videos

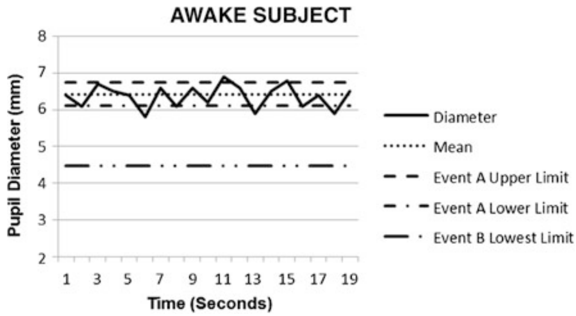


Fig. 12 Graph showing the pupil diameter variations limited to +5 % variations of mean pupil diameter in case of alert subject

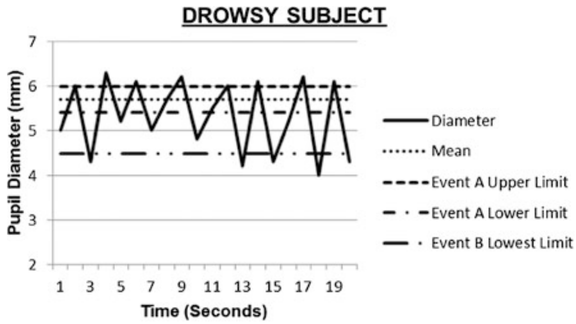


Fig. 13 Graph showing pupil diameter variations in case of drowsy subject. It can be observed that pupil diameter variations are way beyond +5 % variations about mean pupil diameter. Also, there are numerous variations below 30 %

that pilot's face is always in the view of camera but here a few points are pertinent to mention:

1. Any drowsy person's face would be almost motionless so it would not go out of the camera's view. Once it is ensured that the resting position of the face is always captured by the camera, there is a surety of capturing the pupil's image for processing.
2. Whenever a person is drowsy, his/her eye-balls are pulled back to the centre of the eyes by the autonomic nervous system. Thus pupils automatically come to the centre of the eye which ensures the full view of the pupil for the camera. The full view of pupil is always circular. Pupil can assume shape other than circular, like oval, only when a person is looking through the corner of his/her eye. However, a drowsy person cannot look through the corner of the eye.
3. The default position of the eye, when a person is about to fall asleep, is the centre of the eye. This provides an opportunity to test the eyes of the pilot for drowsiness when the pilots head is relatively steady, eye-balls are in the centre and variations of pupil diameter are high with relatively less blinks.

It has been known that the fluctuation of pupil diameter can be a parameter for detection of sleep on-set. However, the exact quantification of these parameters for the detection of sleep-onset reliably is not known. In this work, an algorithm is proposed with +5 % of the mean pupil diameter for alert subjects and in case of a Drowsy subject, the variations more than +5 % of the mean pupil diameter along with the duration and frequency of blinks. The criteria to detect drowsiness were tested with two IR video acquired from subjects on driving simulator. The downside is that the results have been proved just for two video one each of alert and drowsy subjects. The results need to be validated for a much wider group of subjects who are in different states of alertness/drowsiness. The subjects need to be kept in a controlled condition of sleepiness and then the videos need to be acquired and the same need to be tested with the algorithm.

The present study has relied heavily on just 2 videos, one each of alert and drowsy person, which were recorded under controlled conditions. There is a need to increase the sample size to at least 30 to get a much higher confidence in the set criteria. The system has already been designed with clearly defined criteria for alarm activation. It can be considered as a prototype which can be actually fitted on an instrument panel and tested for effectiveness.

Present study was conducted to prove the correctness of the criteria required to set off the alarm. It was conducted on two video clips. The actual deployment of this technique requires that the concept needs to be proved in real-time video streaming and not just on the video clips.

References

1. Levin A (2010) USA Today Updated 18 Dec 1:12 PM URL: http://usatoday30.usatoday.com/news/world/2010-11-18- airindia18_ST_N.htm?csp = 34news&asid = 2f98cfea
2. Ventilation during sleep onset by Colrain IM, Trinder J, Fraser G, Wilson GV (1987) Department of Psychology, University of Tasmania, Hobart, Tasmania 7000, Australia; The American Physiological Society, pp 2067–2074
3. Acute changes in cardiovascular function during the onset period of daytime sleep: comparison to lying awake and standing by Zaregarizi M, Edwards B, George K, Harrison Y, Jones H, Atkinson G (2007) Research institute for sport and exercise sciences. J Appl Physiol 1332–1338, Henry Cotton campus, Liverpool John Moores University Liverpool L3 2ET, UK
4. Electro-oculographic and performance indices of fatigue during simulated flight by Morris TL, Miller JC (1996) Biological psychology, pp 343–360
5. The pupil as a possible premonitor of drowsiness by Nishiyama J, Tanida K, Kusumi M, Hirata Y (2007) Conf Proc IEEE Eng Med Biol Soc 1586–1589
6. Variability of vigilance and ventilation: studies on the control of respiration during sleep Schäfer T (1998) Department of applied physiology, Ruhr-Universität Bochum, D-44780 Bochum, Germany. Respiration Physiology 114 (1998) 37–48
7. Monitoring eye and eyelid movements by infrared reflectance oculography to measure drowsiness in drivers by Johns MW, Tucker A, Chapman R, Crowley K, Michael N (2007) Somnologie, vol. 11, pp 234–242
8. Fatigue detection based on infrared video pupillography by Deng L, Xiong X, Zhou J, Gan P, Deng S (2010) Laboratory of forensic medicine and biomedical information Chongqing medical university Chongqing, China. In: Proceedings of the 4th international conference on bioinformatics and biomedical engineering (iCBBE), pp 1–4
9. Learning OpenCV by Bradski G, Kaehler A (2008) Copyright © 2008, published by O'Reilly Media, Inc., 1005 Gravenstein Highway North, Sebastopol, CA 95472
10. Analysis of blink rate patterns in normal subjects by Bentivoglio AR, Bressman SB, Cassetta E Carretta D, Tonali P, Albanese A (1997) Movement disorders society © 1997, pp. 1028–1034

Discussion About Goal Oriented Requirement Elicitation Process into V Model

Göknur Sirin, Bernard Yannou, Eric Coatanéa and Eric Landel

Abstract The major concern of past and present industry is to find how to make and supply the products for fulfilling customer needs with minimal cost and time. With this motivation, Renault recently decided, in order to improve efficiency and reduce costs, to re-design their distributed and heterogeneous thermal comfort simulation model's activities in order to have a complete simulation environment. The purpose of this work is to represent the preliminary steps in achieving this goal in building a change process model which aid in V model requirement elicitation phase. So, in this work, we propose an extended V model based on Goal Oriented Requirement Engineering (GORE) for complex system's requirement elicitation. Is the existing approach ineffective? What really are the research issues?

Keywords Change process model · Goal oriented requirement engineering · System engineering V model

G. Sirin (✉) · B. Yannou
Ecole Centrale Paris, Laboratoire Genie Industriel,
Grande Voie Des Vignes F-92-290 Chatenay-Malabry, France
e-mail: Goknur.sirin@ecp.fr

B. Yannou
e-mail: Bernard.yannou@ecp.fr

G. Sirin · E. Coatanéa
Department of Engineering Design and Production, School of Engineering,
Aalto University, PO Box 14100,Aalto 00076, Finland
e-mail: eric.coatanea@aalto.fi

G. Sirin · E. Landel
Renault SAS, Techno-Centre, 1 Avenue du Golf, Guyancourt, France
e-mail: eric.landel@renault.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_79, © Springer India 2013

1 Introduction

Engineering changes and lack of requirement elicitation are considered inevitable; especially for complex product producer such as vehicle and plane where customer satisfaction, safety and reliability are key drivers.

According to some research, lack of requirement elicitation and change process model definition could destroy a project's potential value. Furthermore, researches indicated that requirements elicitation or the lack thereof, is often times the chief suspect in the cause of project failures. In a study of complex system engineering projects, McManus and Wood-Harper found that one of the most important factors in the failure of these requirements was "the lack of due diligence at the requirements phase" [1].

Especially, in the 1980s, the V-Model has been used heavily in the automotive industry, and nowadays, V model is always applicable to variant industrial projects which provide a series of steps that make up and simplify the complex system projects. Within Renault Thermal Comfort project, we tend to use V model for project life cycle development. We started Renault Thermic Comfort Project by a standard Requirements analysis phase. In this phase, we collected and grouped all the requirements by analyzing the needs of the user(s). What we propose here is to elicit first the goals (business and operational objectives) before eliciting system requirements. Because good defined objectives, simplify the process for project planning. With a clear understanding of the business and operational objectives, you can then break the work down into the elemental tasks required to meet the system requirements. In addition, the change process model that we prose here by extending V model Requirement analysis phase is provide a well-structured levels in order to identify goals, activities and Information system tools [See Fig. 3]. Thus with this work, we propose an extended V model in where we elicit first of all the system's objectives. The reason to propose an extended V model is that the rigid nature of V model is ineffective in dealing with complex and dynamic situations in where this model is unable to handle change efficiently. So, present work aims at maximizing the combined effect of V model's requirement analysis phase and Enterprise Change Process model where we define first, business and operational goals [2, 3]. In such a way, this paper focuses on explicit goal representations in requirements models. Because goal modeling help to define the inter-dependencies among requirements.

The paper is organized into four sections beyond the introduction, in the second section; we reviewed briefly the literature on change process model integration to System Engineering V model's Requirement Elicitation considerations. In the third section, we introduce our discussion towards Renault thermal comfort simulation model case by introducing its business and operational objectives. Finally, in the last section, a set of conclusions and recommendations for future work are presented.

2 Quick Literature Review on Change Process Model Integration to System Engineering V Model's Requirement Elicitation Considerations

In every organization, regardless of industry or size, there are three organizational elements that both drive change and are affected by change which are Processes, Technology and People. Technology supports the processes designed to respond to changes in market conditions. Ultimately, however, it is the people who must leverage these processes and technology for the benefit of the organization. With the following explanations, we can briefly look at how each of these elements affect by organizational change:

Process: Business processes are defined by process maps, policies and procedures, and business rules that describe how work gets done. This drives the adoption of new technology.

Technology: Technology ensures greater organizational efficiency in implementing the changes. It is a means to process data with greater accuracy, dependability and speed.

People: Generally, organizations excel at designing new or improving existing processes. They also do well at identifying or developing technology to realize the power of new processes. However, most organizations fail to focus sufficient attention on the role people play in the processes and technology used to accomplish the desired organizational changes.

Change management is a cyclic process, as an organization will always encounter the need for change. There are three phases in the Organizational Change Management Life Cycle which are **Identify**, **Engage and Implement**. The elements of change (processes, technology and people) and the phases of the Organizational Change Management Life Cycle are closely linked, and their intersection points must be carefully considered. In this work, we focus only on change's identification phase [4–6].

Identify the Change Phase: In the Identify stage, someone within an organization-typically a senior executive spearheads an initiative to change a current process. This need is then presented to the organization with a general description of the current state of affairs, offset by a high-level vision of the desired future state. While it seems obvious, identifying the change is an absolutely fundamental first step in successful change adoption. It is important that the changed condition be described in a common, consistent language.

The first step to create a change process model is to have a global picture of current engineering system's functionality and structures; second we need to identify the requirements and reasons for change. As illustrated in Fig. 1, *contextual forces* represent external market requirements such as *enter the competition market, increased emphasis on quality, and efficiency of developing product* etc [4, 5]. The idea that we implement here is to integrate change process model to V-model requirement analysis' phase. Because, as we mentioned previously that the biggest disadvantage of V-model is that it's very rigid and the least flexible. If any

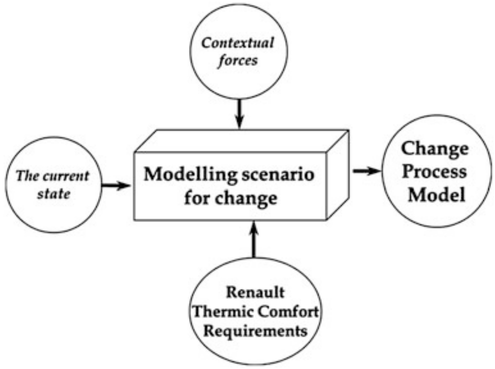


Fig. 1 Change process model

changes happen mid-way, not only the requirements documents but also the test documentation needs to be updated.

As illustrated in Fig. 2, we introduced goal oriented requirement engineering method and change process model to V-model requirement analysis phase. Integration of this change process model to system engineering V model's requirement analysis phase, provide us to share an understanding of how the current project functions. Also it provides to share a vision for whatever change is required, to develop scenario for implementing the change, to develop arguments for and against the various scenario and finally to keep a history of decisions made during the process.

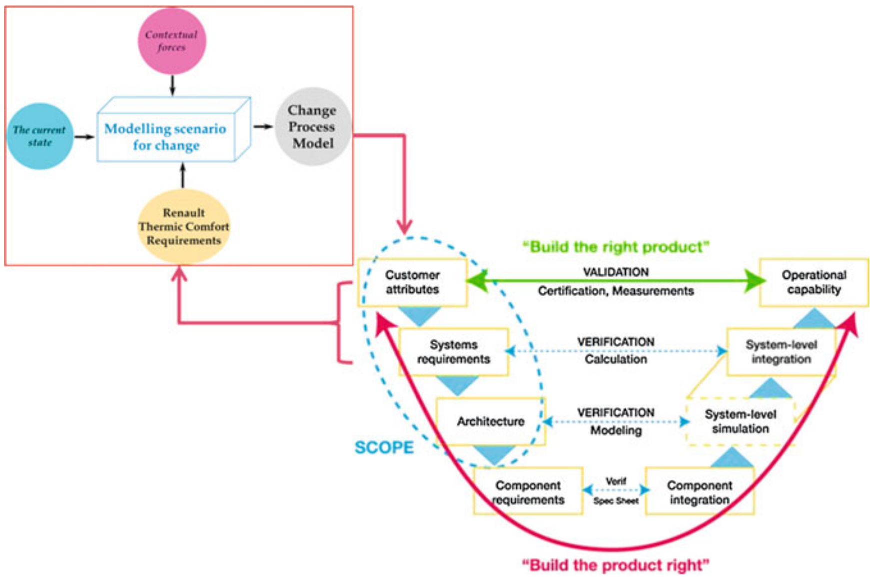


Fig. 2 Change process model implementation into V model

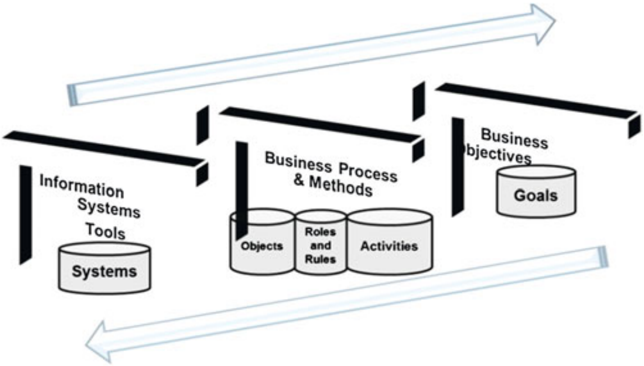


Fig. 3 Change process levels

2.1 Change Process Levels

As illustrated in Fig. 3, enterprises have to form a network which consists of three levels related to change processes. Strategic goals on business objectives level set the direction and purpose of the enterprise. The purpose of the goal model is to describe what the enterprise or department wants to achieve or to avoid. Roles correspond to sets of responsibilities and related activities. The actor/role model aims to describe how actors are related to each other and also to goals. The role/activity model is used to define enterprise processes, the way they consume/produce resources to achieve enterprise objectives. Business objects set the structure of the support systems and their behavior has an identifiable lifecycle. The object model is used to define the enterprise entities, attributes and relationships. Business rules are the way that enterprises function. The business rules model is used to define business rules consistent with the goals model [6]. In this work, we focus on Business Objectives, Goal elicitation phase.

2.2 Goal Identification: Goal Oriented Requirement Engineering

In today view, goals drive the requirements elicitation process and they express a result to reach, an objective to be fulfilled. Goal-oriented requirements engineering has many advantages, such as:

- object models and requirements can be derived systematically from goals;
- goals provide the rationale for requirements;
- a goal graph provides vertical traceability from high-level strategic concerns to low-level technical details;

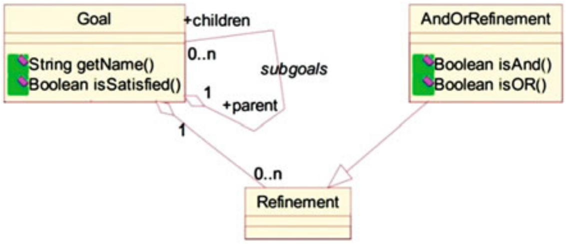


Fig. 4 Goal class diagram

- goal AND/OR graphs provide the right abstraction level at which decision makers can be involved for important decisions etc.… [7, 8].

Thus, the aim of the present work is to reformulate these needs for change by using Goal Oriented Requirement Engineering Method [4–6].

2.2.1 Modeling Goals

The reason of goal(s) modeling is to support heuristic, qualitative or formal reasoning during RE. Understanding the context in which the system will have to function, the rationale for the To-Be system, deriving the system requirements from the explicit representation of the organization's mission & objectives bridging organization objectives to system requirements. The goal model is a goal graph build with AND/OR links (See Fig. 4). Constructing OR links supports identify, evaluate, negotiate and reason on alternatives. AND links mean that the father goal is satisfied only if the children goals are satisfied. It helps in driving the process of goal operationalization [7, 8].

2.2.2 Formulating Goals

Goal could be defined in informal, semi-formal and formal way.

Generally, a goal consists of a verb, a target with a parameter.

Goal: Verb <Target> [<parameter>] [4–6].

Target: verb complement which can be Object or Result

Other parameters: source, beneficiary, destination, means, manner, place, time, quantity, quality, reference

Ex: Improve (Verb), thermal comfort simulation activities (Obj) for vehicle end-user (Ben) by providing a complete simulation model (Man)

In the next section, we implemented our theoretical knowledge to Renault Thermal Comfort case study.

3 Discussion Towards Renault Thermal Comfort Simulation Model Case

We implemented Goal Oriented Requirement Engineering Methods and Change Management Process to Renault's thermic comfort distributed simulation activities.

3.1 Change Reasons

Varying HVAC (Heating, Ventilation and Air-Conditioning) operational modes requires multiple physical testing, which is often not feasible. Thus in the recent past, the only way to properly measure, analyze, and thus manage these thermal issues was to use physical prototypes in climatic wind tunnels—an extremely complex and time consuming process. Renault's distributed thermal comfort simulation model consists of hot loop thermo-hydraulic model, air passenger circuit model, and cold loop model and outside air circuit model (See Fig. 5). Each simulation model has its own set of models, each with its own modeling conventions, nature(0-1D, 2-3D, simulator)and maturity (Draft, validated, obsolete). Various simulation solutions such as Power FLOW, Amesim and Fluent are used in order to reduce the team's usage of physical prototypes by 30–50 %.

On the other hand, heterogeneity and diversity of the simulation model increase the system complexity. The current Renault thermal comfort's problem arises also from multidisciplinary stakeholders, model repetition, silos engineering process,

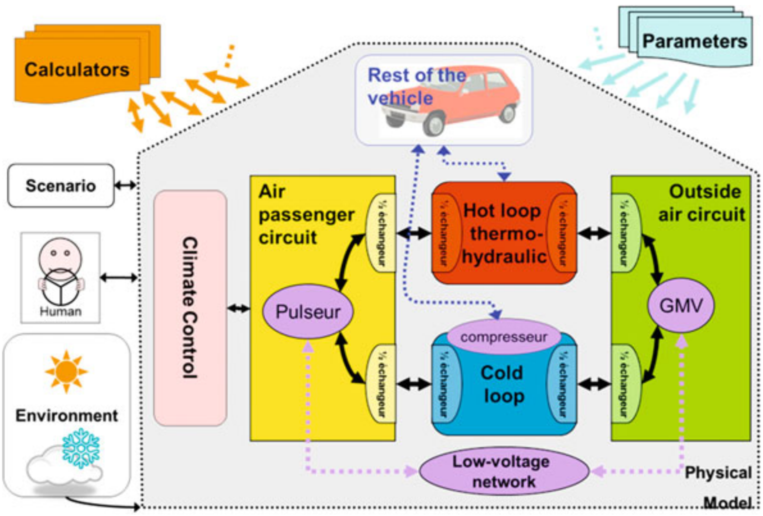


Fig. 5 Renault thermic comfort activities

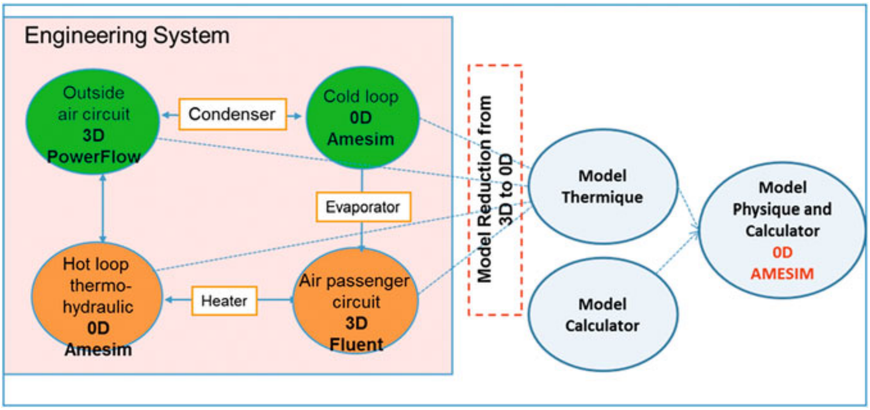


Fig. 6 Coupling of thermal comfort models/entities into a complete model

data and model exchange, etc. The main aim of the change is to reduce the model from 3D to 0D for time saving and to aggregate distributed simulation models in order to have a complete, robust thermic comfort model (See Fig. 6).

The aim of the present work is to reformulate these needs for change by using Goal Oriented Requirement Engineering method. By taking into account the technical process that we have already mentioned in the previous parts, we reformulate the needs for change in the following picture.

Example of requirement elicitation:

- R3: Check Model Consistency
  - R31: Analysis of dependency network
  - R32: Determine decomposition for concurrent engineering
  - R33: Determine workflow
  - R34: …

As illustrated in Fig. 7, goal is divided into two parts which are operational and strategically. AND links mean that the father goal is satisfied only if the children goals are satisfied. It helps in driving the process of goal operationalization. Goal elicitation is on the top level of change process level (See Fig. 3) which called business objectives. This top level determination helps to identify the system's objectives, rules, activities and process because, process is set of activities, each of them be related the role played by an actor, triggered by an event, to produce a result in order to fulfill a goal [4, 5].

We need to manage change, from a current situation As-Is to a future situation To-Be. Change creates a movement from an existing situation captured in an As-Is model to new situation captured in a To-Be model. (See Fig. 8) According to C. Rolland, there are seven types of change goals which are Adapt, Introduce, Cease, Replace, Maintain, Extend and Improve.

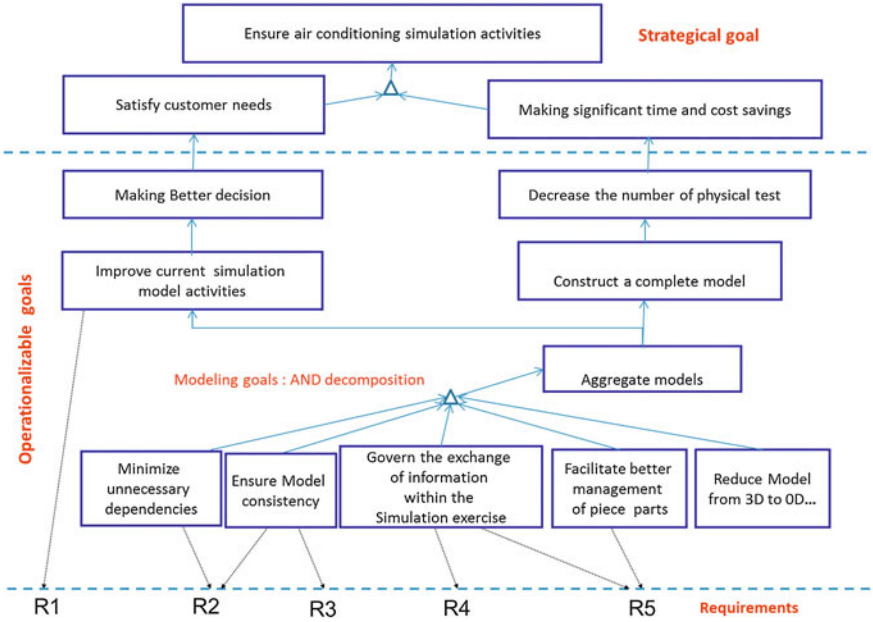
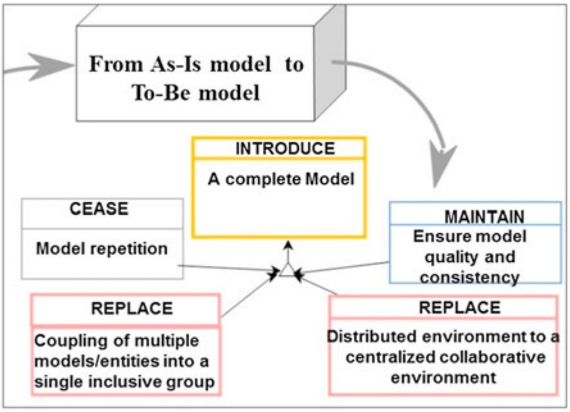


Fig. 7 Goal elicitations for thermal comfort case/as-is

Fig. 8 Goal types to-be



4 Conclusions and Recommendations for Future Work

Thus Renault Thermal Comfort distributed and non-homogenous simulation models were aimed to coupling in order to have a complete developed simulation model for thermal comfort activities. The aim of this work is to re-organize the needs for change by using goal oriented requirement engineering methods. We introduce goal oriented requirement engineering method and change process model to V model requirement analysis phase (See Fig. 2). Integration of this change process model to system engineering V model's requirement analysis phase, help to understand, how the current project functions, to share a vision for whatever change is required, to develop scenario for implementing the change, to develop arguments for and against the various scenario and finally to keep a history of decisions made during the process. Also, the principal aim of this implementation is to minimize inflexibility structure of V model in order to respond to change. Present work does not represent the entire work. This work represents the top level of change process level which is business objectives (goal elicitation).

On the other hand we have some recommendations for future work such as the advantages, needs and obstacles of proposed method for an industrial project.

References

1. McManus J, Wood-Harper T (2010) http://www.bcs.org/content/ConWebDoc/19584
2. Katina PF, Jaradat RM (2011) A three-phase framework for elicitation of infrastructure requirements. Members of IEEE, the 4th annual international conference on next generation infrastructures, Virginia Beach, Virginia, 16–18 Nov 2011
3. van Lamsweerde A () Goal-oriented requirements engineering: A Guided Tour, Département d'Ingénierie Informatique, Université catholique de Louvain, B-1348 Louvain-la-Neuve (Belgium), avl@info.ucl.ac.be
4. Nurcan S, Rolland C (2003) A multi-method for defining the organizational change. Elsevier: J Inf Softw Technol 45(2):61–82
5. Rolland C, Nurcan S, Grosz G (1999) Enterprise knowledge development: the process view. Inf Manage J (Elsevier) 36(3):165–184
6. Nurcan S, Rolland C (1999) Using EKD-CMM electronic guide book for managing change in organisations. In: Proceedings of the 9th European-Japanese conference on information modelling and knowledge bases, Iwate, Japan, 24–28 May 1999, pp 105–123
7. Dardenne A, van Lamsweerde A, Fickas S (1993) Goal directed requirements acquisition. Sci Comput Program 20:3–50
8. Mylopoulos J, Chung L, Yu E (1999) From object-oriented to goal-oriented. Communications of the ACM, vol 42(1), Jan 1999
9. Sirin G et al (2012) Analysis of the simulation system in an automotive development project. Accepted paper to CSDM2012
10. AUTOSAR Seminar WS2008/2009. http://www.advanced-planning.de/advancedplanning-128.htm
11. INCOSE (2006) Systems engineering handbook—a guide for system life cycle processes and activities, version 3. Cecilia Haskins

Prediction of Shock Load due to Stopper Hitting During Steering in an Articulated Earth Moving Equipment

A. Gomathinayagam, B. Raghuvarman, S. Babu and K. Mohamed Rasik Habeeb

Abstract Design of structural members to overcome the failure due to shock loads is a challenging process. In this work, an effort is made to analytically predict the shock load due to hitting of the front chassis stopper on the rear chassis stopper during steering operation in an articulated earth moving equipment. The value of the shock load is obtained by equating the moment due to steering cylinders to the moment due to stopper hitting force. In order to verify the methodology, a prototype plate similar to the stopper was made and strain gauge rosette was pasted to it. Experimentation was done by applying the load to the prototype plate and the strain values are recorded for different load values in a laboratory set up condition. Strain gauging was also carried out by mounting the same prototype plate in the actual field machine. The value of shock load was obtained by calibrating the strain values obtained from the field against that of the laboratory experimental values. It is found that a very good correlation exists between the analytical and experimental values of the stopper load.

Keywords Shock load · Articulation · Earth moving equipment · Steering

A. Gomathinayagam (✉) · B. Raghuvarman · S. Babu · K. Mohamed Rasik Habeeb
Product Development Center, Larsen & Toubro Ltd, Coimbatore, India
e-mail: agnayak@yahoo.com

B. Raghuvarman
e-mail: raghuvarman.b@larsentoubro.com

S. Babu
e-mail: babu.s@larsentoubro.com

K. Mohamed Rasik Habeeb
e-mail: mohamedrasik.habeeb@larsentoubro.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_80, © Springer India 2013

1 Introduction

Earth moving equipment are primarily used for tasks in earthwork, compaction and re-handling. The structures of them are subjected to different kinds of loads like static, dynamic and impact. Designing the structures to overcome failures due to theses loads is a challenging task. The prediction of impact or shock loads is cumbersome than that of static or dynamic loads.

The majority of the earth moving equipment are articulated vehicles. During steering operation the front and rear portions of the structures about the articulation joint come and hit each other causing the shock loads. The stopper plates are generally provided on these equipment to limit the steering angle as well as to avoid these shock loads being transferred to the steering cylinders. Figure 1 shows a few typical failures in the structures due to shock loads during steering stoppers hitting. One of the reasons of these failures is difficulty in prediction of shock loads.

Literatures [1–3] are available mostly for study of operator comfort due to shock loads transferred to the structures in earth moving equipment. A very few literatures like [4] to find the dynamic digging load are available for predicting the shock loads. The individual industry shall use its own methodology based on analytical, simulation or experimental to estimate the shock loads. Many industries use simulation techniques [4–7] like finite element analysis (FEA) and multi-body dynamics (MBD) followed by experimental verification to predict the dynamic and shock loads.

In this paper, an analytical method is developed to predict the shock load due to hitting of the front chassis stopper on the rear chassis stopper during steering operation in an articulated earth moving equipment. The developed methodology is validated experimentally by strain gauging testing at the field.

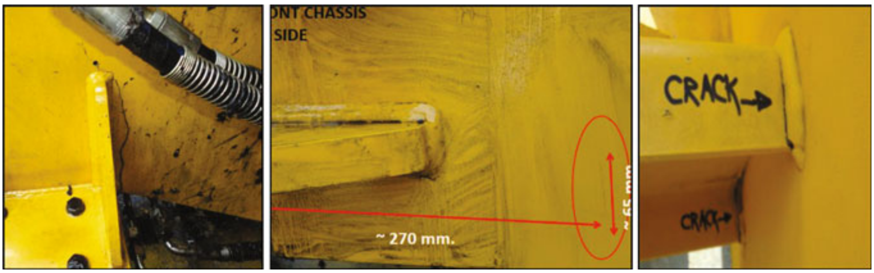


Fig. 1 Failure due to shock loads in the structures

2 Analytical Method

The model of an articulated earth moving vehicle in straight and steered conditions is shown in Fig. 2. It is generally assumed that the front or rear structure with less reaction starts to steer initially. Then both structure together moves and hit each other. The value of the hitting load is obtained by equating the moment due to the steering cylinders to the moment due to stopper hitting force.

During steering one cylinder extends and another cylinder retracts. The force acts on the bore side and the rod side in the extension and retraction cylinders respectively. The operating parameters are shown in Fig. 3 and Table 1.

The hitting force is derived using the equations given below:

$$\text{Area on the bore side of the cylinder,} \quad A_b = \pi * d_b^2/4 \tag{1}$$

$$\text{Area on the rod side of the cylinder,} \quad A_r = \pi * \left(d_b^2 - d_b^2\right)/4 \tag{2}$$

$$\text{Force acting on the extension cylinder,} \quad F_1 = p * A_b \tag{3}$$

$$\text{Force acting on the retraction cylinder,} \quad F_2 = p * A_r \tag{4}$$

$$\text{Moment due to cylinder forces,} \quad M_c = F_1 * d_1 + F_2 * d_2 \tag{5}$$

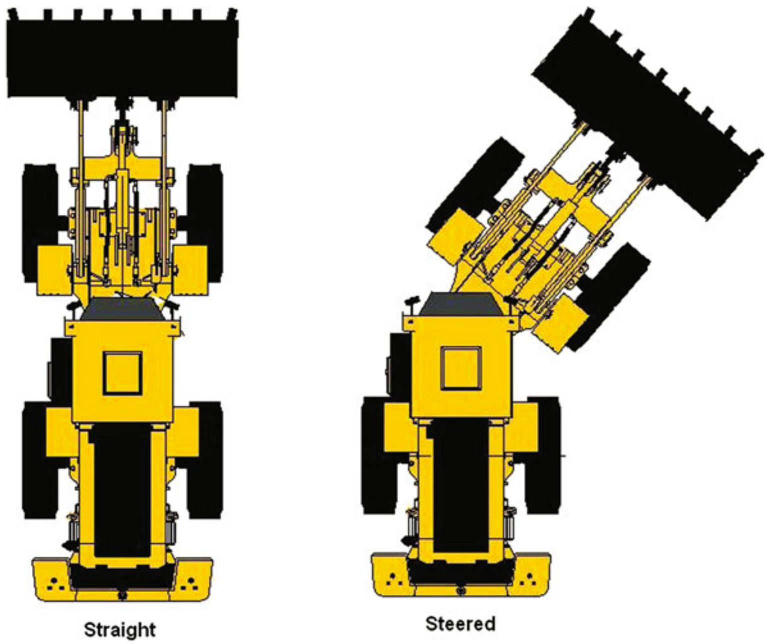


Fig. 2 Articulated earth moving equipment in straight and steered conditions

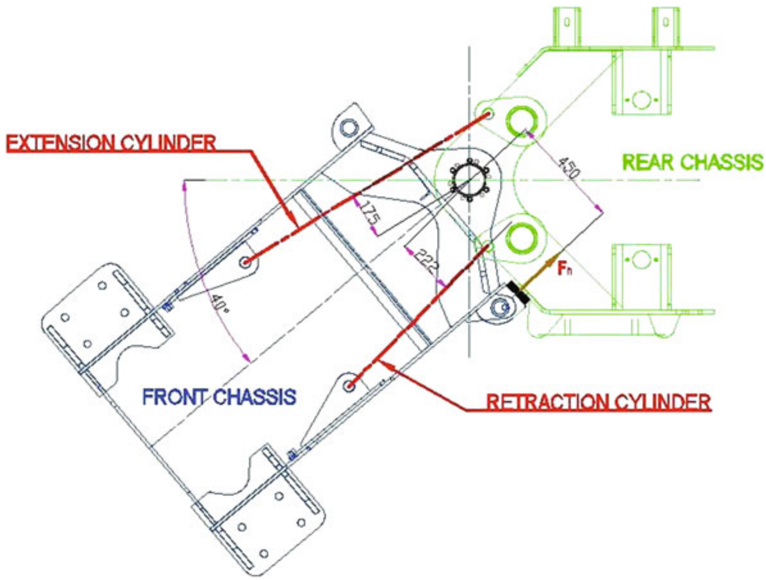


Fig. 3 Details @ steered condition

Table 1 Operating parameters

Parameter	Value	Unit
Articulation angle, α	±40	deg
Bore diameter of steering cylinder, d_b	75	mm
Rod diameter steering cylinder, d_r	45	mm
Perpendicular distance between extension cylinder and articulation joint, d_1	175	mm
Perpendicular distance between retraction cylinder and articulation joint, d_2	222	mm
Perpendicular distance between stopper pad and articulation joint, d	450	mm
Maximum pressure in the steering cylinder at the time of hitting, p	165	bar

$$\text{Moment due to stopper hitting force} \qquad M_s = F_s * d \tag{6}$$

$$\text{By equating } M_c \,\&\, M_s, \text{ the Stopper hitting force,} \qquad F_s = M_c / d \tag{7}$$

Hence the stopper hitting force developed a steering cylinder pressure of 165 bar using the above equations is 5,240 kgf.

3 Experimental Work

In order to verify the analytical approach, experimentation was carried out. A prototype plate similar to the stopper was made and strain gauge rosette was pasted to it as shown in Fig. 4. The trials were conducted by applying the load to the prototype plate in an UTM. The strain values were recorded for different load values in a laboratory set up condition. The load vs strain values for the loading and unloading is shown in Fig. 5.

The prototype plate was fixed to the rear chassis stopper plate in an actual machine working in the field. Strain gauging was carried out in the field machine and the parameters measured at the time of stopper hitting are given in Table 2. It was found that the pressure developed in the steering cylinders was 150 bar which was less than the maximum pressure of 165 bar. The following are the reasons for the less pressure in the cylinders:

- Since the prototype plate was mounted in addition to the rear chassis stopper plate, the full articulation angle of 40° was not achieved. The maximum pressure of 165 bar was achievable only at 40° articulation angle.
- The theoretical maximum pressure of 165 bar was derived based on certain assumed value of coefficient of friction between the tire and the ground. But the coefficient of friction at the tested field might be different than that the assumed value.

The value of shock load was obtained by calibrating the measured strain value against that of the laboratory experimental values. Also the hitting load from analytical approach was found out for the steering cylinder pressure of 150 bar (4,761 kgf). It is found that a very good correlation exists between the analytical and experimental values (Fig. 6). Hence the developed analytical approach shall be used to predict the hitting load in a similar type of applications so that the structures can overcome failures due to shock loads.

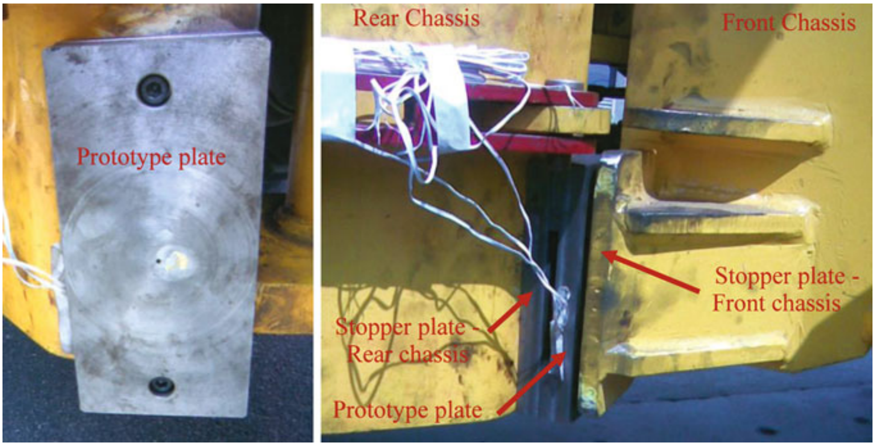


Fig. 4 Experimental setup

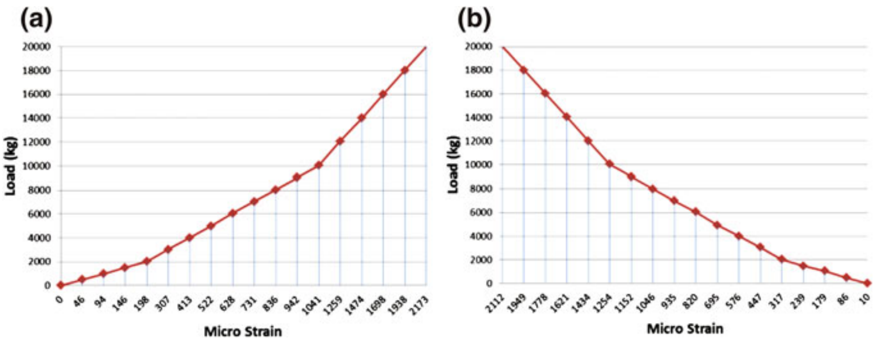
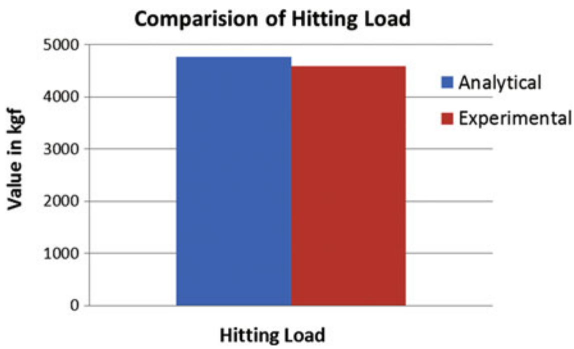


Fig. 5 Load vs strain during loading and unloading

Table 2 Parameters at the time of stopper hitting

Parameter	Value	Unit
Pressure in the steering cylinders	150	bar
Value of micro strain pasted in the plate	477	–
Load value corresponding to Micro strain from the graph (Fig. 5a)	4,591	kgf

Fig. 6 Comparison of stopper hitting load values



4 Conclusions

The analytical methodology is developed to predict the shock load due to hitting of the front chassis stopper on the rear chassis stopper during steering operation in an articulated earth moving equipment. The analytical approach is verified using experiments conducted in the laboratory and field. It is found that a very good correlation exists between the analytical and experimental values of the stopper load. Hence the developed methodology shall be used to predict the shock loads in a similar kind of applications in order to design the structure to overcome failures.

Acknowledgments Authors wish to thank the management of Larsen & Toubro for the use of their articulated earth moving vehicle data and granting permission to publish this article. They also thank their colleagues for their assistance in carrying out the experimental work.

References

1. Martin PH, Tammy RE, Grenier SG (2010) Whole-body vibration experienced by haulage truck operators in surface mining operations: a comparison of various analysis methods utilized in the prediction of health risks. Appl Ergon 41:763–770
2. Milosavljevic S, Bergman F, Rehn B, Carman AB (2010) All-terrain vehicle use in agriculture: exposure to while body vibration and mechanical shock. Appl Ergon 41:530–535
3. Hostens I, Ramon H (2003) Descriptive analysis of combine cabin vibrations and their effect on the human body. J Sound Vib 266:453–464
4. Ericsson A, Slattengren J (2000) A model for predicting digging forces when working in gravel or other granulated material. 15th ADAMS European users conference
5. Sadak P (2000) Test of impact effect on an airplane's LANCAIR landing gear shock absorber. 15th ADAMS European users conference
6. Andersson K, Sellgren U (2005) Reality-driven virtual wheel loader operation. Proceedings of virtual concept, vol 45
7. Rehnberg A (2008) Vehicle dynamic analysis of wheel loaders. Thesis, Royal Institute of Technology (KTH)

A Simple Portable Cable Way for Agricultural Resource Collection

Shankar Krishnapillai and T. N. Sivasubramanian

Abstract A significant problem for Indian farmers today is the difficulty of obtaining labor for farm operations. The most labor intensive operation is the post-harvest resource collection. A simple, economical, compact cable way system has been designed, developed and fabricated to haul sugarcane loads from the field. The cable way is made up of simple collapsible steel 'A' posts, which can be assembled on-site from ready-made frames. The sugarcane loads are slung on trolleys which move on a steel cable passing over the top of the frames, the cable being tightened with a chain pulley block. The trolleys are pulled along by a recirculating rope operated by a winch. The empty trolley is pulled along by the same rope along a cable way running near the bottom of the 'A' post. Several trolleys can move simultaneously along the cable way. With a 2 HP motor the trolley speed was noticed to be about 0.3 m/s and the overall performance of the prototype was satisfactory. The entire setup is fabricated from easy available and low cost components.

Keywords Material handling · Cable way · Rural technology · Socially relevant

S. Krishnapillai (✉)
Department of Mechanical Engineering, IIT Madras, Chennai 600036, India
e-mail: skris@iitm.ac.in

T. N. Sivasubramanian
Pothu Vivasayee Sangam, Thottakurichi, Tamilnadu 639113, India

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_81, © Springer India 2013

1 Introduction

There various problems faced by the Indian farmer in the 21st century, chief among them is a critical shortage of manpower for all sorts of farming activities [1]. The typical Indian farm is small and restricted to a few acres; hence large scale mechanization as in the West is not very feasible [2] and the labor crisis is severe. Lack of insufficient manpower is especially severe in the post-harvest period, when significant manpower is required to transport agricultural produce from the field to the collection point outside. Thus in recent times there are severe labor problems in the collection of agricultural resources which discourages the farming profession in the younger generations [3]. The aim of the cable way is to provide an economical and simple solution to this problem.

Cableway (or ropeway) systems are used for material handling or transportation of passengers. Cableways are particularly useful in rugged terrain and in environmentally sensitive areas. The cableway is possibly the most efficient of all modes of transport. The cableway technology is quite basic and it has many advantages, which are presented by Dwyer [4]. First, it can cover steep, rugged and otherwise inaccessible ground. Being capable of moving goods in a straight line, it can easily reduce road haul distances by a sizeable factor. Another advantage of the cableway is its 'non-intrusive' nature i.e., minimal environmental impact. This is emphasized in the environmental assessment report of ropeway across Guwahati river in Assam State, India by the Pollution Control Board of Assam [5]. The area requirements of cableway are minimum with a small cleared pathway under the posts, which are widely separated. These environmental concerns are highly important in Pugalur where some sugarcane fields are wetlands criss-crossed with canals and cable way is the only method to access the fields with minimum environmental changes. The third advantage of the ropeway is the moderate energy consumption and minimum labor requirements as pointed out by Wuschek [6] in his study of energy saving potential of cableways. Various cableway systems are discussed by Edward et.al. [7] which include mono-cableway and bi-cable way and their many variations. The bi-cable way system is adopted here, where the load moves along on a cable on rollers and is hauled by a moving rope clamped to the load. The current cable way system was implemented with an NGO for the benefit of sugarcane farmers in the Karur District in Tamilnadu State, India.

2 Objective and Challenges

After interactions with the farmers, it was decided that the cableway system and the steel posts must be portable and economical to fabricate and operate. Farmers do not opt for a permanent cable way since such facilities are needed for only about 10–15 days in a year. The main components are (1) steel posts to carry the cableway (2) winch and motor unit and (3) chain pulley block and (4) steel cables and (5) recirculating rope. Several farmers could share the portable cable way. Given the budgetary constraints of the project, it was decided the prototype cableway could be fabricated and tested for 100 m. This distance could be readily extended with more posts. It should be able to continuously haul several head loads of sugarcane (each 25 kg) over this distance at a moderate speed; the speed could be readily increased with a more powerful winch. The components must be cheap and economically purchased and fabricated.

3 Description of the Portable Cable Way

Figure 1 shows the photograph of the portable cable way in operation. It shows a typical cableway post made of easily available tubular steel pipes. The pipes are bent into two trapezium frames, which are hinged at the top and opened at the bottom and held thus with tie rods to form a sturdy ‘A’ shaped post when viewed transverse to the cable way (this assembly is shown in Fig. 2). Also shown is a trolley (with sugarcane load in sling) fitted with two nylon wheels moving along the top cable, and the recirculating rope which pulls it.

More technical details are shown in the next schematic diagram (Fig. 3). There are many ‘A’ posts which are assembled on-site from the portable frames. There

Fig. 1 Photograph of portable cable way

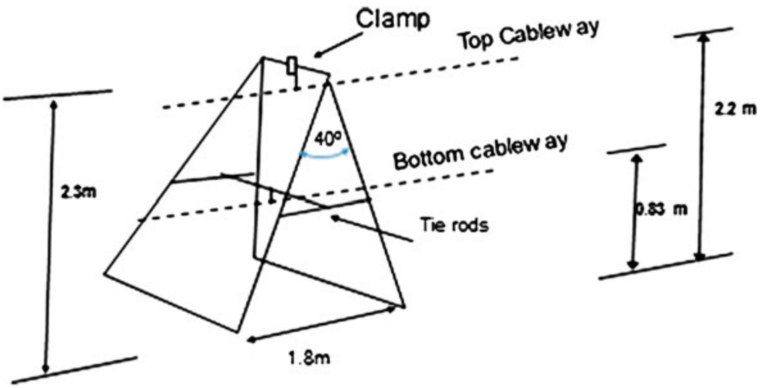


Fig. 2 Assembly of a cable way post

are two end posts which are especially sturdy, and a number of weaker intermediate posts (20 were used in the project). The 'A' post opens at an angle of about 40° (see Fig. 2) and is 2.3 m high with a base of 1.8 m (measured parallel to the cableway) and 1.78 m (transverse to cable way) forming a sturdy structure resistant to compressive and sidewise forces. The frames are held in place with tie rods (shown in Fig. 2). These tie rods also support the bottom cable. Usually there is a spacing of about 5–7 m between two posts.

A 12 mm steel cable passes over the top of the posts. Both ends of this cable are buried 1.5 m in the ground and tightened with a 2 tonne chain pulley block. A recirculating rope provides the motive power to pull the loaded trolleys along the top cable and the unloaded trolleys along the bottom cableway (in opposite directions). This rope is wound round a winch drum driven by a 2 HP motor; the loads moving at a walking speed. The upper cable is tightened using the chain pulley block. A turnbuckle suffices for the lower cable way which carries lighter

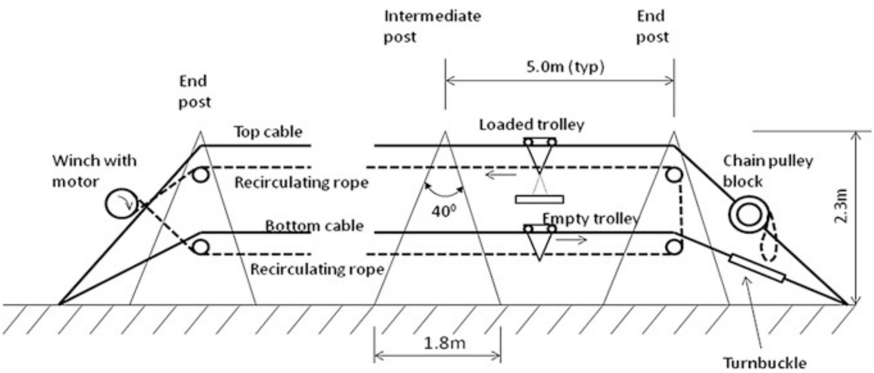


Fig. 3 Schematic diagram of cable way

Fig. 4 Chain pulley block to tighten cable

loads (it is also possible to connect both cables to the chain pulley block, with a slight modification).

The cable tension when calculated for a single concentrated load of 50 kg at mid-span for a permissible sag [8] of 3 % of span (span being 7 m) is 500 kgf. The downward compressive force on the end posts was 500 kgf and in the intermediate posts was considerably smaller. Hence the end posts have large tubular cross sections (38 mm OD, 2 mm thick) and intermediate posts have smaller cross sections(32 and 2 mm). The diameter of the cable was finalized as 12 mm (with about 7 tonne breaking capacity) because it has to be sufficiently broad for the trolley wheels to roll on.

Figure 4 shows a photograph of the chain pulley block, usually used for hoisting loads, now adapted to tightening the cable. It is capable of considerable mechanical advantage in lifting heavy objects. The ‘hook’ end of the device, which is normally connected to the load to be hoisted is now attached to the end of the cable coming from an end post. The other end of the chain is wrapped on a concrete block and buried about 1.5 m under the ground. By pulling the side loop chain, the operator tightens the cable with ease to the desired tension. Thus by using a simple chain pulley block, tightening is accomplished without recourse to more expensive hydraulic and pneumatic devices usually seen in cableways.

Figure 5 shows the photograph of the winch with 2 HP motor with a rated speed of 1,500 rpm. A standard reduction gear box is used to connect the motor to the winch drum. The drum is about 0.34 m in diameter with a corrugated surface for better grip. An 8 mm diameter nylon rope made endless is wrapped around on the drum. This rope (see Fig. 3) pulls both the top and bottom trolleys in opposite directions.

Among the other components of less significance is the trolley in the photograph (Fig. 6) which is made of a triangular steel plate (with about 0.18 m sides).

Fig. 5 Winch to pull the load

Two nylon rollers attached to this plate roll over the 12 mm diameter cable. The trolley can be clamped or unclamped to the recirculating rope. There is a simple sling to put the sugarcane load. Once the loaded trolley reaches the destination, it is unclamped from the recirculating rope. It is lifted off and put on the lower cable way and again clamped to the rope. When the cable way is in operation, up to five loaded trolleys were simultaneously hauled before deterioration of speed and performance took place.

4 Economy and Labor

A brief cost comparison is attempted here between the traditional head-load method and the cable way. The total cost of cableway development and fabrication (including 20 posts and one 2 kVA generator) was Indian Rupees 2,50,000. This device can be shared by many farmers. In the absence of a cable way, 10 headload workers per day are usually engaged in small farms, at a labor cost of Rs 250 per head per day. Ten head-load workers carrying about 25 kg head-load of cane per person, do not exceed 5 t of load transferred per day (it is variable, depending on terrain, weather etc.). The cable way operating at a modest speed of 0.3 m/s, can take a fresh load every 30 s (i.e., the time taken for the previous load to cover the initial span of 5 m). Thus a cable way working 8 h a day can transfer 24 t per day, with only 3 operators required to operate the cable way. However, it may be required to engage four workers for half a day to install the cable way, and also incur a transportation charge of about Rs 500 to carry the posts to the field. Thus it is seen that the cable way transportation rate is about 5 times that of manual transfer, and only 3 workers are required per day as opposed to 10.

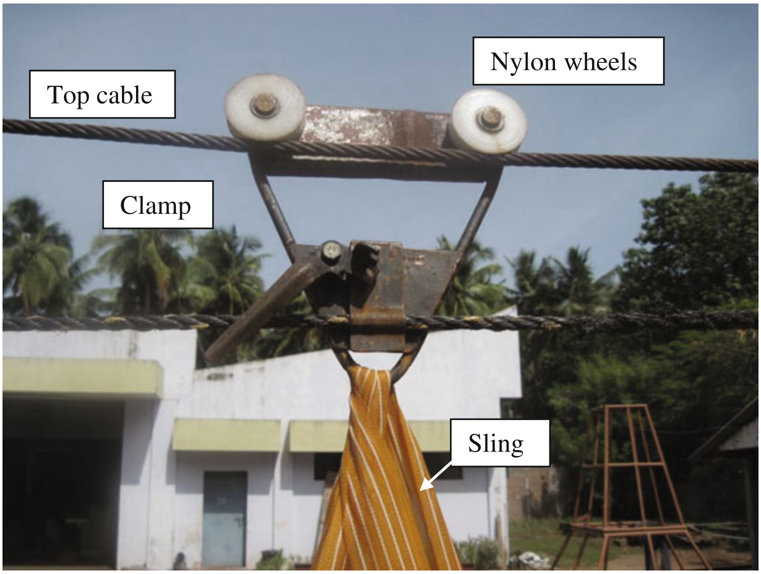


Fig. 6 Photograph of trolley with clamp and sling

It may be noted in the above analysis that the number of workmen and time required for transportation increase with obstacles such as small trenches, furrows, water ways, irregular surface and also the weather, and more workers may be required in such cases. With the portable cable way such obstacles do not matter once the cable way is erected and in continuous operation. In a cable way of the current design only 3 workers are required to continuously operate the cableway irrespective of its length and the effort required of them is less demanding than head-load operations.

5 Conclusions

A simple, economical, compact portable cableway has been developed, fabricated and tested for transportation of sugarcane loads from farm to collection point. The cable is tightened by a chain pulley block. Using the concept of recirculating rope, and by means of upper and lower cable ways contained in the post, there is provision for two way travel of trolleys (loaded and unloaded). Within the budget constraints of the project, the prototype cableway has been tested for a distance of 100 m and works well. There are significant economies in labor charges by using this device.

Acknowledgments The authors thank the IIT Madras Alumni (Class of '81) for funding this project.

References

1. Mahesh R (2004) Labour mobility and paradox of rural unemployment—farm labour shortage: a micro level study. Indian J Labour Econ 47(1):25–37
2. Majumdar A, Karmakar S, Gupta JP (2004) Status of farm mechanization in Bihar, India. J Interacademicia 4(4):21–30
3. Sharma A (2007) The changing agricultural demography of India: evidences from a rural youth perception survey. Int J Rural Manag 3(1):27–41
4. Dwyer CF (1975) Aerial tramways, ski lifts, and tows. Forest Service, U.S. Department of Agriculture
5. Wuschek M (1982) Ropeways-economical and energy-saving. Int Seilbahn Rundschau J 3:118–222
6. State Pollution Control Board (2009) Environmental impact assessment report. Guwahati Ropeway Project, Assam
7. Neumann ES, Bonasso S, Dede ADI (1985) Modern material ropeway capabilities and characteristics. J Transp Eng 111:651–653
8. Brockenbrough RL, Merritt FS (1999) Structural steel designers handbook, 3rd edn. McGraw Hill, New York

Bio Inspired Motion Dynamics: Designing Efficient Mission Adaptive Aero Structures

Tony Thomas

Abstract Birds gave humans the idea of flight. Detailed study of bird flight reveals the complexity of nature's engineering. Birds are highly adaptive in flight. Blending man made technologies with nature's natural engineering designs help in improving efficiency and operational flexibility of flying machines. In-flight alterations corresponding to flight characteristics are crucial for better operational efficiency and flexibility. The paper discusses the research and design methodology used to develop small Nature (Bio) Inspired Mission Adaptive Aero Structure models. Conventional aircraft frame and structures are re-engineered to seamlessly respond to instantaneous flight requirements and adapt suitably. The two primary objectives of this study are to design aircraft structures for

- Time critical mission scenarios (military/counter terrorism/law and order)
- Efficient and comfort flying (civil aviation/commercial aircrafts).

Keywords Aircraft dynamics · Nature engineering · Flexible airframes · Adaptive flying structures · Next generation aircraft]

1 Introduction

The earth has been a living planet for nearly four billion years. During this time nature had to solve many problems of life. Later humans became part of this breath taking diversity. We humans with our large brains set us apart from the natural

T. Thomas (✉)
Mechanical Engineering Division, I.E.I Kochi Centre, Homeo Hospital Road, Near Pullepady ROB, Kochi, Kerala 682 017, India
e-mail: tony-thomas@in.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_82, © Springer India 2013

world to an artificial one by using man made technologies to solve the various problems of life. This alienation has made us successful to a great extent, but at a greater cost to our planet Earth. Now it is high time to start looking at the nature with new eyes. At these starting years of the third millennium, we stand in the brink of a new revolution; a world where technology and nature stay hand in hand. There are answers already in nature, and we need nature and technology to work together to solve problems efficiently.

1.1 Flight in Nature

In nature, the creatures need to move long distances as economically as possible. It is clearly understood that no creature that wastes energy will survive the unforgiving hand of natural selection. It was birds that first gave humans the idea of flying. Dreaming of flight and actually taking to the air are two very different and complex things. Around hundred years ago this dream finally took off. Well now the basics of flight are known to many of us, but birds are actually more complicated. An example; a flapping wing produce forward thrust; in short the birds' wings are both 'engine' and 'wings'.

A simple example—House flies

It might hold the secrets to new spy vehicles or aerial search and rescue equipment. Normally it is considered as a germ carrying nuisance, but it is really a marvelous flying machine. It is extremely complex and difficult to engineer and recreate one. Understanding the insect flight in high detail will help us in building smaller and smarter flying machines.

Understanding the basic principles behind nature's designs is the key to successful 'Bio-Inspired' thinking. Natural systems rarely break down. This is because nature goes in for a lot of redundancy i.e. there is always a backup system.

2 Mission Adaptive Aero Structures

Mission Adaptive Aero Structures (MAAS) refer to technologies introduced to the aircraft frame and structure enabling them to change or adapt themselves (or with manual assistance) to instantaneous flight conditions or operational requirements. In short these are flying machines that can morph seamlessly in-flight.

2.1 MAAS: The Civil Aviation Perspective

Albatross, a bird with the largest wingspan on earth and possess very high thermal efficiency; can remain airborne for months at a time. It is one of the most perfect flying machine ever created. When coming to aircraft flight, there is something that pilots and aviators refer as ‘the real joy of flying’. It is not easy to recreate this ‘flying like a bird’ experience in aircrafts. MAAS technology in commercial aviation perspective focuses on ‘designing an artificial albatross’, a humble approach to be part of a new era in civil aviation with next generation aircrafts capable of in-flight morphing for comfort and efficient air travel.

2.2 MAAS: The Military Perspective

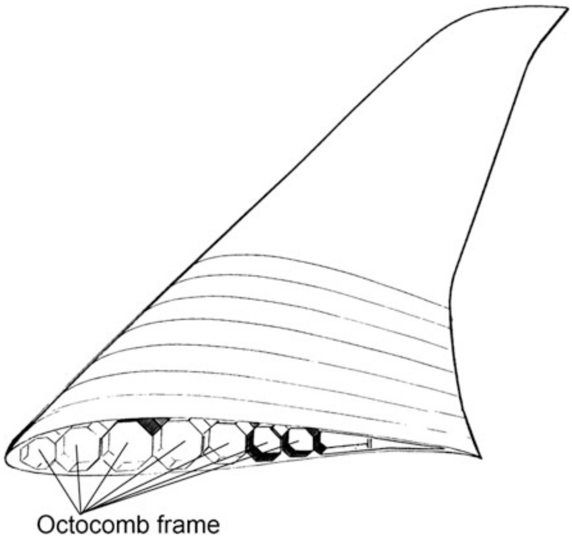
In a multi threat global environment, there is an unprecedented need for operational flexibility and responsiveness. In future battle fields wide variety of aerial vehicles deployed in various combinations are required. But huge costs involved hinder such diversity. The solution is a single aircraft capable of morphing instantaneously to multiple operational requirements.

3 The MAAS Technology

Conventional aircraft wing frames and structures are re-engineered to obtain flexible but strong sections that can undergo profile changes in-flight. These profile alterations change the aerodynamic properties of the whole aircraft depending on the situational/mission requirements. Since these shape changes are on a large scale (depending on aircraft size), developing and controlling them are complex tasks. Numerous modifications and the use of many advanced materials are required to develop it. Carbon fiber wing skin, network of integrated sensors, flexible strong airframe and micro actuators are some of the essential technologies required. The network of sensors detects the force, loading, temperatures and other parameters at different regions/sections on the wings and structural frame. This data is combined with the flight path and profile requirements, so that alterations can be made to the wing structure to change the aircraft’s aerodynamic property instantaneously in flight. The most important design concern is to imply and maintain large seamless shape change on the aircraft’s wing.

The basic design of MAAS consists of an internal lightweight Aluminum-Carbon composite octagonal frame (Octocomb) structure with three dimensional flexibility. This enables smooth alterations in wing structure and geometry. The wing is covered with thin and high strength carbon composite interweaved skin. The wing consists of multiple sections with individual motion and flexibility. The longitudinal and lateral deformations induced in the Octocomb frame change the camber and chord of the wing’s aero foil. The wing profile can be altered by contracting or expanding the wing sections. The wing skin is designed according to the sectional arrangement corresponding to that of the frame. An additional layer of elastic support is provided between the sectional joint regions under the

Fig. 1 Wing cross-section in default configuration



skin in order to impart more flexibility and strength. This avoids failure as these regions experience more mechanical load during shape change. The wings are designed to be lighter and smoother in-order to maintain a laminar airflow over a large portion of the wing. This is an important feature, as it can reduce drag that in-turn reduces fuel consumption. The wing has to be rigid as well as flexible (Figs. 1, 2).

3.1 The Design Features

The important aspects taken into account while designing are

- Silent and eco-friendly flying.
- Lightweight structure.
- Integrated airframe and wings.
- Less pollutive propulsion systems.

The propulsion systems, structure and airframe integration of the aircraft is an important area that requires fine tuning. The integration of body and wings into a "single" flying wing profile, otherwise called the Blended Wing Body possess many advantages. Both the body and wings provide lift, allowing a slower approach and takeoff, which would reduce noise as well as improves fuel efficiency. The flaps, or hinged rear sections on each wing (as seen on conventional designs) can be eliminated. These components are a major source of airframe noise when an aircraft takes off and lands. Engines can be embedded in the aircraft fuselage with air intakes on the upper side of the plane rather than underneath,

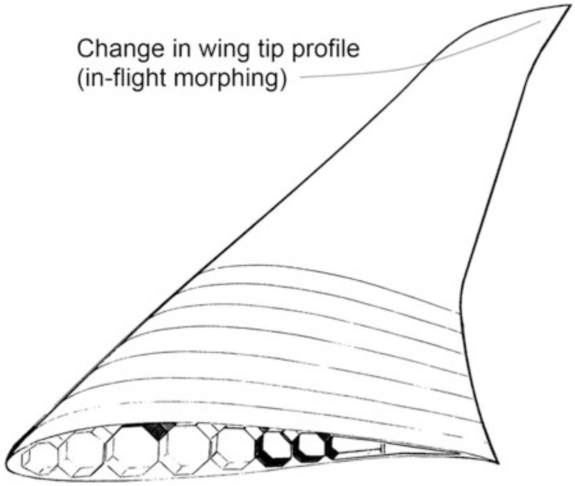


Fig. 2 Wing tip morphing (*seamless shape* change of the wing)

which screens much of the noise from the ground. This design is different from conventional ones. The engine air intakes are designed to provide a smooth airflow. Bringing together such modifications from conventional designs along with the incorporation of mission adaptive structures can produce an aircraft with numerous advantages.

4 Model 04Ax and 05Ax

The Models 04Ax and 05Ax are basically conceptual designs developed to analyze some unique aircraft features. Two palm sized models are currently used in the study. The swift and eagle are the two birds that were closely studied to develop the 04Ax and 05Ax models.

In case of eagles, when they are high in the sky they soar and their wings are fully extended. They glide to increase lift and reduce drag. This helps them to glide effortlessly and navigate for long durations in their search for a prey. To catch a prey, they fold their wings (fast attack profile) and dive in.

Swift, a bird whose wing-morphing ability makes it an exceptionally versatile flyer and allows it to eat, sleeps and mates in air. It spends almost its entire life in the air. During flight, it continually changes the shape of its wings. When they fly slowly and straight on, their extended wings carry them 1.5 times farther and keep them airborne twice as long. To fly fast, it sweeps back its wings to gain a similar advantage (Figs. 3, 4).

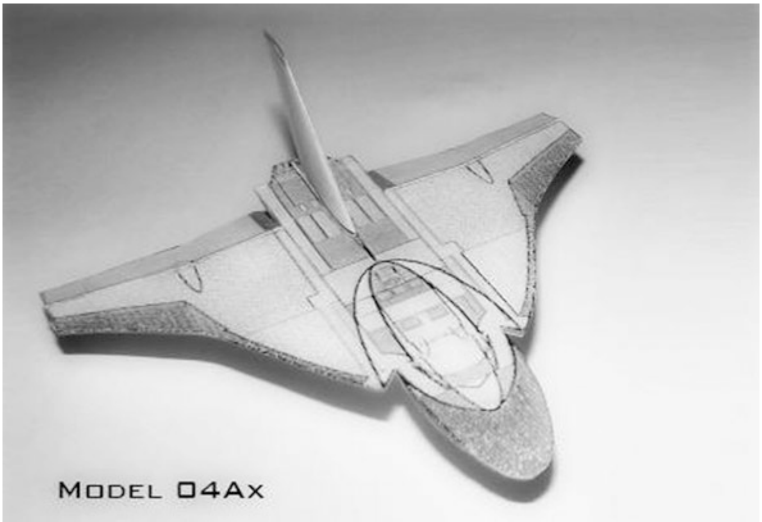


Fig. 3 Model 04Ax

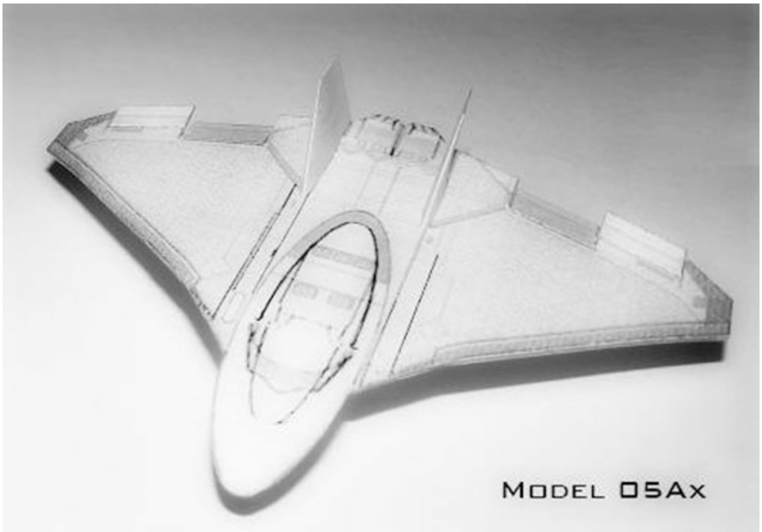


Fig. 4 Model 05Ax

5 Intelligent Micro Air Vehicles

Intelligent Micro Air Vehicles (IMAVs) refer to micro aerobots that are extremely light, palmtop flyers powered by small power cells. Their small size is apt for spying, flying through windows, finding and tracking insurgents, search and reconnaissance inside buildings, confined spaces and disaster struck areas.

For example, consider a typical mission profile; A human controller launching an IMAV from his palm on a mission to fly around a building, take images and transmit them live back to a small control console with him. The craft can be guided to enter the building through a window or hover outside undetected. Real time information can be transmitted from the IMAV to the controller and decisions can be taken without delay.

The IMAVs with MAAS can be highly adaptable and flexible as mission changes. A single aircraft can perform different missions. Conventional aircrafts can be optimized for a maximum of perhaps two flight characteristics like high-speed flight, maneuverability, or for range. The requirement of a whole fleet of different types of planes can be eliminated once such micro aerial vehicles (MAV) are in operation.

6 Conclusion

Mission Adaptive Aero Structures can provide high levels of in-flight adaptability combined with multi-operational flexibility and responsiveness unmatched with any other conventional aircraft designs. The models 04Ax and 05Ax are conceptual designs developed to analyze and study various flight-structural dynamics related to MAAS on a small scale.

The advantages of MAAS technology are:

- Development of reduced cost multipurpose & multi-mission aircraft.
- Higher levels of adaptability, operational flexibility and responsiveness than conventional designs.
- Silent, Eco-friendly and Energy efficient design.
- Reduce defence costs and aircrew losses in combat.
- Development of automated, stealth platform for Intelligence Surveillance and Reconnaissance (ISR) missions as well as combat (especially time critical targets) missions.

Acknowledgments I wish to thank Er. V. Vijayachandran and Dr. P.M Radhakrishnan for sharing their views and suggestions on various aspects of this project.

References

1. Skillen MD, Crossley WA (2007) Modeling and optimization for morphing wing concept generation, NASA/CR-2007-214860, Purdue University, Indiana
2. Weisshaar TA (2006) Morphing aircraft technology: new shapes for aircraft design, RTO-MP-AVT-141 (http://www.rto.nato.int/abstracts.asp), Aeronautics and astronautics department, Purdue University
3. Biologically inspired technologies in NASA's morphing project keynote address on 'smart structures and materials'; vol 5061, 2003
4. Gonzalez L (2005) Morphing wing using shape memory alloy: a concept proposal, University of Puerto Rico, Mayaguez
5. Majji M, Rediniotis OK, Junkins JL (2007) Design of a morphing wing: modeling and experiments, Texas A&M University, College Station, TX, 77843-3141
6. Bliss TK, Bart-Smith H (2005) Morphing structures technology and its application to flight control, Department of mechanical and aerospace engineering, University of Virginia
7. Iannucci L, Fontanazza A (2008) Design of morphing wing structures. In: 3rd SEAS DTC technical conference, Imperial College, Edinburgh
8. Smith K, Butt J, von Spakovsky MR (2007) A study of the benefits of using morphing wing technology in fighter aircraft systems. In: 39th AIAA thermophysics conference (AIAA 2007-4616)
9. Center for energy systems research, department of mechanical engineering, Virginia Polytechnic Institute and State University, Blacksburg, 24061, David Moorhouse, US AFRL, Wright-Patterson AFB, OH 45433

External Barriers to User-Centred Development of Bespoke Medical Devices in the UK

Ariana Mihoc and Andrew Walters

Abstract It is widely accepted that user-centred approaches to the development process produces better products and therefore brings commercial rewards. Despite such acceptance, the majority of manufacturers of medical devices fail to adopt such development principles. This paper will examine cases of manufacturers of bespoke medical devices, where one might perceive that the engagement with the end-user throughout the development process is critical to product quality. In a previous study undertaken by the author, interviews with manufacturers of bespoke medical devices indicated a perception that three external stakeholders to present barriers to the application of a user-centred design approach. This paper reports on a follow up study to understand the practice and agendas of the three external stakeholders, in order to draw a comparison with the manufacturers' views. The findings revealed mismatch between the product development process that manufacturers of medical devices are encouraged to apply and the practicalities of complying with the needs of the identified stakeholders.

Keywords User-centred design · Medical device · Product development process

A. Mihoc (✉) · A. Walters
The National Centre for Product Design and Development Research,
Cardiff Metropolitan University, Western Avenue, Cardiff CF5 2YB, UK
e-mail: armihoc@cardiffmet.ac.uk

A. Walters
e-mail: atwalters@cardiffmet.ac.uk

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_83,

1 Background

The challenge of making better products has pushed the design process from a linear approach, to an iterative one, placing the end-user at its heart [1]. User-centred design processes have proved to increase the usability and accessibility of products [1–4]. These characteristics are especially important in the case of medical devices, where products' misuse can have devastating effects [1, 5, 6]. Despite the support from research, legislation and standards, manufacturers of medical devices have proved to be reluctant to engage end-users in their product development process or to follow specific usability tests [6–9]. The causes for this have been identified as: the perceived high cost and delays from adopting a user-centred design approach, the lack of tools and awareness for such approaches and, many manufacturers perceiving a little value in engaging with end-users [6, 9].

This paper examines the case of manufacturers of bespoke medical devices e.g. artificial limbs, facial prosthetics etc., where the engagement with the end-user throughout the development process is believed to be critical to product quality. In this study, bespoke medical devices have been defined as medical products that are based upon the specific geometrical measurements of individual end-users.

In a previous study undertaken by the author, interviews with manufacturers of bespoke medical devices indicated three external stakeholders that were perceived to be barriers to the application of a user centred approach [10]. The identified stakeholders where:

- Research Ethics Committees (REC): through the long and complex mechanism of obtaining approval to access the patients;
- National Healthcare Services (NHS): through their predominantly cost based purchasing decisions that exclude the views' of the products' end-users;
- Standard Agencies, namely the British Standard Institution (BSI): through the lack of harmony amongst the standards of quality across international regions and, the lack of specialised standards for this type of medical device.

2 Aim

This paper reports on a follow-up study to understand the practice and agendas of the three external stakeholders in order to draw a comparison with the manufacturers' views [10]. This will help clarify the external barriers that the manufacturers face in the development of bespoke medical devices, the environment in which they operate and, how the climate can be improved.

3 Method

The research method chosen for this study has been developed with consideration to the complexity and roles of the three external stakeholders. For this reason, there have been employed two different methods for running the study: a literature review followed by a qualitative study. Due to the nature of the stakeholders running a quantitative study would have been difficult. The study started with reading and analysing literature regarding the three stakeholders. This offered insights into how REC, NHS procurement department and BSI are organized, how they function, what are their roles and, who is governing them. Studying the literature had some limitations; it offered only general information about the stakeholders and their practice in theory. The literature did not provide answers regarding their interaction with manufacturers of medical devices, and, it did not always make clear how development happens in practice. Thus, a plan was developed to contact these stakeholders directly, to arrange face-to-face interviews. Survey research was restricted due to the exploratory nature of the questioning. Additionally, as the aim is to develop depth of understanding, a focussed engagement with a small sample group was deemed more appropriate. Because all three bodies have been appointed by the government and, act according to a precise code of practice and regulations, it was sensible to interview only one key stakeholder from each body and to exclude the use of quantitative research. Semi-structured interviews have been undertaken with key people from each stakeholder. The transcribed interviews were analysed and provided valuable insights into how these bodies function, what is their role and what regulations apply to them. The findings have been compared with the manufacturers' views as revealed in the previous qualitative study [10]. Figure 1 illustrates the method used in the previous study and this one.

Each interview was tailored for the particular stakeholder and the participants' selection was undertaken with consideration for whom the manufactures of bespoke medical devices are most likely to interact.

The interviewee from the REC was the chair of a committee that is flagged for medical devices applications (including bespoke medical devices). The interview covered subjects regarding the application process, guidance in making the application, timeline in obtaining the approval, reasons for refusing an application, considerations in limiting the access to end-users.

In the case of NHS, accessing people from procurement department has proved to be difficult. Despite repeated attempts to contact key stakeholders with purchasing decision powers from NHS, over the 3 months allocated for this study, nobody has accepted to take part in an interview. In order to overcome limitations that these refusals have imposed, a semi-structured interview was carried out with the director of NHS product testing laboratory, a key player in the procurement process within NHS Wales. The interviewee is employed by NHS to run tests on mass consumption products that will be bought by NHS Wales. His role is to inform the procurement department prior to purchasing decision meetings on the

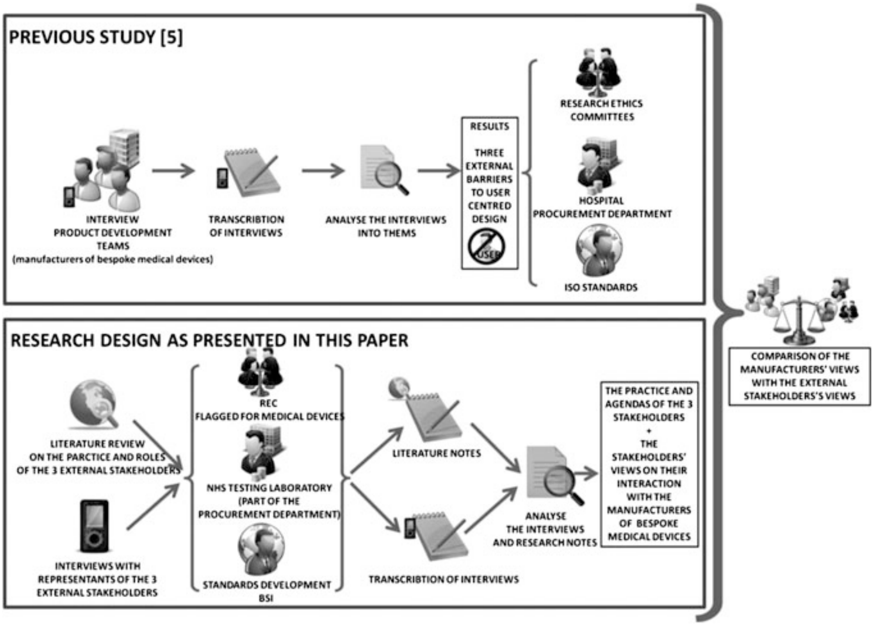


Fig. 1 Research method used in the two studies

results of the tests. The organisation independently tests and reviews the quality of products. Although the interviewee had no purchasing decisions in NHS, through his involvement in the procurement department he was able to offer direct insights on the activities and practice of the department. The interview revealed the impact that cost has on the purchasing decisions and the differences in procurement practice between NHS Wales and England.

BSI is the national standards body. They are appointed to develop new standards and publish European standards in the UK. As the manufacturers indicated that a lack of standards harmony and a lack of detailed guidance for the development of bespoke medical devices is a particular barrier, it was relevant to interview a key stakeholder from BSI. The interviewee was working in the BSI's department that develops standards. This interview covered the role and practice of BSI, the method of developing standards, harmonisation of standards and, issues regarding standards for medical devices.

This study presents some limitations. Although in the first study the interviewed manufacturers were both British and international companies that provide bespoke medical devices in the UK, the second study has been limited to the UK stakeholders. This is partly because the study is concentrating on the UK context and also because of the limited time for delivering this study (3 months). However the interviewed manufacturers are developing products outside UK and are dealing with the equivalent of other's countries health services, standards and regulations bodies and research ethics committees that might behave similar to the British ones.

4 Results

The results indicate mismatch between the product development process that manufacturers of bespoke medical devices are encouraged to apply [11, 12] and the practicalities of complying with the identified stakeholders.

The user-centred design process proposed by the literature derived from ISO 13407 on Human Centred Design Process (Fig. 2) is composed of 4 iterative steps [11, 12]:

- Analyse: the product development team identifies who are the end users of the product, how, when, where and for what will they be using the product. This stage is characterised by direct observation of the end user with the aim of correct identification of their needs.
- Design: the identified needs of the end users are translated into requirements for the new product. The development team generates concepts for the product based on the resultant requirements.
- Implement: the generated concepts from the previous stage are implemented in prototypes.
- Validate: the prototypes are tested with the end users. If the requirements have been met, the prototype is validated and can go onto the launching stage. If not all the requirements are satisfied, the prototype is refined until validation. The refinement of the prototype is done via the iteration of the whole process.

The interviews with the manufacturers indicated a perception that the three external stakeholders created barriers to the adoption of a user-centred-design process [10]. As a consequence the development process adopted by the manufacturers is markedly different from Fig. 2, the one proposed in the literature.

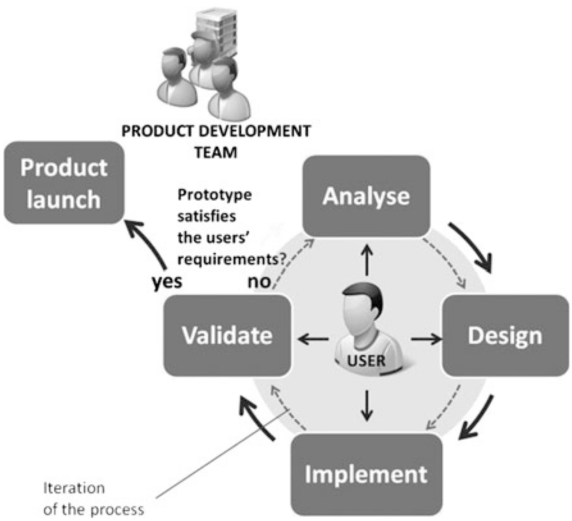


Fig. 2 The user-centred design process proposed by the literature. *Source* [11, 12]

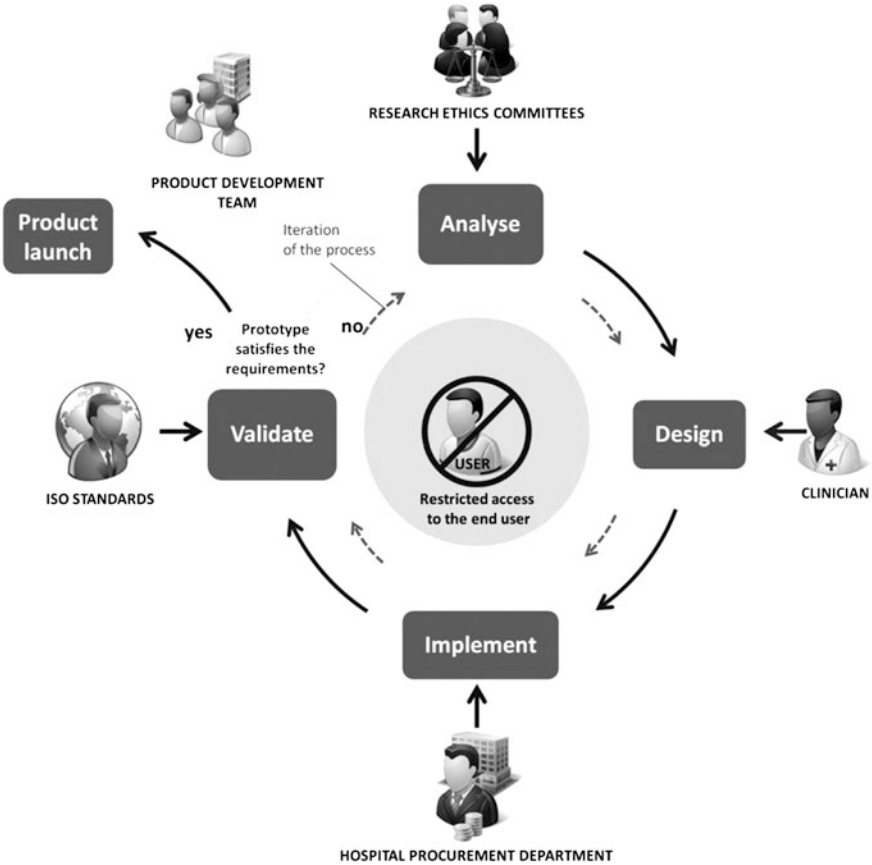


Fig. 3 User-centred design in the context of bespoke medical devices. *Source* [10]

Figure 3 illustrates the influence of the three external stakeholders at every stage of the development process.

The long and complicated application process for research ethics encourages manufacturers to find other sources of obtaining data with regards to the end-user. Most of the manufacturers will turn towards the clinicians who are perceived to have expert user knowledge and might also play a key role in the purchasing decisions made by hospitals. As a result the design of products is often done according to a clinician's requirements [10]. During the implementation stage, the use of prototypes and the material choice will depend on the budget imposed by the client which in most cases is represented by hospitals. The purchasing department within hospitals are perceived to base most of their decisions on cost and as a result force manufacturers to create low cost products [10]. Additionally, manufacturers perceive that currently there are insufficient standards of quality that would offer clear guidance with regards to the development and validation of these devices [10].

This study compares the manufacturers' views [10], with the views of the three external stakeholders. Interviewing and analysing the practice of these stakeholders has validated many of the manufacturers' statements, and revealed further issues that could raise concerns in the development of bespoke medical devices. Table 1 draws parallels between some of the manufacturers' statements [10] and the statements of the external stakeholders interviewed in this second study.

4.1 Research Ethics Committee Study

Interviewing members of the REC, flagged for medical devices applications has indicated the following issues.

The application process that manufacturers have to go through is still long—at least 2 months, and it necessitate a long and detailed preparation prior to the submission of the application.

Although the website of the REC offers detailed guidance, most applicants still need the help of an advisor in order to complete an application.

Interviewed members of the committee have admitted that although the website has been updated, it still needs improvements so that it is easier for people to prepare applications.

The manufacturers must predict all the tests and changes that they will require for each prototype at the time of the application. Any change not considered in the application, necessitates a new application. This final point is where the development process adopted by manufacturers clashes with the research review mechanism. It is difficult, and in some cases impossible, to predict the results of prototype tests and the modifications that the design team will need to make. Further, depending on the solution that is adopted, new tests might need to be defined in order to refine and validate the prototype. The potential requirement to go through the application for research review every time an unforeseen modification arises, discourages manufacturers from applying due to the imposed delays, thereby actively discouraging user engagement.

4.2 NHS Procurement Department Study

Stakeholders from the procurement department within NHS have been interviewed. The NHS England makes much of their purchasing decisions on a commercial basis that is due to the cost conscious economy. As a result the price set by manufacturers represents a major criterion in the purchasing decision. In Wales, NHS has a testing laboratory for the basic products that hospitals buy. When a contract needs renewing, the laboratory will test the products offered by participating manufacturers. The laboratory submits the products to tests according to both the standards and the requirements expressed by the users. However, this

Table 1 Comparison of statements from the two studies

Manufacturers' statements	Stakeholder statement	Insights
"Ethical approval is very hard. It takes us 5–6 months to get it. This is affecting us very much because for instance when we wanted to do tests in the summer because of the hot days, we ended up having to do them in the winter so the results were futile for some of them. This was a sweat management test"(Design Director at a UK Prosthetic Company)	"In the application process the most difficult part to complete is the IRES form definitely… The guidance [for completing the application] is on the website, is not always easy to use but the information is there and the coordinators will always help"	-The research ethics approval application process is difficult -From the manufacturers perspective it can cause great delays
"The vast majority of the NHS procurement teams base all their orders, their procurement pretty much on cost. Most of them have a scoring system. You have to submit your cost for products and then that makes 70 % of your overall score for the contract… We are planning to apply for a new contract with the NHS. We are looking now to see where we can cut more the cost of our products. This might mean using a lower quality material for our devices" (Clinician at an International Bespoke Medical Devices Company)	"Our funding from the Welsh Government is to test medical devices on behalf of the Welsh NHS and to provide technical advice on medical device related issues" "Because the NHS is trying to get value for money all the time, is driving prices down. The way some manufacturers and suppliers can get prices down is by sourcing pour quality" (Director of NHS Wales, product testing laboratory)	-NHS procurement method constraints manufacturers on reducing the cost of products. - The cost reduction has a high impact on the product's quality
"Standards are needed because they are there to reduce risks" "The problems arise where the people that wrote the regulation or the requirement are not directly involved with the end-users. They are either politicians or administrators, or they write the things generally, for a different purpose". (Project Manager at a U.K. company)	"If you are thinking of a medical device, the directive pretty much sais it's got to be safe. (…)there will be a standard that supports it, how can you manufacture a product in accordance to that directive. But actually within each country it will be up to the government to determine how that directive comes about". (BSI representative)	-Manufacturers need standards that specially developed for bespoke medical devices -The development of standards depends on government's agenda

laboratory does not have the capability to test complex products. The laboratory will also ensure the maintenance of quality of the stock delivered by manufacturers throughout the duration of the contract. The purchasing department within the NHS Wales makes much of their purchasing decisions based on the recommendations of this laboratory in order to ensure good quality products. But the final decision is still being done on a value for money basis.

In the UK, an independent organisation exists that has the capability to test all medical devices. However they can only issue reports with regards to the quality of the products tested. It is then up to individual hospitals if they wish to refer to these reports when they make purchasing decisions. Further, this body has the power to issue warnings if one of the products fails the quality standards.

The model adopted in Wales helps the manufacturers to improve their products, and, it encourages them to include the end-users in their design process. The model followed by England and Scotland imposes greater cost constraints on the manufacturers and as a result reducing cost becomes a priority in the design process. Furthermore, not including the views of the end-users of the product will turn manufacturers towards satisfying the requirements of the purchasing body and not the real user.

4.3 BSI Study

The interview of the representative from the BSI has revealed the following:

The British Standards are generic guidelines for manufacturers to follow in order to improve the quality of the products.

The standards of quality in the area of medical devices are based on the Medical Device Directive adopted by the European Union. Every country has translated this directive into standards of quality or regulations. Although the aim is to achieve harmonisation between standards at an international level, this is not yet the case. Thus, manufacturers of medical devices are forced to decide on the standard of quality to follow depending on the countries in which the product will be commercialized.

The lack of detail and specifications for the particular case of bespoke medical devices makes it even more difficult for manufacturers to follow specific and relevant standards.

5 Conclusion

The results of the interviews and analysis of the three stakeholders confirm the barriers to user-centred design indicated by the manufacturers of bespoke medical devices. This study reveals how external stakeholders influence the development process of bespoke medical devices. This provides an important contribution to the field of design. It makes apparent where the functioning of these bodies is at odds with the design and development process. Thus the study is the first step towards the development of solutions to overcome theses barriers.

It is evident that REC, NHS procurement department and BSI have become barriers to a user-centred design due to their practices. A better climate for the application of a user-centred design might be created if each of these stakeholders reviewed their methods. Listed below are the proposals and future research themes to begin to overcome the barriers.

REC has been criticised by the interviewed manufacturers for the rigidity, complexity and timeline of the application process. Adjusting their application process to the current commercial environment is a critical step in not only maintaining the ethics of the research but also encouraging research overall.

NHS has been criticised during the first study for its money driven approach. Concentrating on people can be much more cost effective than providing them with the bare minimum. A user-centred design approach would determine that purchasing bespoke medical devices should be done with the end user in mind.

BSI has been criticised in the first study for the lack of harmony in standards at international level and lack of guidance for the case of bespoke medical devices. The harmonisation of standards is a problem that needs to be reviewed at international level. As the main provider of guidance in product development, BSI plays an important role in assuring a high quality of bespoke medical devices. The lack of standards for such devices needs to be filled with specific guidance that has been developed through thorough research and tests in collaboration with the industry. However, it must be recognised that REC, NHS and BSI have developed their practices to safeguard risk and exploitation of users. Although it may seem ironic that their current practice is not serving users of bespoke medical devices well, creating new suitable and robust procedures is surely to be a significant challenge.

The study raises awareness over barriers that commercial organisations face, that might not otherwise be considered in the academic environment. Therefore, the research provides a practical resource for the translation of design theory to practice.

6 Future Study

The first two studies offered insights from a macro level in the development of bespoke medical devices. The research will continue to identify barriers to a user-centred design process at a micro level, through analysing the manufacturing companies that are producing such products in more depth. Further analyses of needs and attitudes of end-users towards their inclusion in the development process will also be undertaken. This will present a fuller picture of the issues that developers of bespoke medical devices have in engaging the end-user within their processes. The overall aim will be the generation of a user-centred design approach for the development of bespoke medical devices that will be applicable in the commercial environment, together with recommendations, tools and techniques for its application.

References

1. Thimbleby H (2008) Ignorance of interaction programming is killing people. Interact, Sept/Oct 2008, 15:52–57
2. National Patient Safety Agency (2010) Design for patient safety: user testing in the development of medical devices. NPSA and MATCH, Mar 2010
3. Nordic Innovation Centre (2011) New methods for user driven innovation in the health care sector. Available at http://www.nordicinnovation.net/prosjekt.cfm?Id=3-4415-244. Accessed 25 May 2011
4. Ulrich KT, Eppinger SD (1999) Product design and development, 3rd edn. McGraw-Hill, London International Edition, pp 53–68, 187–207
5. Kyberd P, Wartenberg C, Sandsjö L, Jönsson S, Gow D, Frid J, Almström C, Sperling L (2007) Survey of upper-extremity prosthesis users in Sweden and the United Kingdom. J Prosthetics Orthot 19(2):55–62
6. Winters JM, Story MF (2006) Medical instrumentation: accessibility and usability considerations, CRC Press, New York (31 Oct 2006)
7. Council Directive (1993) 93/42/EEC of 14 June 1993 concerning medical devices. Official J Eur Communities, L169
8. Lemke MR, Winters JM (2008) Removing barriers to medical devices for users with impairments. Ergon Des: Q Human Factors Appl 6(3):18–25 (20 June 2008)
9. Money AG, Barnett J, Kuljis J, Craven MP, Martin JL, Young T (2011) The role of the user within the medical device design and development process: medical device manufacturers' perspective. (BioMedCentral), BMC Med Inform Decis Making 11:15
10. Mihoc A, Walters A, Eggbeer D, Gill S (2012) Barriers to user-centred design in the development of bespoke medical devices: a manufacturers' view.In 13th national conference on rapid design, prototyping and manufacturing, Lancaster, 22 June 2012
11. Medical Safety Design (2011) User-oriented interface design for medical products. Available at http://www.medical-safety-design.de/en/medical-safety-design/user-centered-interface-design/. Accessed 12/03/2011
12. Usability Professionals' Association (2011) What is user-centred design? Available at http://www.upassoc.org/usability_resources/about_usability/what_is_ucd.html. Accessed 20/09/2011

Autonomous Movement of Kinetic Cladding Components in Building Facades

Yasha Jacob Grobman and Tatyana Pankratov Yekutiel

Abstract Movement of building façade cladding is used to control buildings' exposure to environmental conditions such as direct sunlight, noise and wind. Until recently, technology and cost constraints allowed for limited instances of movement of facade cladding. One of the main restrictions had to do with the limitations that architects face in designing and controlling movement scenarios in which each façade or cladding element moves autonomously. The introduction of parametric design tools for architectural design, combined with advent of inexpensive sensor/actuator microcontrollers, made it possible to explore ways to overcome this limitation. The paper presents an ongoing research that examines the potential of autonomous movement of façade cladding elements. It defines types of autonomous movement strategies and compares the advantages of these strategies over those of traditional methods of centrally controlled movement. Finally, it presents and discusses several case studies systems in which autonomous movement for building cladding elements is implemented.

Keywords Kinetic cladding components · Responsiveness · Interactive · Decentralized control · Arduino

Y. J. Grobman (✉) · T. P. Yekutiel
Architecture and Town Planning, Technion Isreali Institute of Technology, Haifa, Israel
e-mail: yasha@technion.ac.il

T. P. Yekutiel
e-mail: tanyapankratov@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_84,

1 Introduction

The notion of kinetic architecture can be traced back as far as the Roman Empire with legendary tales describing revolving rooms in Emperor Nero's palace [1]. Although the modern fascination with motion is associated with movements like Futurism in the early 20th century [2], research on kinetic architecture dates back to the 1960s [3]. From its earliest days, the research in this field encompassed a wide range of directions in various scales: plug-in cities by Archigram on an urban scale; the moving roof elements in Santiago Calatrava's Milwaukee Art Museum on a building scale; moving or folding walls in the Rietveld Schroder house or the moving office space in the OMA Bordeaux house on an interior design scale; moving structures as the Strandbeest by Theo Jansen or the Crate House by Alan Wexler on a furniture scale [4].

Starting from the early 1990s, when the immense implications of the information technology (IT) revolution in architectural design became evident, new types of computer-controlled movements in architectural design have emerged (mainly physical but also virtual). These new types were based on ideas such as interactive design and responsive environments [5–7].

One of the building industry's leading trends in both research and actual implementation is kinetic building facades, or more precisely, kinetic building cladding systems [8]. Indeed, the increasing focus on green architecture and especially on the environmental behavior of buildings has greatly increased the interest in high-performance facades. Until recently, technology and cost constraints allowed for only limited centrally controlled scenarios for movement of building facades or facade cladding. Centralized control over the facade elements limits the amount and type of movements they can perform to simple operations that are usually executed simultaneously by all the elements. The introduction of parametric design tools for architectural design, combined with advent of inexpensive sensor/actuator microcontrollers, makes it possible to examine different and more complex types of control over the building facade elements.

The following paper presents an ongoing research study that examines the potential of employing decentralized control of building facade kinetic elements. It begins with a brief discussion of the function of building facades and the types of kinetic movement of facade elements. It then looks at possible scenarios in which decentralized control could be employed. Finally, it presents and discusses two different case studies that examine a framework for decentralized control of cladding elements.

2 Controlled Elements/Mechanisms in Building Facades

Building facades have numerous distinct functions. Hutcheon [9] organized these functions into two groups with a total of 11 functional requirements. The first group consists of the items that relate to the facade as a barrier for the control of heat flow; air flow; water vapor flow; rain penetration; light, solar and other radiation; noise; and fire. The second group consists of overall requirements, such as providing strength and rigidity; being durable; being ecstatically pleasing; and being economical. Another aspect, which was not mentioned by Hutcheon and has become increasingly important, is visibility or visual exposure (both from inside outward and from outside inward) [10].

Introduction of kinetic elements influencing the facades performance may be done into main aspects; the first will influence the parameters of the openings of the facade itself. The second will influence the geometry of the facades or of an external cladding layer that is part of the facade. This research concentrates on the second group.

Numerous kinetic facade cladding systems have been developed in each of these aspects over the last 15 years. Loonen [11] presents in his thesis an overview of 100 different systems that control the performance of parameters from both groups. The control systems that actuate those kinetic façade mechanisms or systems can be differentiated into three main types, which also correspond to the evolution of these systems. The first type consists of elements that are actuated directly by a manual switch. In the second type, sensors are introduced. The information from the sensors is used to actuate the kinetic cladding elements. This type, which makes up the majority of present-day kinetic façade cladding systems, relies on centralized control, in which actuation is controlled through a central unit (computer).

The third type, which is the focus of this research, introduces the idea of decentralized control. The idea is based on the use of newly developed tools in parametric design, combined with sensor/actuator microcontrollers such as Arduino (an open-source single-board microcontroller, able to process signals passed by sensors to the microcontroller and translated through code into physical actions such as lighting or activating engines [12]). It refers to autonomous and direct actuation of kinetic facade elements by sensor/actuation units.

The following diagram describes the evolution of the types of control and the differences between them (Fig. 1).

3 Implications of Decentralized Control Over Building Elements

The idea of a centralized control over kinetic facade elements is easy to understand: It is meant to provide a single solution to a change in the basic conditions. For example, it is clear that once an environmental condition such as sunlight has changed, the control device must change the position of the cladding elements so that more or less light can penetrate the building.

Decentralized control is more complex. By definition, it's meant to handle multiple conditions and generate various responses. It is based on local, cheap and

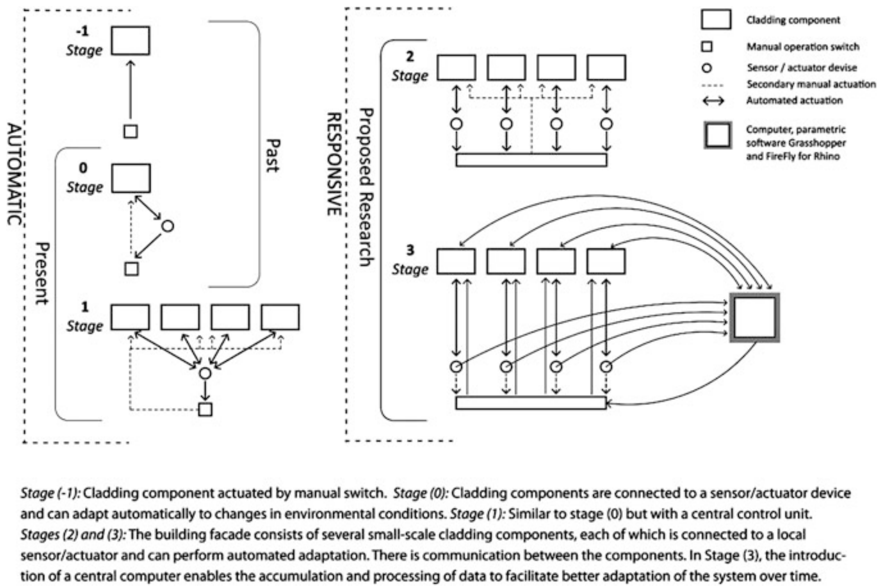


Fig. 1 Evolution of types of control over kinetic facade cladding elements

less powerful [than a central control computer (PC)] computers or microprocessors, which are connected to the kinetic elements.

The following advantages were identified to decentralized control in relation to traditional centralized control:

1. Efficiently—the possibility of insulated response to local environmental conditions emerging in a particular part of the façade. As opposed to traditional method where the adaptation can only be carried out by the whole facade
2. Redundancy—in multi connection system each component can substitute for its neighbor
3. Low cost—each component is relatively cheap and does not require high cost central operation system
4. Calculation time—the microprocessor located in each component will perform only the basic calculations and thus increase the efficiency of the system rather than performing the calculations of the data within the hole facade
5. Functional and compositional freedom.

The move form centralized control to decentralized control could be seen as three steps in terms of the relationships between the micro controllers and a central control unit. In the first level (centralized control) each cladding component is connected to a sensor devise and collects information about its immediate environmental conditions. The collected data from the entire facade is transferred to the main computer where the data processing takes place; as a result the facade will perform the necessary kinetic adaptation. The kinetic adaptation may be

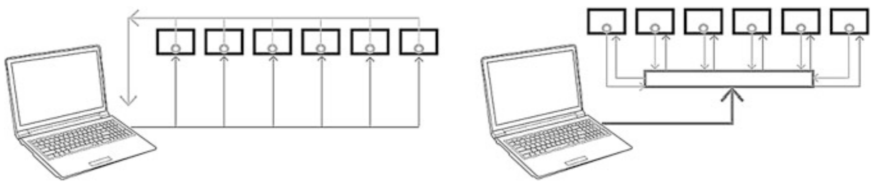


Fig. 2 Centralized control information flow (*left*). Decentralized control information flow through an "information hub" or a "bus systems" (*right*)

different for each cladding component but will be based on data processing in the main computer (see Fig. 2).

The second level preserves the data collecting principals of the previous level but disconnects the actuation process from the main computer and introduces an information hub or a "Bus system" for information navigation with in the facade. Each component will receive data from the environment and translate it to actuation. The information hub shares the information each unit has with all the units (Fig. 2).

The third level introduces the autonomous decentralized operation. Each component will receive data from the environmental conditions and data inputs from the neighboring components as well. The first evaluation will be done between the external and internal sensors of each unit, at the next stage the data from the neighboring component will be added as secondary input in order to preserve the systems equilibrium as whole. In this setting the components will influence each other and the kinetic adaptation of the facade will be performed by methods of flock behavior. The connection to the main computer in this case is not necessary and could serve as user interface for maintenance and occupants control device (Fig. 3).

Before developing a decentralized control mechanism for a cladding system, one must define scenarios in which this type of control could have potential either to handle situations that could not have been handled before or to introduce better results than those produced by the current method of centralized control. The following subsections presents trajectories that were identified as possessing this kind of potential.

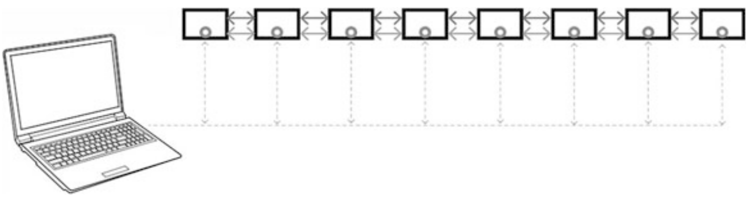


Fig. 3 Autonomous decentralized control information flow

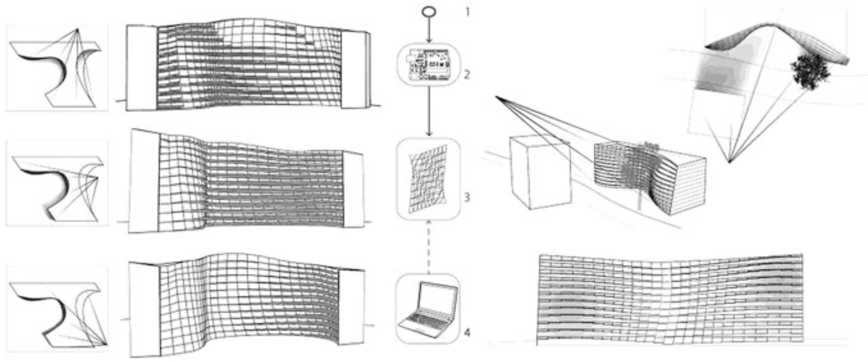


Fig. 4 Evolution of types of control over kinetic facade cladding elements

3.1 Handle Changing Local External Conditions

Partial shading by building, building elements or external elements—change the local position of kinetic shading elements according to the shade/reflection created by, inter alia, neighboring buildings, balconies and trees (see Fig. 4).

Visual exposure control—change the visual exposure of designated areas of a facade (see Fig. 5).

3.2 Handle Local Internal Changing Conditions

This possibility deals with internal changing conditions that require different facade settings, such as an increase in the number of people within a space that requires more natural ventilation, a change in the room's functions (see Fig. 6a, b).

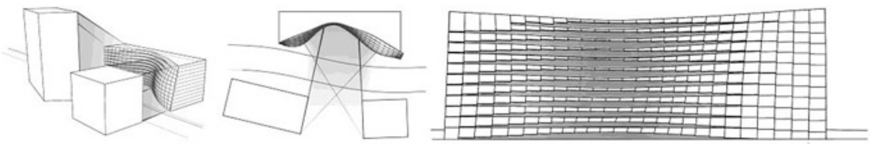


Fig. 5 The complexity of urban layout may cause undesirable privacy issues to building's occupants

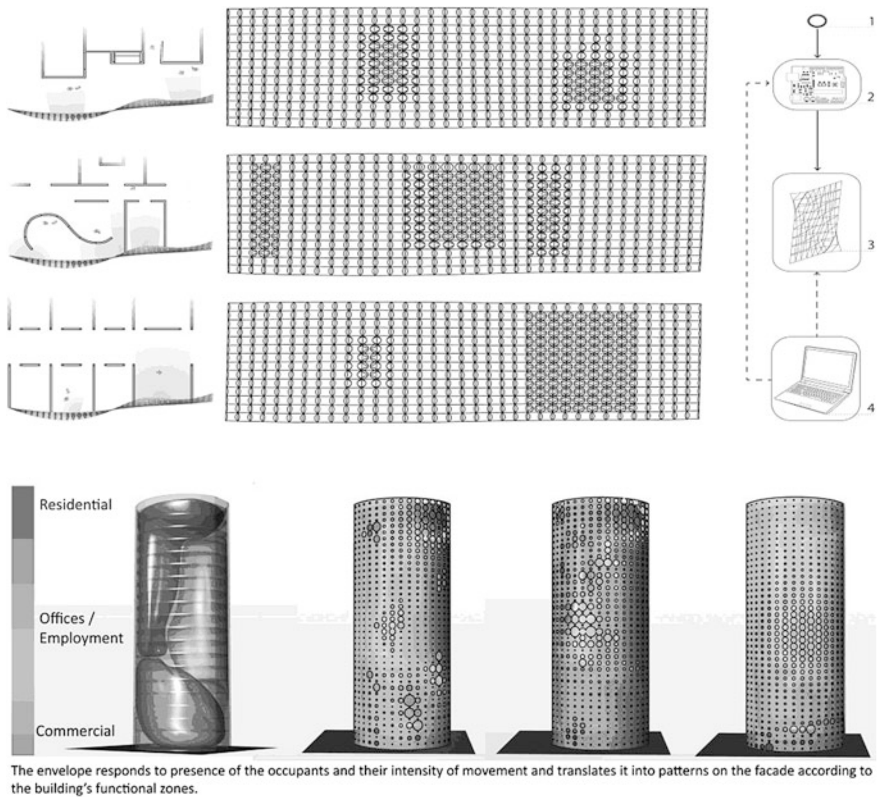


Fig. 6 **a** Programmatic flexibility. **b** Building's functional zones

3.3 Preceding Reaction or Flock Behavior

Actuating elements before their sensor feels the change based on information coming from the sensors of neighboring facade cladding elements (see Fig. 7).

4 Design Experiments

To examine the potential of the trajectories mentioned earlier, several design experiments were performed. In these initial experiments, light was chosen as a performance criterion for the actuation of the kinetic reaction The experiments' main aims, at this stage of the research, were to examine the efficiency and suitability of the kinetic mechanisms and the possibility of activating decentralized control with Arduino.

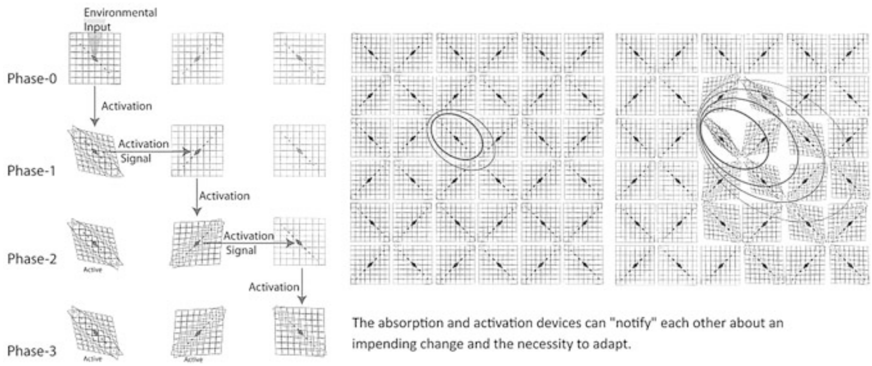


Fig. 7 Communication between the components

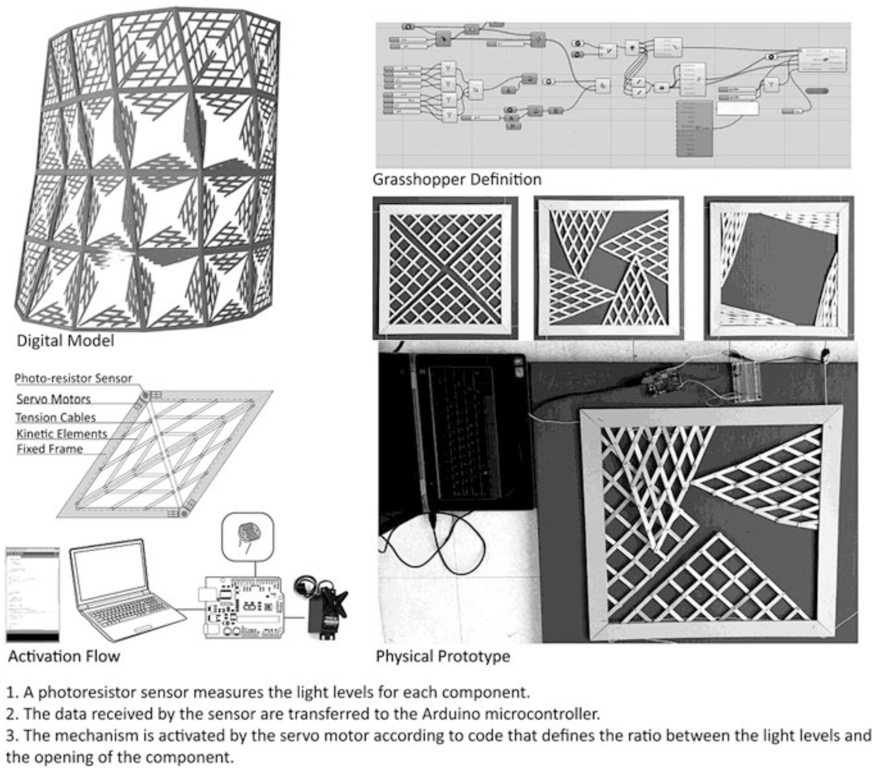


Fig. 8 Design experiment no. 1

4.1 Design Experiment No. 1: Cladding Component System Based on a Pantograph Principle

Based on a pantograph principal, the components' mechanism is able to fold and expand. The cladding components are divided into triangular elements connected to light-measuring sensors and servo motors, which operate the mechanism through a net of cables.

An algorithm (in Grasshopper for Rhino) connects between the components'geometry and the various parts of the kinetic mechanism. Each component can move both autonomously (activated by the sensor and controlled by the Arduino microprocessor) and via instruction from the main computer. A physical working example of this experiment was developed. The model is described in Fig. 8.

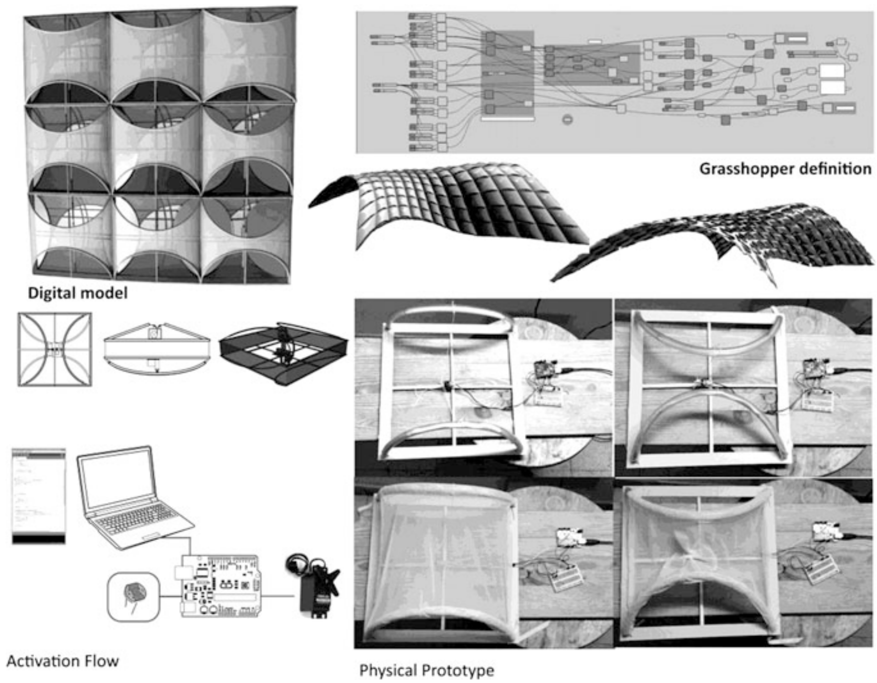


Fig. 9 Experiments no. 2

4.2 Design Experiment No. 2: Telescopic—Tension Components

The operating mechanism in this experiment combines two complementary principles. The main functional element consists of telescopic arches that are stabilized by a net of cables operated by servo motors. The main component has two perpendicular layers providing independent control over the different climatic parameters and allowing various degrees of shading and ventilation. The components' geometry is based on a rectangle and can be applied to facades that are based on quadrilateral geometry. The cladding movement is based on an algorithm (similar to the one in previous case study) and can vary in size and angles, making it suitable for application to complex geometry. A physical working model was developed for this experiment. The model is described in Fig. 9.

5 Conclusions and Future Research

Decentralized control over building facade cladding systems generates a new level of architectural complexity, one in which the designer cannot entirely control all of the design's architectural aspects [13] or to a certain extent needs to internalize how to allow the "human eye" to lose control over the design [14].

The design experiments and the preliminary research presented in this text are obviously only the initial steps of the research in this realm. Nevertheless, they seem to show both the plausibility and some unique possible capabilities of the proposed approach. The next stage of the research will concentrate on a comparative performance examination throw working prototype of various scenarios for decentralized control over kinetic cladding components in relation to traditional kinetic cladding systems.

References

1. Apollonio U (ed) (1973) Documents of 20th century art: futurist manifestos. Viking Press, New York, pp 19–24
2. Randl (2008) Revolving architecture: a history of buildings that rotate, swivel, and pivot, 1st edn. Princeton Architectural Press, New York
3. Zuk W (1970) Kinetic Architecture. Van Nostrand Reinhold, New York
4. Kronenburg R (2007) Flexible: architecture that responds to change, 1st edn. Laurence King Publishers, London
5. Kroner WM (1997) An intelligent and responsive architecture. Autom Constr 6(5–6):381–393
6. Fox M, Kemp M (2009) Interactive architecture, 1st edn. Princeton Architectural Press, New York
7. Oosterhuis K (2002) Kas oosterhuis: programmable architecture. L'Arcaedizioni, Milan

8. Moloney J (2011) Designing kinetics for architectural facades: state change, 1st edn. Routledge, Londan
9. Hutcheon N (1963) CBD-48 Requirements for exterior walls—IRC—NRC-CNRC. Can Build Dig 48
10. Shach-Pinsly D, Fisher-Gewirtzman D, Burt M (2011) Visual exposure and visual openness: an integrated approach and comparative evaluation. J Urban Des 16(2):233–256
11. Loonen R (2010) Climate adaptive building shells. Faculty of Architecture, Building and Planning. Eindhoven Univ Technol
12. Banzi M (2012) "Arduino tinkering," decoded conference. Available http://vimeo.com/24489835. Accessed 31 Mar 2012
13. Saggio A (2005) Interactivity at the centre of avant-garde architectural research. Architect Des 75(1):23–29
14. Eisenman P (1992) Visions unfolding: architecture in the age of electronic media. Domus 734:17–21

Design, Development and Analysis of Press Tool for Hook Hood Lock Auxiliary Catch

Chithajalu Kiran Sagar, B. W. Shivraj and H. N. Narasimha Murthy

Abstract The use of hook hood lock auxiliary catch is vital to all automotive cars. This paper deals with the design, development and analysis of new hook hood lock auxiliary catch and design the press tool to reduce number of stages of operations to manufacture hook hood component. The study of existing hook hood lock auxiliary catch revealed that there was development of potential crack on hook side and to overcome this, new hook hood auxiliary catch was designed with embossed profile located on the center of hook side and bend leg side. Stress analysis was performed, results revealed that new hook hood design had no potential cracks and was able to with stand higher stress value of 7–17 MPa. In design of press one stage of operation was reduced. Misalignment in embossed profile was 200 microns and was reduced to 20 microns. Further press tool can be analyzed for nonlinear and fatigue analysis.

Keywords Press tool · Embossing · Potential crack

1 Introduction

The design of press tools and its manufacturing functions are highly specialized and knowledge in nature of stampings parts, which are cut and formed from sheet materials. Bang and Thomas [1], reported a concept design of safety hook latch system was used in an weight reduction and design optimization process. When

C. K. Sagar (✉) · B. W. Shivraj · H. N. Narasimha Murthy
Department of Mechanical Engineering, R. V. College of Engineering, Bangalore, Karnataka 560059, India
e-mail: ckiransagar058@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_85, © Springer India 2013

force of 2,700 N was applied to safety hook there was development of potential crack. To overcome this, new design was development with lesser weight material SAPH440 steel and this was analyzed using Abaqus Software. Author reported that new design had no potential crack, with higher load bearing capacity of 3,300 N and weight of safety hook was reduced.

Nye [2], had developed an algorithm for orienting the part on the strip to maximize material utilization. The algorithm optimally nests convex or non-convex blanks on a strip and predicts both the orientation and strip width that minimize material usage. Based on minkowski sum concept, strip orientation was described by sweep line vector and strip width for any blank orientation were described by maximum perpendicular distance between the strip longitudinal axis and perimeter of component, using these results material utilization has been calculated and minkowski sum was generated. Venkata Rao [3], Presented analytic hierarchy process (AHP). This helped in selection of a suitable strip layout from amongst a large number of available strip layouts for a given metal stamping operation. This methodology was capable of taking important requirements of metal stampings. By this author had obtained logical and rational method of strip layout evaluation and selection. Shailendra [4], presented an intelligent system for selection of materials of press tool components for sheet metal work. Knowledge for the development of the system was acquired, analyzed, tabulated and incorporated into a set of production rules of IF-THEN variety. The system was coded in the Auto LISP language and loaded into the prompt area of AutoCAD. The output of this system gave easily available material for press tool and was useful for preparing bill of material. Eugen and Gavril [5], this paper presents analysis behavior of deformed sheet material. The analysis method, used here, was Finite Element Analysis, on ANSYS software. Author had considered that the work piece was pre-deformed, using a conventional method, by deep forming process. Author reported that most deformed zones, and most exposed ones by considering stress and strain state, von mises equivalent stress and strain and buckling region were studied.

The objective of the present work is to develop new hook hood lock auxiliary catch design with embossed profile and no weight reduction has been made. Design of press tool was to reduce one stage of operation in progressive press tool by using support punch concept in first stage of profile piercing operation. Press tool 2D&3D assembly designed, manufactured and tested for defects. Redesign of press tool to overcome defects.

CRCA is selected for hook hood lock auxiliary catch and D2 is selected for punches and dies. Material properties are shown in Table 1.

Table 1 Material property as per ASTM

CRCA (cold rolled close annealed steel) ASTM-A336	
Yield strength	270 MPa
Young's modulus	2.05×10^5 MPa
Poisson's ratio	0.28
D2 (high carbon high chromium steel) ASTM-A681	
Yield strength	2,150 MPa
Young's modulus	2.1×10^5 MPa
Poisson's ratio	0.28

*A MISUMI CORP. Standard component for press dies catalog

2 Study and Development of New Hook Hood Lock Auxiliary Catch Design

The study of existing hook hood design has intricate profile at center of hook, bend leg side and two piercing holes as shown in Fig. 1. New hook hood design was developed with embossed profile on hook side and bend leg side as shown in Fig. 2.

Fig. 1 Existing hook hood design

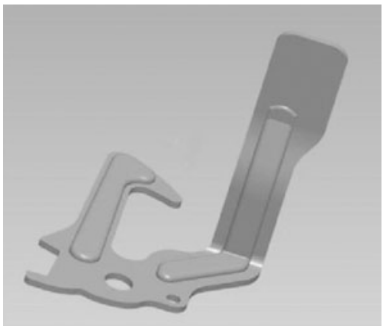


Fig. 2 New hook hood design

2.1 Stress and Total Deformation Analysis of Hook Hood Lock Auxiliary Catch

Meshed model shown in Fig. 3. Initially mid-surface was taken and meshed with 2D elements using four nodded quad, chosen element type shell 181, it contains 847 number of elements and 964 number of nodes and meshed using hyper mesh software [5].

Meshed model shown in Fig. 4 meshed with 2D elements and shell 181 element type was chosen, it contains 4,345 number of elements and 4,555 number of nodes [5].

Equivalent stress induced in existing hook hood was 7 MPa, when a load of 2,700 N was applied and there was development of potential cracks near hook side as shown in Fig. 5. Equivalent stress induced in new hook hood was 17 MPa, for same load of 2,700 N and there was no potential cracks developed as shown in Fig. 6.

Total deformation in existing hook hood was 9 microns, but there was development of potential crack by this we can predict that for every cycle of loading of 2,700 N there was plastic deformation of 9 microns on hook side as shown in Fig. 7. Total deformation in new hook hood was 17 microns and there is no potential crack or deformed regions as shown in Fig. 8.

Fig. 3 Meshed existing hook hood

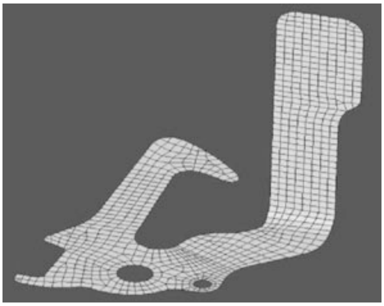


Fig. 4 Meshed new hook hood

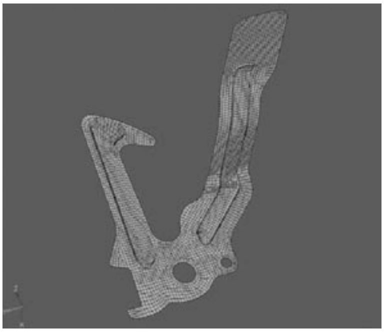


Fig. 5 Equivalent stress of existing hook hood

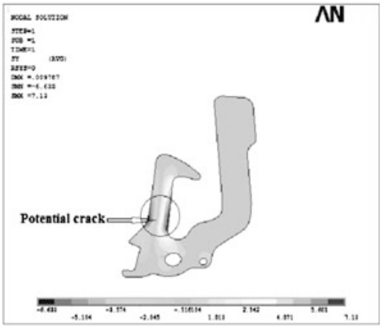


Fig. 6 Equivalent stress of new hook hood

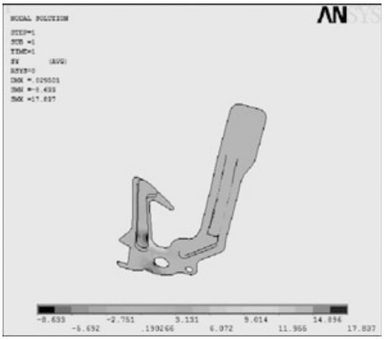


Fig. 7 Total deformation of existing hook hood

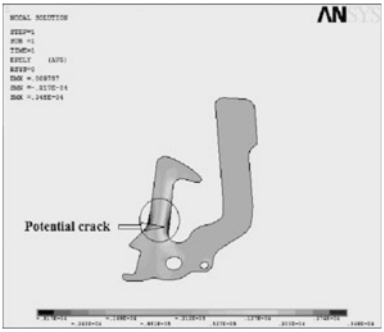
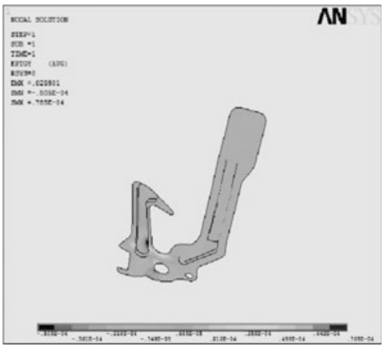


Fig. 8 Total deformation of new hook hood



3 Press Tonnage Calculation for Progressive and Stage Tool

Shearing force:

$$F_{sh} = SLt \quad (1)$$

S Shear strength of the material, N/mm^2
L Shear length, mm
T Material thickness, mm

3.1 Press Tonnage Calculation for Progressive Tool

3.1.1 Stage 1: Piercing

$$F_{sh1} = 360 \times 115.32 \times 2 = 830{,}304\,N,\ F_{sh1} = 830{,}304/(9.81 \times 1{,}000) = 8.46\,tons.$$
$$F_{sh2} = 360 \times 110.38 \times 2 = 79{,}473.6\,N,\ F_{sh2} = 79{,}473.6/(9.81 \times 1{,}000) = 8.10\,tons.$$

3.1.2 Stage 2: Forming Piercing

$$F_{sh1} = 360 \times 75.4 \times 2 = 54{,}288\,N,\ F_{sh1} = 54{,}288/(9.81 \times 1{,}000) = 5.53\ tons.$$
$$F_{sh2} = 360 \times 289.75 \times 2 = 208{,}620\,N,\ F_{sh2} = 208{,}620/(9.81 \times 1{,}000) = 21.26 \approx 22\ tons.$$

For embossing operation take 50 % of shear force

$$F_{sh2} = 0.5 \times 21.26 = 10.63\ tons.$$

3.1.3 Stage 3: Piloting and Coining

$F_{sh} = 360 \times 21.99 \times 2 = 15{,}832\,N,\ F_{sh1} = 15{,}832/(9.81 \times 1{,}000) = 1.61$ tons.
For coining operation take 20 % of shear force

$$F_{sh} = 0.2 \times 1.61 = 0.33\ tons.$$

3.1.4 Stage 4: Piercing

$$F_{sh} = 360 \times 37.7 \times 2 = 27{,}144\,N,\ F_{sh1} = 27{,}144/(9.81 \times 1{,}000) = 2.76\ tons.$$

3.1.5 Stage 5: Piloting and Blanking

$$F_{sh} = 360 \times 388.56 \times 2 = 279,763.2\,\text{N},\ F_{sh1} = 279,763.2/(9.81 \times 1,000) = 28.51 \text{ tons}.$$

Total tonnage = 33 + 32 = 65 × 1.5 = 97.5 ≈ 100 tons, based on standard machine available.

3.2 Press Tonnage Calculation for Stage Tool

3.2.1 Stage 1: Coining Operation

$$F_s = 360 \times 162.09 \times 2 = 116,704.8 = 11.89 \text{ tons}$$

3.2.2 Stage 2: Bending Force

$$F_b = 60\,\% \text{ of the shear force of blanking operation in N} \quad (2)$$

$F_b = 0.6 \times 279,763.2 = 167,857.92\,\text{N},\ F_b = 167,857.92/(9.81 \times 1,000) =$ 18 tons Total tonnage = 12 + 18 = 30 × 1.5 = 45 tons ≈ 63 tons, based on standard machine available.

$$\text{Cutting Clearance} : C = 0.005\ t\ \sqrt{Fs} \quad (3)$$

$C = 0.005 \times 2 \times \sqrt{50} = 0.07$ mm per side, for progressive and stage tool.

2D detail drawing was drawn using Mechanical desktop. Based on above calculations shut height, plate size, die block thickness, punch and die sizes were decided and based on this sectional and top assembly views were drawn for progressive and stage tool shown in Figs. 9, 10, 11, and 12.

4 Analysis of Punches and Dies

Embossing punch and die were 3D meshed using solid 92 tetrahedron element with element size 4 mm and fine meshing were made near loading region i.e. punch and die segment as shown in Figs. 13 and 14. A load of 208,620 N was applied and stress induced in punch was 128.7 MPa and die was 162.16 Mpa which was lesser, when compared with the yield strength of 2,150 MPa. By this we can predict that design is safe.

Bending punch and die were 3D meshed using solid 92 tetrahedron element with element size 2 mm and fine meshing were made near loading region. A load of 167,857 N was applied and stress induced in punch was 2,388.2 MPa which

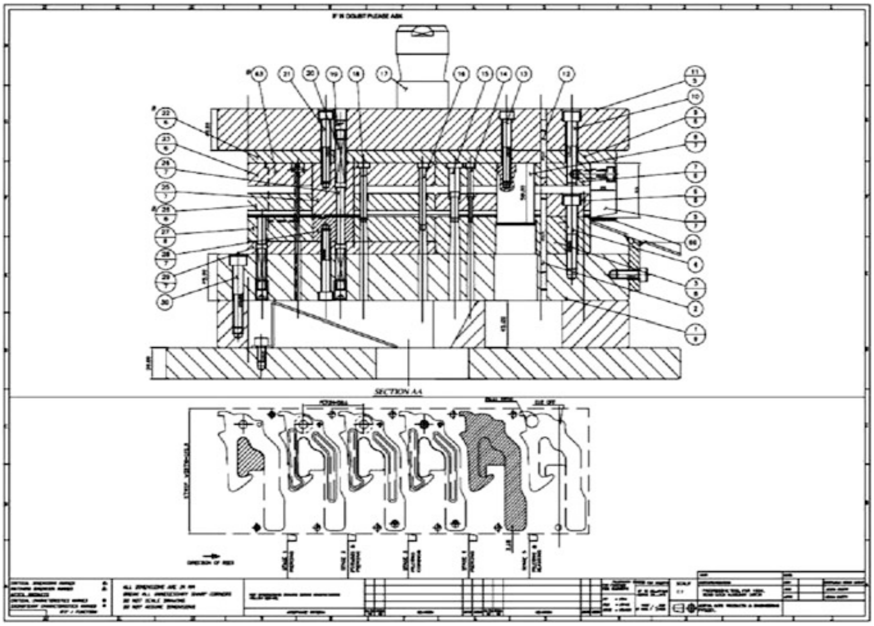


Fig. 9 2D sectional view of progressive tool assembly drawing

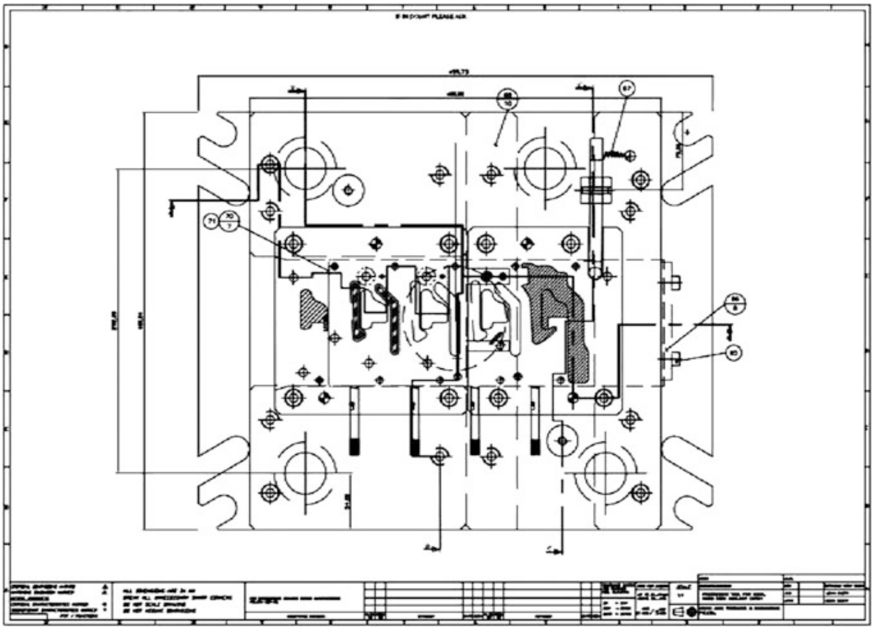


Fig. 10 2D Top assembly view of progressive tool

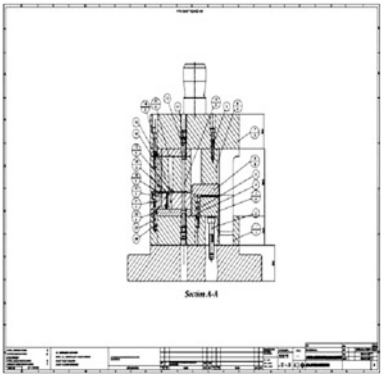


Fig. 11 Sectional view of stage tool assembly

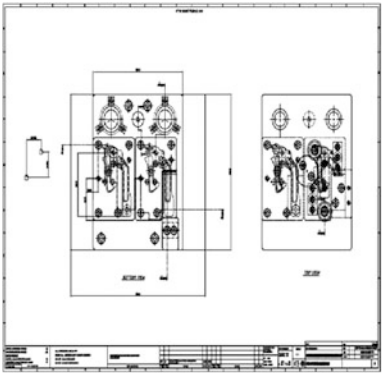


Fig. 12 Top assembly view of stage tool

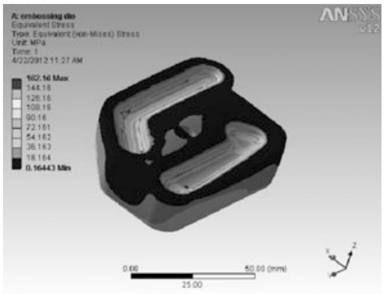


Fig. 13 Equivalent stress on embossing punch

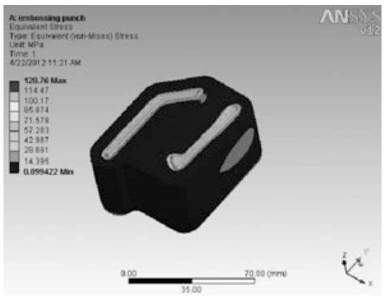


Fig. 14 Equivalent stress on embossing die

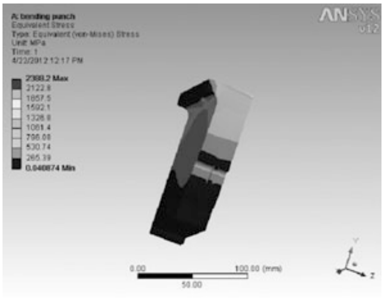


Fig. 15 Equivalent stress on bending punch

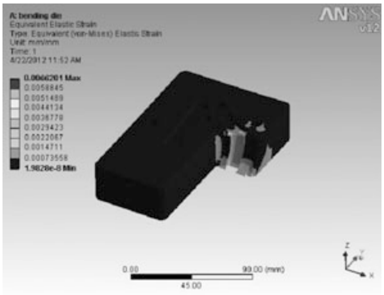


Fig. 16 Equivalent stress on bending die

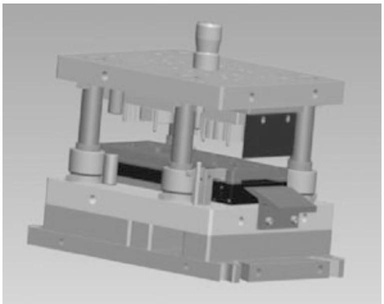


Fig. 17 3D model of progressive tool assembly

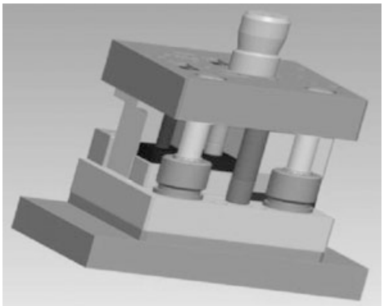


Fig. 18 3D model of stage tool assembly

Fig. 19 Manufactured progressive tool assembly

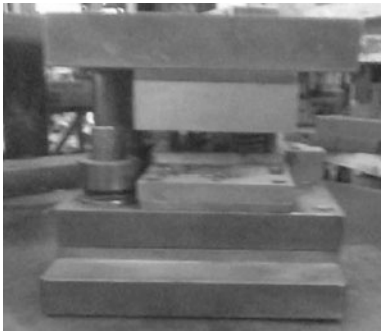


Fig. 20 Manufactured stage tool assembly

exceeds yield strength value of 2,150 MPa, so to overcome this problem, top plate thickness of stage tool was increased to 2 mm and stress induced in die was 1,390.2 MPa which was within the yield strength value and by this we can predict that design is safe shown in Figs. 15 and 16.

3D assembly model of progressive and stage tool were design to check misalignment between punches and dies as shown in Figs. 17 and 18. Later Press tool was manufactured for progressive and stage tool as shown in Figs. 19 and 20.

In initial strip layout a support punch concept was introduced in first stage of profile piercing operation and in second stage pilot piercing operation was carried along with embossing operation as shown in Fig. 21. Later tool test was carried out for progressive tool, result revealed that there was a misalignment of 200 microns in embossed profile due to improper locating operation carried in second stage of embossing, so to overcome this pilot piercing operation was adapted in first stage itself, so that proper locating operation will be made in second stage, again tool has been redesigned and tested. Result reveal that misalignment in embossed profile was reduced to 20 microns as shown in Fig. 22.

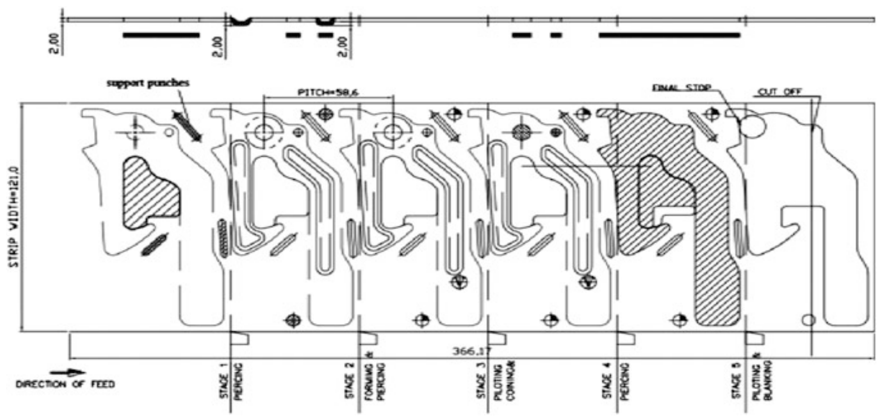


Fig. 21 Initial strip layout design of progressive tool

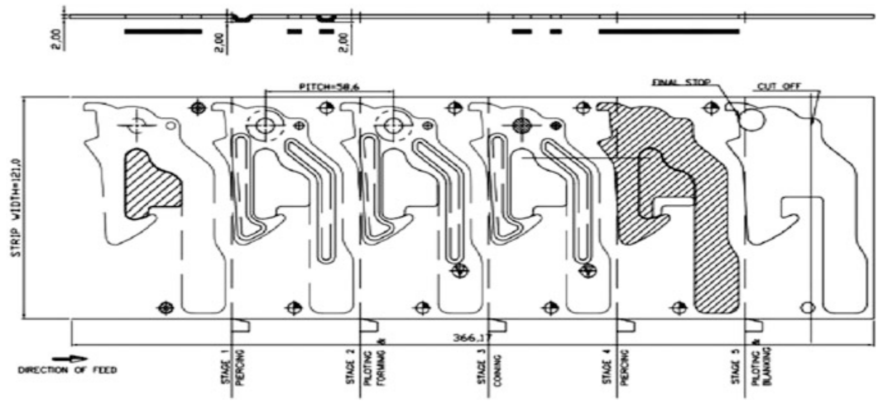


Fig. 22 Redesign strip layout of progressive tool

5 Conclusion

Design of new hook hood lock auxiliary catch with embossed profile was able to withstand higher stress value with no potential cracks when compared with flat existing hook hood lock auxiliary catch.

Use of support punch concept had reduced one stage of operation in progressive press tool, but test result revealed there was 200 microns misalignment. So use of pilot piercing operation instead of support punches in first stage and results reveal that misalignment was reduced to 20 microns. By this we can conclude that design of hook hood and press tool were optimized and was cost effective.

Acknowledgments Thanks are addressed to R.V. College of Engineering and Aditya Auto Products and Engineering PVT. LTD. faculty for its support.

References

1. Bang J, Thomas JC (2008) Optimization of a hood latch system. Bachelor of Science thesis, Worcester Polytechnic Institute, pp 46–52
2. Nye TJ (2004) Stamping strip layout for optimal raw material utilization. J Manuf Syst 19(4):239–242
3. Venkata Rao R (2004) Evaluation of metal stamping layouts using an analytic hierarchy process method. J Mater Process Technol 152:71–76
4. Shailendra K (2011) An intelligent system for selection of materials for press tool components. J Eng Res Stud 2(2):119–130
5. Eugen RI and Gavril G (2010) Finite element analysis of a forming process, using static structural (ANSYS) and ANSYS LS-DYNA. Fascicle Manage Technol Eng, NR2 9(19):1–177

Design of a Support Structure: Mechanism for Automated Tracking of 1 kWe Solar PV Power System

Pravimal Abhishek, A. S. Sekhar and K. S. Reddy

Abstract In the current scenario of increasing environmental problems and their global effects, there is a pertinent need to explore research in renewable energy technologies that do not affect the environment adversely, yet sustain the progress of mankind's growth and development. This paper presents the work intended to address the aforementioned needs by designing cost-effective solar tracking units for improving the solar power generation. Literature review reveals that tracking the Sun in both East–West direction and North–South direction can improve the power output by 25–30 %. This improvement can particularly play a significant role in the scenario of large scale grid connected solar power generation. Within this frame work, the present study attempts to develop a solar tracking system that can enable the photovoltaic solar panels to effectively trap the available solar energy by tracking the Sun. The system is designed such that it can withstand the fluctuating wind loads, remain safe even in the most adverse weather conditions, and possess the quality of frugality, ease of maintenance and repair.

Keywords Solar energy · Photovoltaic power system · Solar tracking · Bi-axial rotation mechanism

P. Abhishek · A. S. Sekhar (✉)
Mechanical Engineering/Machine Design Section, Indian Institute of Technology Madras, Chennai, India
e-mail: as_sekhar@iitm.ac.in

P. Abhishek
e-mail: pravimalabhishek@gmail.com

K. S. Reddy
Mechanical Engineering/Heat Transfer and Thermal Power Laboratory, Indian Institute of Technology Madras, Chennai, India
e-mail: ksreddy@iitm.ac.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_86, © Springer India 2013

1 Introduction

It is quite conspicuous that increasing environmental problems and their global effects are mounting a pressing need to push the frontiers of research in renewable energy technologies which do not manifest environmental adversities, yet sustain the progress of mankind's growth and development. Among such renewable energy sources, Solar Energy is a promising option. Its affluence, scalability and ease of access, makes it one of the most promising renewable energy resources.

In order to tap the full potential of such energy resource, one must design a system which can effectively capture the available solar energy and efficiently convert the captured solar energy into electrical energy. This paper is a definitive attempt to explore the opportunities in effectively capturing the solar energy by designing an optimized mechanical system and a support structure to support and rotate a set of solar photo-voltaic modules which are capable of generating 1 kWe power for about 8–10 h per day at Chennai.

1.1 An Insight into Solar Photovoltaic Technology

Solar Photovoltaic collectors, available in the market, can be broadly classified into two types, based on the nature of the collection of Solar Energy—Flat Plate collectors and Parabolic Dish collectors [1].

Flat-plate collectors are the more commonly used type of collector today. They are arrays of solar panels arranged in a simple plane. They can either be fixed in a static position, or rotated continuously to track the Sun. Tracking the Sun using automated machinery that keeps the Solar Panels facing the sun throughout the day, results in the better effectiveness in capturing the solar energy. The additional energy they take is due to the correction of facing more than compensates for the energy needed to drive the extra machinery.

Focusing collectors are essentially parabolic-dish collectors with optical devices arranged to maximize the radiation falling on the focus of the collector. These are currently used only in a few scattered areas. Solar furnaces are examples of this type of collector. However, one problem with focusing collectors in general is due to temperature. The fragile silicon components that absorb the incoming radiation lose efficiency at high temperatures, and if they get too hot they can even be permanently damaged. The focusing collectors by their very nature can create much higher temperatures and need more safeguards to protect their silicon components [1]. The present study deals with the flat-plat solar collectors.

1.2 Effect of Tracking on Performance of PV System

Solar Energy Conversion depends on two factors—Efficiency and Effectiveness. While efficiency deals with the ability in converting one form of energy into another, effectiveness deals with the ability to collect the available energy. Both these factors determine the power generation capacity of solar photovoltaic cell. At present, the efficiency levels of solar photovoltaic cells are quite limited. Therefore, tapping as much energy as possible will improve the power generation capacity significantly. In other words, for a given value of efficiency of a Solar Photovoltaic cell—the greater the effectiveness of tapping the solar energy the better the power generation capacity, irrespective of the degree of efficiency. Literature review on this subject reveals that a tracking solar photovoltaic cell can generate 25–30 % [2] more power than the static one. Achieving that increment in power production in a cost effective way is the primary goal of the present study.

Challenges in pursuit of greater effectiveness are multitude ranging from complexity in design, cost-effectiveness, exposure of mechanisms to adverse atmospheric conditions, accuracy in tracking, social acceptability etc. All the possible challenges were comprehensively taken into cognizance alongside an explicit outlay of the need matrix to embrace an 'inclusive design approach' for accomplishing the established goals.

2 Methodology

1. The methodology of the study is to perform a comprehensive design analysis of an existing solar tracking system. Computational techniques like Computer Aided Design (CAD) and Finite Element Analysis (FEA) were used to meet these goals.
2. The second step following the design analysis is to develop a multi-dimensional need matrix and a product function addressing the technical requirements and latent needs of the end users.
3. Based on the information acquired from the above processes, the final step is to conceptualize a set of feasible design solutions, deploy a decision making criteria and select the most optimal solution that can fetch maximum results and fulfill all the needs of the users. Standard principles of product design were followed in the second and third steps.

2.1 Organization of the Work Elements

The layout of the study is broadly discussed in three sections. A thorough study on the various aspects of solar tracking was conducted on a single axis tracking system. This is outlined in the Sect. 3. Following this comprehensive study, a detailed need analysis is presented in Sect. 4. With the study results and the need analysis at hand, standard principles of product design were deployed to make a conceptual design of a solar tracking system in Sect. 5. Approximate estimates of the cost of such a system were outlined in Sect. 6. Summary and important conclusions of the entire study are presented in a nutshell in Sect. 7.

3 Design Analysis of a Single Axis Solar Tracking System

3.1 Modeling of the Existing Single Axis Solar Tracking System

The existing single axis solar tracking system is configured to generate 1 kWe power for about 8–10 h per day at Chennai. It consists of six nos. of the solar modules with a capacity of 175 W each. The configuration is be made in two rows of three modules each. The base mount is made in the shape of a 'Y' and the solar panels along with the support structure are mounted on the base frame using knuckle joints. The gear mechanism and the motor are placed at the center of the 'Y' frame which connects to the shaft that rotates the solar panels. The details of the system are modeled in Solid Work and are shown in Fig. 1a and b.

The analysis involves a three stage process. The first stage comprises of evaluating all kinds of loads that are acting on the system. The second stage includes the development of solid 3D model using a CAD tool. The third stage involves a comprehensive stress analysis using an FEA tool to generate the detailed information of the stresses induced. Due attention was given to consider the use of standard procedures so that the obtained results are reliable and repeatable. The outcomes of these processes form the foundation for re-design of system taking into consideration all the engineering requirements, manufacturing and assembly aspects, reliability, frugality, safety, ergonomics and ease of maintenance and reparability.

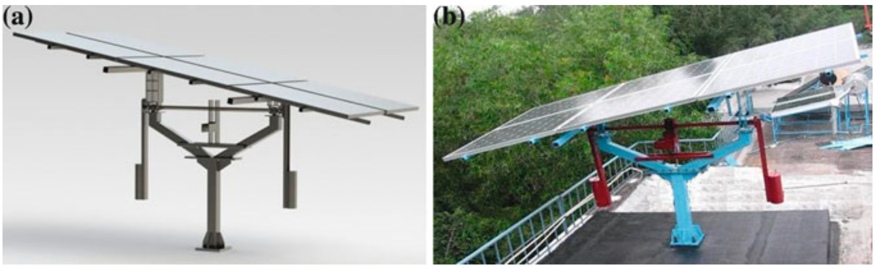


Fig. 1 1 kWe solar PV system with tracking at IIT Madras. **a** 3-D model. **b** Photograph

Table 1 Typical dimensions of a 175 W solar PV module

Parameter	Value
Power output	175 W
Length	1318 mm
Width	994 mm
Depth	46 mm
Weight	16 kg

3.2 Types of Loads

The loadings were calculated on the basis of standards given in ANSI/ASCE [3]. According to the given standards, there are five basic types of loadings on the structure.

1. Dead Loads (DL): Self-weight of the structure
2. Wind Loads (WL): Lift and drag due to flow of wind over the structure
3. Imposed Loads (IL): Sum of all the loads like rainfall, sand etc
4. Snow Loads (SL): Loads due to snow falling on the structure
5. Special Loads (SPL): Loads which are unpredictable, and impulsive

Among all the loads the most important ones considered for the analysis were the dead loads and wind loads. Since the loads caused by the other three are not quantifiable, a sufficient factor of safety was considered to account for them. Typical dimensions of a 175 W Solar PV Module are shown in Table 1.

3.3 Estimation of Loads

Six solar panels are mounted in 3×2 matrix each panel with a capacity of 175 W. The panels were supported using a grid type steel structure. Each panel weighs 16 kg and the grid frame along with the connected cables weighs around 14 kg. Therefore, the total dead load on the structure is 110 kg. While the dead loads are always constant, wind loads create a random time-varying loading on the structure. The amount of load subjected on the structure depends on the velocity of the wind, and the angle of attack of the wind, inclination of the solar panels, structural design, geographical factor and proximity with neighborhood structures. It also depends on the density of the air, but the variations due to these factors are assumed to be negligible. The flow of wind over the structure is a typical fluid mechanics problem that deals with flow of fluids over a body. Two kinds of forces are generated in such a situation—the drag force which acts along the flow of the wind and the lift force which acts on the body perpendicular to the flow of wind. These forces are calculated for a particular wind speed with varying inclination of the solar panels. The highest values of the forces generated are calculated and the structure was designed to with stand the highest load to ensure high degree of safety and reliability.

In order to calculate the wind speeds and to estimate various correction factors, standards were used based on IS 875: 1979 [4]. The structure falls within the scope of the standards and they are aptly applicable to the current analysis. Chennai belongs to the wind zone 5 of India. Basic wind speed is the based on the peak gust speed averaged over a time period of round about 3 s and corresponds to 10 m height above the mean sea level in an open terrain. The details of the winds speeds are as below:

Designed wind speed is given as:

$$(V_Z) = V_b \times k_1 \times k_2 \times k_3 \quad (1)$$

Location: IIT Madras, Chennai, Tamilnadu (13° N, 82° E)
Wind Zone: 5
Basic wind speed (V_b) = 44 m/s
k_1 = probability factor; the existing system was designed for 25 years. Thus $k_2 = 0.9$
k_2 = terrain height and height factor; the terrain of IIT Madras belongs to category 3. This category includes terrains with numerous closely placed structures. The structure is placed on the roof top whose total is round about 15 m. k_2 is determined based on both height and terrain characteristics. The above conditions suit Class A criteria and thus $k_2 = 0.9$
k_3 = This factor deals with the local topographic features like hill, cliffs, valleys and escarpments etc. which can significantly affect the wind speed. Since the location has no such features in the vicinity, the factor is chosen to be one ($k_3 = 1$).

Using the above factors, the design wind speed is calculated based on the basic wind speed. The design wind speed so arrived is 35 m/s.

The speed data of the above standards is used to ensure the structures are stable even when there is a significant increase of the wind velocity for a short time. However, the average wind speed at the ground level in Chennai is round about 12 m/s. The analysis on the existing design was done both at the 12 and 35 m/s and the stress values have been computed. The proposed new design was conceptualized to ensure maximum stability with minimum amount of material.

FEA analysis was done for the current solar tracking system to investigate the maximum induced stress, and it was further elaborated in the design of the new system for a different configuration of the solar panels. The temperature of air was set to be 25 °C and the density of the air was chosen to be 1.17 kg/m^3. The values of the lift and drag forces acting on the solar panels were computed and the results are shown in Table 2. Pressure and velocity contours and the lift and drag forces acting on the solar panels were obtained from the above analysis. Typical velocity contour and pressure contours are shown in Fig. 2a and b.

Table 2 Lift and drag forces due to flow of air on the solar panels

Angle (θ)	Lift (N)		Drag (N)	
	35 m/s	12 m/s	35 m/s	12 m/s
0°	92.45	NA	776.9	NA
30°	−8,935	−717	5,678	456
45°	−10,832	−826	11,564	859
60°	−10,020.2	−662	17,940	1,189
80°	−5,080	−248	19,780	1,478

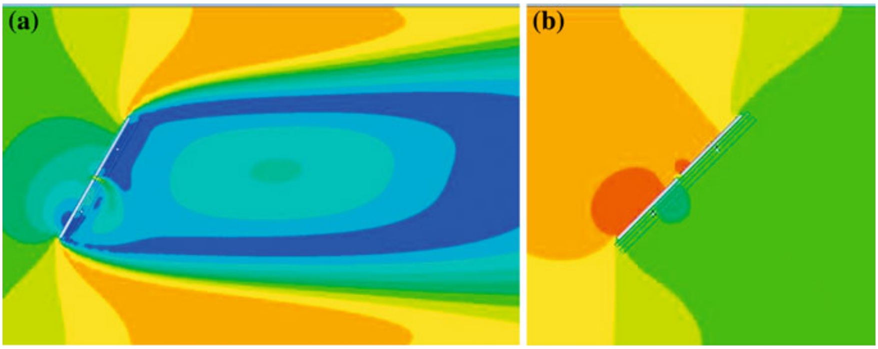


Fig. 2 FEA analysis of the solar PV system. **a** Velocity contour, **b** Pressure contour

Stress Analysis for the above structure was done using a FEA Tool. The material used for the structural support is AISI 1020 structural steel. Since it is a ductile material and the situations involve combined tensile and shear stresses acting on the same shape, defining an effective stress that create equivalent amount of distortion would be easier to conceive. Therefore, Von-Mises effective stress was used to determine the maximum stress induced in the structure. The maximum value of von-mises equivalent stress at a wind speed of 12 m/s is 81.65 MPa, while it is 220 MPa when the wind speed is 35 m/s. These values should be compared against the yield strength of the material which is 280 MPa. Therefore, the structure is under critical loading when the wind speed is around 35 m/s.

4 Need Analysis and Product Function

A complete identification of the need analysis is imperative prior to the design process. It would provide the designer detailed information of what to develop and also serves as resource material for future reference and research on improvisation of the system. Requirements for the system are summarized in Table 3 with their relative importance.

Table 3 Need Analysis Matrix

Need	Description	Rating
Automated E-W tracking	The system has to track the Sun every day from east to west for about 12 h	10
North–south tracking	Rotation along the North South direction across 1 year to account for the change in solar angle of incidence	10
Ease of use	System should be easily operable, maintainable and repairable	9
Structural stability	Should withstand the loads caused by dead weights and the wind loads. The structure should be stable at least for a standard design speed of wind	10
Dual RPM rotation	The system should have an incorporated dual RPM rotation in order to facilitate quick return motion	10
Frugality	The design should be frugal to ensure that the capital cost invested in solar power plants is the least	9
Scalability	The design should be scalable to be used for smaller are larger systems of similar configuration	8
Flexibility	The system should be flexible that it can cater to the needs of any solar module purchased from the market	9

Based on the above requirements, a set of functions were listed out which should be performed by the tracking system. These functions form the production function for development of new design. Various types of methods in which these functions could be performed were explored. Out of all the functions, those set of functions which could be feasible for further study were filtered. From the feasible domain, a single solution was selected based on relative advantages and the final functional configuration was developed by integrating the individual functional units [5].

The most basic function is to track the Sun in the East–West direction. In order to achieve this function, various actuation systems and mechanisms have been studied. The relative advantages and disadvantages are mapped in Table 4 for driving mechanisms and Table 5 for actuation systems. An appropriate choice of the systems was made based on needs. This exercise decision making was followed for all the other functions that need to be performed and a conceptual design was made incorporating all the solutions obtained in the decision making process. These conceptual sketches were further developed into CAD models and a detailed

Table 4 Relative advantages and disadvantages of various driving mechanisms

Mechanism	Advantages	Disadvantages
Power screws	Most important advantage is the ability of self-locking [9, 10] provides one step reduction in the RPM by serving as one of reduction pairs	Axial thrust forces induced on the shaft upon which the gear is mounted
Ratchet Mechanism	Reduction of the speed with least number of gears	Cannot provide a self-lock system. A separate mechanical system to lock the shaft at every position is required

Table 5 Comparison of actuation systems

Feasible actuation system	Advantages	Disadvantages
Piston	Eliminates the need for a multiple gear reductions as in the case of a motor driven mechanism. Improves structural simplicity	Cannot take the load of the solar panels. A supplementary support system needed. Fluid sensitivity to surrounding temperatures can cause inaccuracies. Pistons are costlier and their reliability is relatively low when compared to motors
Normal DC motor	Cheap and widely available. Ease of installation service and repair	Requires a series of reduction gears to reduce the speed to the required level. Different set of gears have to be used for providing dual RPM motion
Stepper motors	Very compact and a minute angular rotations can be controlled with high accuracy	Highly expensive

design was made in the later stages. The following section gives a brief overview of the new design features.

5 Design Features of the New Solar Tracking System

Taking into consideration the complexity and the cost benefit analysis, the design was equipped with a manual North–South Rotation instead of an automated rotation. The angle that needs to be rotated is quite and the cost-to-benefit ratio of such a mechanism is intuitively quite low. Therefore, the system has one automated East–West tracking mechanism and a provision for manually adjusting the North South inclination across the year. This mechanism is shown in Fig. 3.

A quick return mechanism is required to revert back the solar panels to the initial position to start tracking the sun for the next day. This rotation should be quicker than the regular tracking which is at an RPM of 0.00645. Since the driving mechanism is chosen to be power and the driver, a DC motor, a simple gear changing mechanism can provide dual RPM rotation to the worm. This is also shown in Fig. 3. The worm is attached with two spur gears at both the ends and motor can be housed inside the column and the worm can be rotated by two different gears trains to achieve dual RPM

Trusses were designed to bear the loads transferred from the solar panel frames. These Trusses are cheap and easy to make; most importantly, they give a great flexibility in varying height of the solar tracking system, as shown in Fig. 3. All the components of the new design were subjected to stress analysis using an FEA

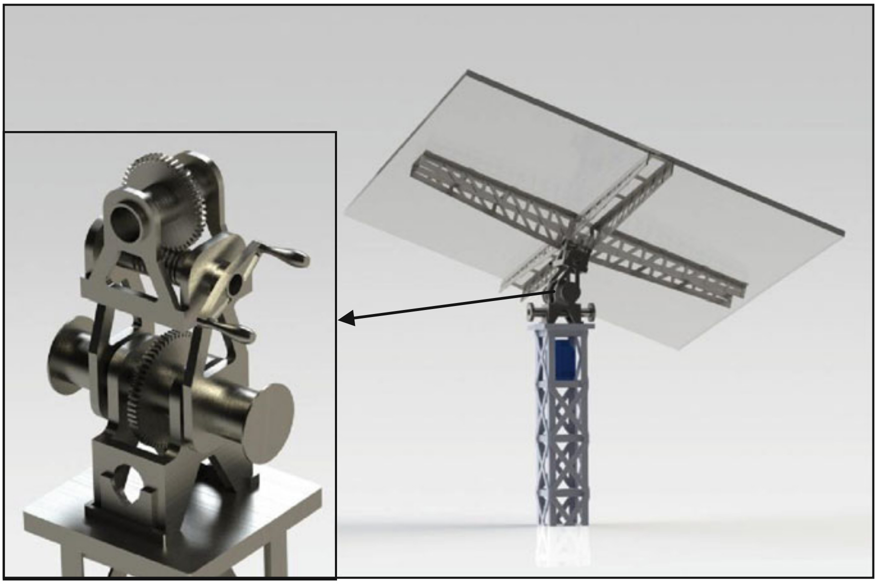


Fig. 3 Design of the new solar tracking system. Inset—Bi axial rotation mechanism

tool. The yield strength of the material is around 384 MPa, and safety factor of 2.5 was chosen which will peg the upper limit of allowable stress at 153.6 MPa. Against this maximum allowable stress, the induced stress on the structure was 98.91 MPa which is well within the allowable stress limit. This brings the study to the last stage of the design process.

6 Economics of Solar Power

Compared to conventional power, (coal based thermal power) solar energy is four times more expensive [6]. Nevertheless, cost is not always the determining criteria. Solar power is much flexible and scalable which it more attractive in areas where access to conventional power sources is forbidden due to geographical impediments. Efforts are also being made to improve the efficiency of the solar panels. At the same time, national governments across the globe are assisting effective penetration of solar power by various market interventions. Currently, India is implementing the National Solar Mission, under the National Action Plan for Climate Change (NAPCC) which envisages installing 20,000 MW of solar power by 2022 [7]. Taking into consideration all the techno-commercial factors, the Central Electricity Regulatory Commission (CERC) in India has come up with a normative capital cost for Solar Photovoltaic power generation. It must be noted that the CERC normative costs do not distinguish tracking solar photovoltaic systems and static photovoltaic systems. For the FY 2011–2012, the normative capital cost was pegged at 1442 Lakh/MW [8]. The estimated cost of solar tracking system is round about 1,650 Lakh/MW which is a significantly high when compared to the normative limits. However, the increase in power production by 22.65 % can deliver an additional power generation of 2.05 kWhr power per day. The CERC estimates assume that the operational timer period of solar power generation system is 25 years. Therefore, the additional power harnessed by tracking systems across 25 years has a much greater value which can offset high capital cost. Also a single unit of solar tracking system can save 2,784 kg of carbon dioxide emissions per unit power generations, which can earn 2.78 carbon credits per unit power generation.

7 Summary and Conclusions

The primary objective of the study is to design a tracking system that can support solar panels which are capable of generating 1 kWh electrical energy. The methodology adopted for carrying out the study is to first perform a comprehensive design analysis of an existing structure, and then use the information to develop a new design by adopting standard principles of product design.

An improvised design was made catering to a multi-dimensional need matrix. The key features of the new design include a biaxial rotation of the solar panels, dual rpm drive for quick return, reduced stress levels in the structure along with reduced usage of the material and a robust safety mechanism to withstand adverse cyclonic conditions. 25 % material usage reduction was achieved from the previous design with a simultaneous increase in the ability to track the Sun and produce more power.

The support structure need not be necessarily a single column. Use of more legs might save more material. But the idea behind using a single leg is to ensure that the foot print of the structure is as low as possible on the ground. This is can allow the designer to increase the height of the column according to the needs. For instance, the height of the solar tracking system can be doubled from the ground so that more clearance is available at the ground level. Since, the footprint is least possible, more land would be available for any other productive usage instead of getting underutilized for solar power production.

References

1. Mousazadeh H (2009) A review of principles and sun tracking methods for maximizing solar outputs. Renew Sustain Energy Rev 13:1800–1818
2. Renewable Energy Report—Global Status (2011) Renewable Energy Policy Network for 21st Century

3. ANSI/ASCE 7-88 ACSE (1990) Minimum design loads for building and other structures
4. IS875:1979 Code of practice for design loads (other than earthquakes) for buildings and structures
5. Akiyama K (1991) Function analysis: systemic improvement of quality performance. Productivity Press, Portland
6. Avijik Nayak (2012) Cost economics of solar kWh. In: Energitica-India, vol 22. National Productivity Council, Kolkata (Jan/Feb 2012)
7. Jawaharlal Nehru National Solar Mission, Mission Document, Government of India
8. Renewable Energy Tariff for the FY 2011–2012, Order-256-2010, Central Electricity Regulatory Commission, Government of India
9. Norton RL (2007) Machine design: an integrated approach. Dorling Kindersley Publishers, India, ISBN 81-317-0533-1
10. Hudley DW (1984) Handbook of practical gear design. McGraw-Hill, New York, p 366

Automated Brain Monitoring Using GSM Module

M. K. Madhan Kumar

Abstract I propose to develop a project to simulate an abnormal bio-signal synthetically for analysis and testing of the device built for monitoring a person's brain status. This system acquires and analyzes neural signals with the goal of creating a communication between the brain and GSM mobile. It is a low cost solution for an automated emergency response system and also provides constant patient monitoring without affecting their day to day activities. This system ensures safety as well as mobility at all times.

Keywords Automated constant monitoring · Brain status · GSM mobile · Neural signals

1 Introduction

Monitoring the brain using **Electroencephalograph (EEG)** is usually done with maximum steps and a care taker need to monitor the patient's status consecutively. This system is used for acquiring normal brain activity and also for monitoring abnormal brain activity in patients.

For example, Coma patients in intensive care will be continuously monitored by **Health care taker (HCT)**. In this concept, the HCT can get earlier information after patient's brain decides. The brain is sensed and the brain status is informed to HCT through text (SMS) or call to their mobile which is called Biotelemetry system.

M. K. Madhan Kumar (✉)
Department of ECE, G.K.M College of Engineering and Technology, Chennai, India
e-mail: newtalantons@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_87, © Springer India 2013

Other than Coma patients, for mentally retarded persons even for senior citizens it will be helpful in finding out whether they are in hungry, tension and also whether in sleeping. For normal people it will help in knowing their situation like whether he/she is alcohol or drug addicted, attitude and behavior change and so on from any distance. Below, we made the Bridge to understand the relations between 'Brain activity' and GSM Mobile is provided by the EEG.

2 Innovations

Emergency response system helps us to identify the consciousness of the patient and the Medical history of the patients stored within the GSM module or ROM that helps with immediate and effective treatment. Integration of two sensors (brain and pulse) using a single processor to improve the accuracy of the measurements. The significance of this project is to continuously monitor the brain status via GSM module.

3 Salient Features

Multiple parameters such as Brain waves and pulse rate are sensed. The sensed report makes emergency response system and can be used for first aid info and patient medical history stored as SMS in the mobile phone at all times. The system is low power consumption with Battery powered and efficient power management system. It is the motion Capture of brain in continuous time.

4 Motivations

In most emergency situations we are lacking of quick access to hospitals/trained medical care and Sometimes, emergencies even go unnoticed for a long period. Need for Low cost portable solutions to enable even in small nursing homes, dispensaries and can be carried out everywhere. It increases the need of continuous in-house monitoring of patients without affecting mobility in hospitals. Availability of life saving first aid support cannot be expected in all situations, so a novel monitoring system addressing these issues is needed. Hence this system improves necessity for continuous monitoring of patients for neurodegenerative and neuropsychological disorders. The caretaker can monitor the patient's mind status via mobile phone (text message or call).

5 Block Diagram

5.1 Figures

The system will sense the Brain waves and pulse rate of patients using sensors placed in our body (Figs. 1, 2 and 3).

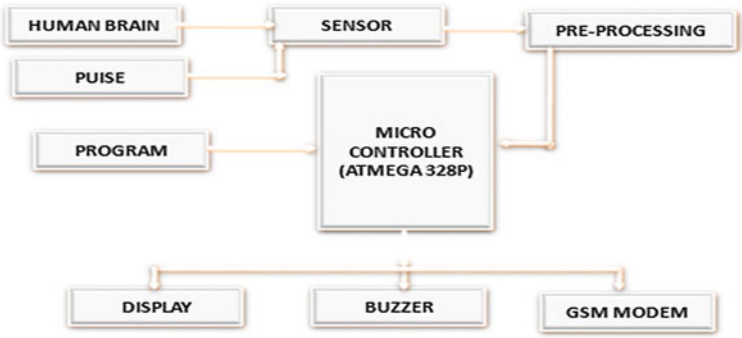


Fig. 1 General block diagram

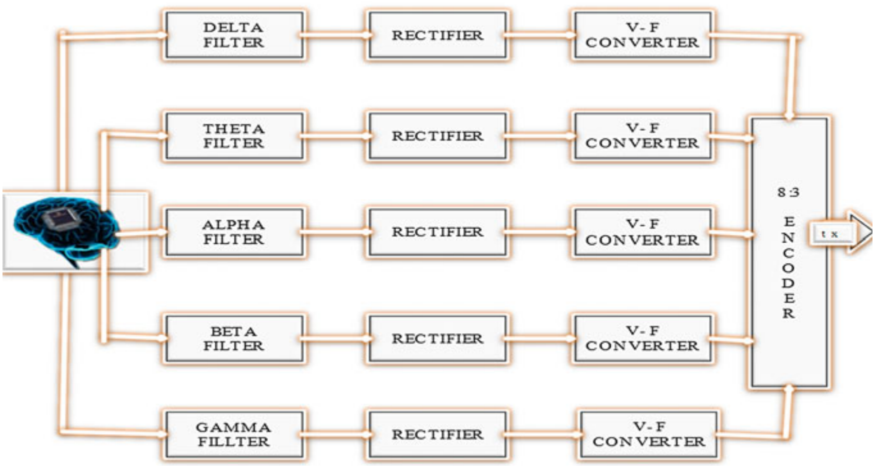


Fig. 2 Transmitter side

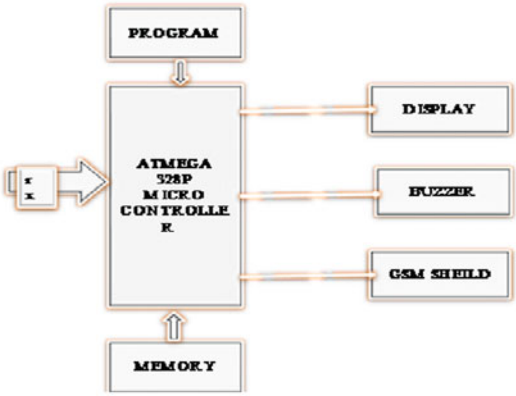


Fig. 3 Receiver side

5.2 In Case of an Emergency

The system will communicate with a GSM module and send the status to emergency (or pre-defined custom) numbers that can be along with the GPS co-ordinates for ease of locating the person.

Necessary information is displayed/played out loud in buzzer for assisting nearby people around, to provide immediate first aid.

5.3 In Case of Constant Monitoring

All measurements and diagnosed report will be transmitted to the paired mobile, where it is stored in a micro-SD card. Thus, these measurements keep a constant check on the patient's health conditions.

Previous medical histories of the patient are also stored in the mobile. This report would be very helpful in case of emergencies, for any physician to treat immediately.

6 Technologies

1. **EEG**: For monitoring Brain waveform.
2. **Induino board**: Evaluated board with ATmega328p controller.
3. **GSM Shield**: GSM modem for transmitting SMS (Bio telemetry).

Biosignal: Any signal measured and monitored from a biological being, although it is commonly used to refer to an electrical biosignal.

Neuro-Signal: Neuro means brain; therefore, 'neuro-signal' refers to a signal related to the brain.

6.1 What is EEG?

An electroencephalograph (EEG) is the recorded electrical activity generated by the brain. In general, EEG is obtained using electrodes placed on the scalp with a conductive gel. In the brain, there are millions of neurons, each of which generates small electric voltage fields.

The aggregate of these electric voltage fields create an electrical reading with which electrodes on the scalp are able to detect and record. Therefore, EEG is the superposition of many simpler signals. The amplitude of an EEG signal typically ranges from about 1–100 µV in a normal adult, and it is approximately 10–20 mV when measured with subdural electrodes such as needle electrodes.

The 10–20 international system is used as the standard naming and positioning scheme for EEG measurements (Figs. 4, 5).

The original 10–20 system included only 19 electrodes. Later on, extensions were made so that 70 electrodes could be placed in standard positions. Generally one of the electrodes is used as the reference position, often at the earlobe or mastoid location.

6.1.1 Placement of Electrodes

The electrodes placed in right side, numbers are even and left side numbers are odd.

Start: Nasion to Inion
Position: FP2—FZ—CZ—PZ—O2
Second: Ear to Ear

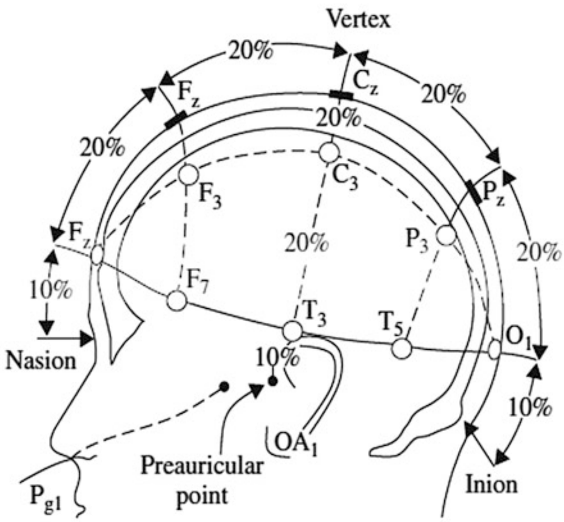
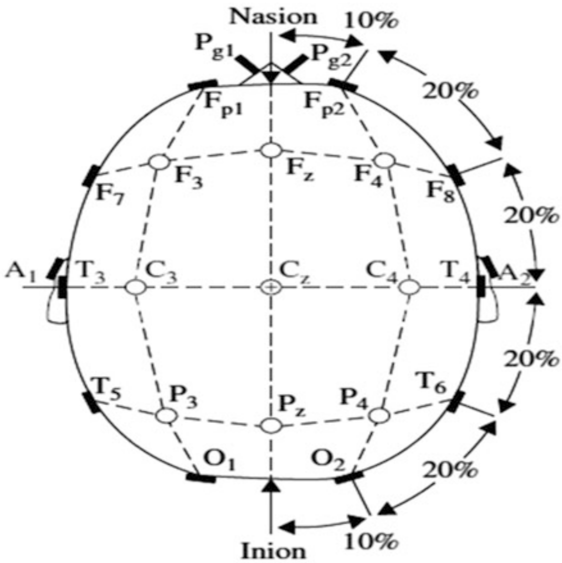


Fig. 4 Electrode placements-1 [15] (*side view of head*)

Fig. 5 Electrode placement-2 [15] (*top view of head*)



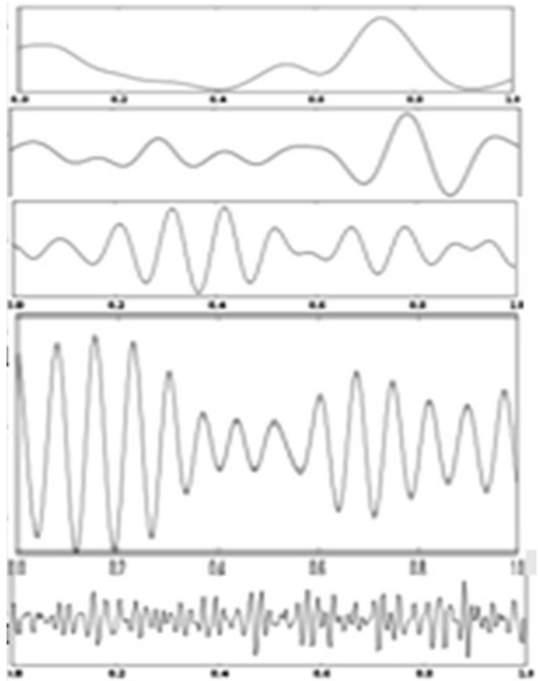
Position: T3—C3—C2—C4—T4
Third: Full circumference around
Position: Starts from FP2
Left side ≫ FP1—F7—T5—O1
Right side ≫ FP2—F8—T6—O2
Last: Marks between located
Position: F3—F4—P3—P4

6.1.2 Brain Waveforms

EEG is generally described in terms of its frequency band. The amplitude of the EEG shows a great deal of variability depending on external stimulation as well as internal mental states. Delta, theta, alpha, beta and gamma are the names of the different EEG frequency bands which relate to various brain states.

The intensities of the brain waves on the surface of the brain may be 10 mV; where as those recorded from the scalp have smaller amplitude of approximately 100 μV. The frequency of these brains ranges high in Hz but due to skull we can obtain the range of 0.5–100 Hz. The character of the brain wave is highly dependent on the degree of activity of the cerebral cortex.

Table 1 3 Brainwave frequency (HERTZ) and mental states listing

S. no	Brain wave type	Frequency range (Hz)	Mental status and conditions	Waveform
1	Delta	0.1–3	Deep, dreamless sleep, non-REM sleep, unconscious	
2	Theta	4–7	Creative, recall, fantasy, imaginary, dream	
3	Alpha	8–12	Relaxed, but not drowsy, conscious	
4	Low beta	13–15	Relaxed yet focused, integrated works	
5	Midrange beta	16–20	Thinking, aware of self and surroundings	
6	High beta	21–30	Alertness, agitation	
7	Gamma	30–100	Motor Functions, higher mental activity	

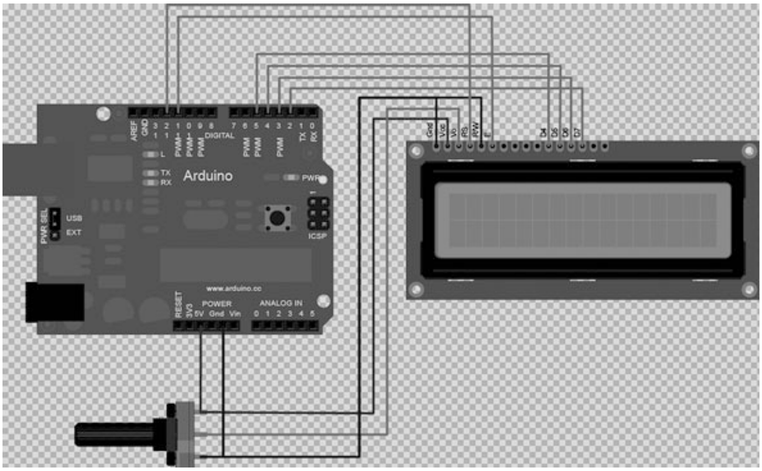


Fig. 6 Induino board with LCD display

6.1.3 Brainwave Frequency (HERTZ) and Mental States Listing

These frequencies are of all types; light, sound, electrical, etc. The two- or three-character source codes after each frequency [16] (Table 1).

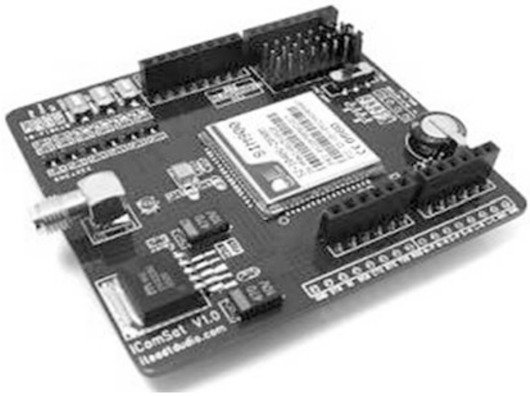
6.2 Induino Board

The InduinoX is an Indian made clone of the Arduino Duemilanove with a host of added features. It is inbuilt with ATmega168 microcontroller. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, an ICSP header, and a reset button (Fig. 6).

6.2.1 Specifications

Microcontroller	ATmega328
Operating Voltage	5 V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6

Fig. 7 GSM modem



6.3 SIM900 GSM/GPRS Shield for Arduino–IComSat v1.0

IComsat is a GSM/GPRS shield for Arduino and based on the SIM900 Quad-band GSM/GPRS module. It is controlled via AT commands (GSM 07.07, 07.05 and SIMCOM enhanced AT Commands), and fully compatible with Arduino (Fig. 7).

7 Prototypes

Instead of EEG machine, we are using Brain Wave frequency oscillator to show immediate action where it finds easier to explain. It produces the frequency of 0–100 Hz. Voltage is of up to 3 V that supports Microprocessor (Figs. 8, 9).

7.1 Results and Observation

By varying the frequency (brain) in the prototype, the mental status which is coded with respect to frequency is received by the HCT. We have tried with patient in: (1) coma, (2) retrieved from coma, (3) person in hunger, (4) tension and (5) in sleep and got successful result by text format in mobile.

8 Future Works

The Entire kit can be made compact inside a wrist watch. An additional SD card storage can be provided in the wrist watch to store all the relevant brain activity, which can be used for future references. Neuro sky can be used to detect brain activity. The cost of this project will be around 10,000 (Figs. 10, 11).

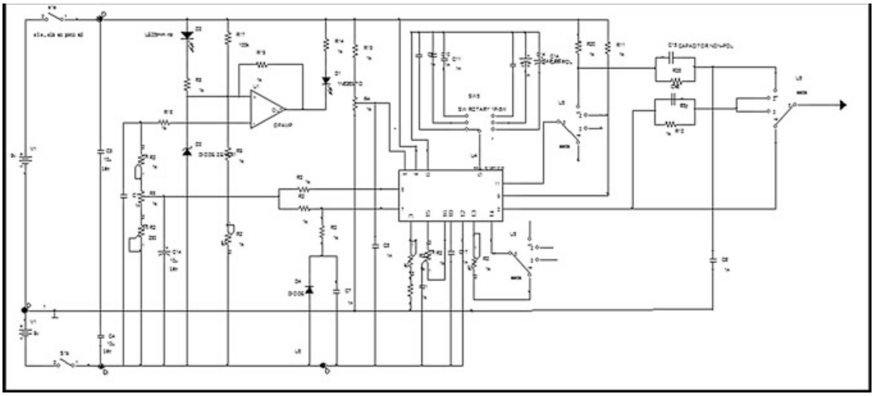


Fig. 8 Circuit diagram of brain frequency oscillator

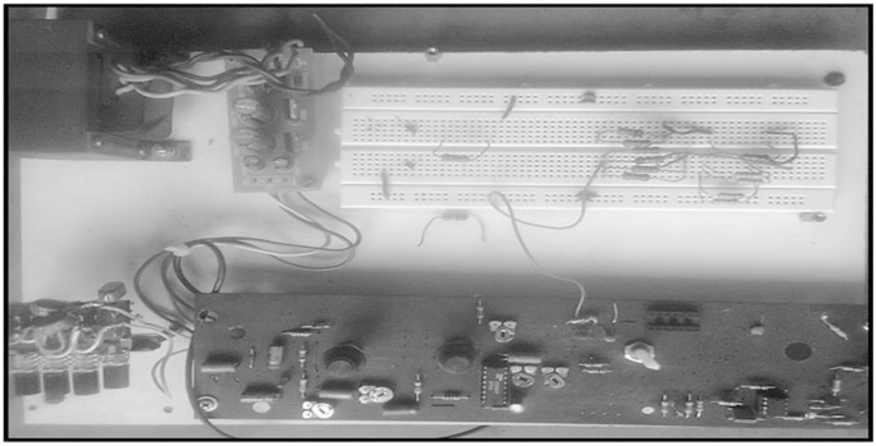


Fig. 9 Snap shot of brain frequency oscillator

9 Difficulties Faced

1. Minute variations in frequencies are complex to handle for the prototype.
2. Brain frequency oscillator produced voltage of maximum 8 V where micro controller limit is up to 5 V.
3. Access to brain functioning and the properties of waves were hard due to the multi disciplinary nature of the project.

Fig. 10 Neuro sky

Fig. 11 T.I. wrist watch

10 Solutions to Problems Faced

1. We found that the Brain frequency will be constant for short duration.
2. Limited the voltage using Voltage rectifier and made 3 V to pass on micro controller.
3. Queried with doctors, research students and Bio medical dept. engineering college students and professors of various colleges for collecting data's.

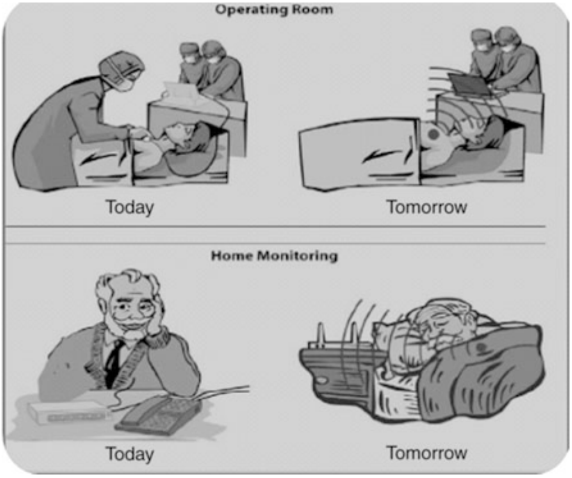


Fig. 12 Precaution is better than curing

11 Advantages

- Patients can be monitored via mobile phones.
- This can be utilized by the senior citizens who feel hard to communicate.
- Storing of Neural signals can be used for Investigation and for future medical affairs (Fig. 12).

12 Applications

For Monitoring

- Mentally retarded person
- Coma patients
- Senior citizens
- Defense purpose

13 Conclusions

In summary, it is possible to interlink brain and a mobile phone with an EEG machine. Monitoring the brain is usual but notifying instantaneous brain status or mental activity like hunger, anger and tension is a new thing we have implemented with biotelemetry. Thus it can be concluded that it is the immediate system that can be more comfortable for patients as well as for care takers in emergency situation.

Acknowledgments This project prototype has been done and success fully submitted to final phase of ***PDMA India innovation contest*** (***National level student design contest*** **2011–2012**). Through PDMA, ***LAP Lambert Academic Publishing, Germany*** asked this project for *publishing in their magazine*. This project idea has discussed with Dr. Premnath Kishan, PhD in ***National Institute of Mental and Neuro Science***, Bangalore. The overall project activity is monitored by Dr. D. Balasubramaniam, PhD, *HOD of GKM college of engineering* and Mrs. Su. Suganthi, *Asst. Professor of GKM college of engineering*. B. Ananda Narayanan, *M. Tech. IIT,* R. Anand final *year ECE from RMK Engineering College* and R. Sujitha *final year ECE from Jerusalem college of Engineering* supported well to finish this project.

References

1. Parelus P, Principe J, Rajasekaran S (eds) (2001) Making sense of brain waves: the most baffling frontier in neuroscience. Biocomputing. Kluver, New York. Chap. 3, pp 33–55. Lecture: "International conference on biocomputing" at the University of Florida, Gainesville FL 25–27 February 2001 Organizers: Parelus P, Principe J, Rajasekaran S
2. Harper R, Rodden T, Rogers Y, Sellen A (eds) Being human: human-computer interaction in the year 2020. Microsoft Research Ltd, Cambridge, ISBN: 978-0-9554761-1-2
3. Brain fingerprinting From Wikipedia, the free encyclopedia
4. Brain Wave Signal (EEG) of NeuroSky, Inc. December 15, 2009
5. http://www.youtube.com/watch?v=HVGlfcP3ATI&feature=fvwrel
6. http://www.youtube.com/watch?v=yI_8cx4m0Is&feature=related
7. Langleben DD et al (2005) Telling truth from lie in individual subjects with fast event-related fMRI. Hum Brain Mapp 26:262–272
8. Freudenrich C, Boyd R How Your Brain Works
9. Figueiredo N, Silva F, Georgieva P, Tomé A. Advances in non-invasive brain-computer interfaces for control and biometry. Department of Electronics, Telecommunications and Informatics Institute of Electronic Engineering and Telematics of Aveiro (IEETA) University of Aveiro Portugal
10. Makeig S Mind monitoring via mobile brain-body imaging. Swartz Center for Computational Neuroscience, Institute for Neural Computation, University of California, San Diego
11. The effect of high frequency radio waves on human brain activity: an EEG study Ke Wu, 1 Amirsaman Sajad, 2 Syed A. A. Omar, 3 and William MacKay 4 1Third Year Undergraduate, Human Biology Specialist, Genes, Genetics and Biotechnology. 2Fourth Year Undergraduate, Physics and Human Biology Double Major, University of Toronto. 3Fourth Year Undergraduate, Human Biology specialist in Genes, Genetics and Biotechnology, University of Toronto. 4Professor at Department of Physiology, University of Toronto; email: william.mackay@utoronto.ca. Corresponding author: Ke Wu, ke.wu@utoronto.ca
12. Baporikar V et al Wireless sensor network for brain computer interface. Int J Adv Eng Sci Technol 8(1):75–79
13. IEEE/Bio-medical papers of EEG
14. Sanei S, Chambers JA EEG Signal Processing. Centre of Digital Signal Processing Cardiff University, UK, p 17

15. FBA Fundacio de Biofisica Aplicada, Material de apoyo, Brainwave Frequency Listing
16. Ghiyasvand MS, Guha SK, Anand S, Deepak KK A new EEG signal processing technique for discrimination of eyes close and eyes open. Centre for Biomedical Engineering, Indian Institute of Technology New Delhi, India. Department of Physiology, All India institute of Medical sciences
17. Anderson A III, Wegener C, Thome R, Shikha, Lorenz M (2005) Portable electroencephalogram biofeedback device. Final Report Update: 16 Dec 2005 BME 200

Part X
Design Training and Education

Mapping Design Curriculum in Schools of Design and Schools of Engineering: Where do the Twains Meet?

Peer M. Sathikh

Abstract Schools of engineering in established universities such as Purdue offer courses in engineering design which, '… allows (students) to apply the fundamentals of engineering and science to solve open-ended design problems' and to learn a structured problem-solving process in the broad context of product design, considering marketing, problem definition, conceptual design, design evaluation, detailed design, manufacturability, and economic feasibility. To anyone teaching in a design school, it sounds like industrial design taught in a school of design. If both the schools proclaim that they teach 'design', then what are they teaching? Where is the difference? Where do they overlap? Where are the commonalities? This paper sets about mapping the typical courses taught at schools of design and schools of engineering offering undergraduate degrees in industrial design and mechanical engineering respectively. Through this the author highlights the possibility of a hybrid programme, which may represent the real world nature of design in the built environment today.

Keywords Engineering design · Industrial design · Education

P. M. Sathikh (✉)
School of Art, Design and Media, Nanyang Technological University,
81 Nanyang Drive, Nanyang 637458, Singapore
e-mail: peersathikh@ntu.edu.sg

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_88, © Springer India 2013

1 Introduction

Design, together with creativity and innovation, has become a common word in the Vocabulary of the 21st century, seen and heard more often, be it in the newspapers or social media or television, etc. As an industrial designer the author is left wondering what 'design' means to different people. Is it the shape; the function; the software, the performance? As an educator, the author is left with even more intriguing question, 'what do we mean by *teaching design*?' These questions became more apparent with more and more students facing the dilemma faced by students considering design education options between an engineering school and a design school? The world over, design (industrial design or product design) is a four year degree programme.[1] Product design is also taught as a specialisation or as a part of mechanical engineering in four-year engineering degree programmes in most of the countries. Which way should one go?

What, is the difference between design as taught in design schools and engineering schools? Where lie the focus and the difference? Is there an overlapping area that can be exploited to develop an undergraduate programme that can produce designers who are can fit into a 'total product development' environment.

The objectives of this paper are:

- To look at the curriculum, syllabus, aims and objectives of design courses/programmes at undergraduate level offered in design schools and engineering schools, taking examples of each.
- To identify the differences between these two.
- To present a visual map which shows the elements of the two courses within the same spectrum.
- To explore the possibility of a curriculum that can combine elements of both which could be relevant to the future direction of the globalised world.

2 Curriculum, Syllabus, Course Aims and Objectives (Outcomes)

Heywood [1] defines curriculum to be *the formal mechanism through which intended educational aims are achieved*. Curriculum pertains to the entire length of study in a programme and consists of a set of courses, which allows an institution to achieve the overall aims and objectives of a particular programme and/or course as

[1] While most offer four year degree programmes (BFA, BID or BDes), some schools, especially in the United Kingdom offer a three year BA programme in design which usually requires students to have completed a one year foundation in art and design which then adds up to a four year equivalent.

it was originally intended. Syllabus, on the other hand could be defined as an outline or overview of a particular course setting out the topics, reading materials, time lines, expectations of class engagement by the lecturer, expected learning outcome (objectives) from the student at the completion of that course. In essence, studying the curriculum, syllabus and the aims and objectives of individual courses of an institution could be an indicator as to what the students may turn out to be at the end of the studies. A study of the course of aims of design programmes in engineering schools against those in design schools could then lead to a better understanding of ‘design’ as taught in engineering schools and design schools.

3 Aims and Outcomes for Engineering Design in Some Engineering Schools

The following have been taken from either the brochure/prospectus or the website of the respective universities mentioned. The highlighting in bold letters is by the author.

3.1 Purdue University

Students in the School of Mechanical Engineering at Purdue University have many opportunities to participate in design projects, which allow them to apply the fundamentals of engineering and science to solve open-ended design problems. Sophomores in the Cornerstone design course learn a structured problem-solving process in the broad context of **product design, considering marketing, problem definition, conceptual design, design evaluation, detailed design, manufacturability, and economic feasibility**. Seniors in the Capstone design course bring together design process knowledge with technical analysis capabilities that they have learned in the core curriculum to **develop their own conceptual designs into working prototypes**.

3.2 Nanyang Technological University, Singapore

This flagship four year Mechanical Engineering degree programme has been meticulously tailored to meet the needs of the local economy and beyond…The programme has three streams to cater to our students’ differing needs and interests. Most students will enrol in the mainstream while approximately **20 % of the students in each cohort may choose to pursue an in-depth specialisation in either Design or Mechatronics** starting from their second year of study…The Design Stream’s emphasis (is) on creativity, technology and design methodology.

Trains you to be an innovative design professional, competent in engineering. Courses you can expect to explore:

- Creative Thinking and Design
- Product Presentation.

4 Engineering Education Accreditation Body's Requirement for Engineering Design Curriculum

ABET, Inc., is the recognised accreditor for college and university programmes in applied science, computing, engineering and technology in the USA. The design-related requirements that ABET places on US engineering programmes for accreditation states that a curriculum must include most of the following features:

- development of student creativity;
- use of open-ended problems;
- development and use of modern design theory and methodology;
- formulation of design problem statements and specifications;
- consideration of alternative solutions;
- feasibility considerations;
- production processes;
- concurrent engineering design; and detailed system descriptions;

ABET seems to specify what are the necessary requirements but **does not mention the essential requirements** that is necessary in order to produce an engineering designer (http://www.abet.org). The course examples shown in Sect. 3 of this paper shows a level of adherence to ABET's requirements for accreditation of an engineering design course.

5 Aims and Outcomes for Product Design in Some Design Schools

The following have been taken from either the brochure/prospectus or the website of the respective universities mentioned. The highlighting in bold letters is by the author.

5.1 Nanyang Technological University, Singapore

The BFA in Product Design at the School of Art, Design and Media, offers a **curriculum in design methodologies and an environment conducive to**

innovative thinking. Beyond problem-solving skills and in-depth analysis of users, markets and cultural values, students also learn to redefine problems and question traditional methods while developing **new means of seeing and thinking**. Through close interaction with faculty, in small studios and classes, and with a dynamic laboratory and workshop for producing new forms, students gain the experience, knowledge and vision to create innovative work of strong conceptual value.

5.2 Purdue University, USA

The undergraduate programme (in industrial design) is a four-year degree with an emphasis in form giving for manufactured goods. Students' graduate with the ability to be **innovative problem solvers** and create **aesthetically appropriate forms** that can be **manufacture** by industry.

6 Design Accreditation Body's Requirement for Product/ Industrial Design Curriculum

National Association of Schools of Art and Design (NASAD), (http://nasad.arts-accredit.org/) is the recognised accreditor for college and university programmes in art and design in the USA. NASAD's competency requirements for recognising an industrial design programme in US as well as in other countries are:

- A foundational understanding of how products work; how products can be made to work better for people; what makes a product useful, usable, and desirable; how products are manufactured; and how ideas can be presented using state-of-the-art tools.
- Knowledge of computer-aided drafting (CAD), computer-aided industrial design (CAID), and appropriate two-dimensional and three-dimensional graphic software.
- Understanding of the history of industrial design.
- Functional knowledge of basic business and professional practice.
- The ability to investigate and synthesise the needs of marketing, sales, engineering, manufacturing, servicing, and ecological responsibility and to reconcile these needs with those of the user in terms of satisfaction, value, aesthetics, and safety. To do this, industrial designers must be able to define problems, variables and requirements; conceptualise and evaluate alternative; and test and refine solutions.
- The ability to communicate concepts and requirements to other designers and colleagues who work with them; to clients and employers; and to prospective clients and employers. This need to communicate draws upon verbal and written

forms, two-dimensional and three-dimensional media, and levels of detailing ranging from sketch or abstract to detailed and specific.
- Studies related to end-user psychology, human factors and user interface.
- Opportunities for advanced undergraduate study in areas which intensify skills and concepts already developed, and which broaden knowledge of the profession of industrial design. Studies might be drawn from such areas as engineering, business, the practice and history of visual art and design, and technology, or interdisciplinary programs related to industrial design.
- Easy access to computer facilities; woodworking, metalworking, and plastics laboratories; libraries with relevant industrial design materials; and appropriate other work facilities related to the major.
- Opportunities for internships, collaborative programs, and other field experiences with industry groups.
- Participation in multidisciplinary team projects.

7 Differences Between the Two Schools

NASAD defines industrial design as 'the professional service of **creating and developing concepts and specifications that optimise the function, value, and appearance of products and systems for the mutual benefit of both user and manufacturer**. Industrial design involves the combination of the visual arts disciplines and technology, utilising problem-solving and communication skills'. This definition is the same as that adopted by the Industrial Designers Association of America, [2].

ABET defines engineering design as **'**the process of **devising a system, component, or process to meet desired needs**'. This could be elaborated as 'the process of ensuring, through systematic analysis, simulation and testing, that a(product) design functions as intended and that it can be produced at acceptable cost' as stated by Templemann and Pilot [3].

7.1 Clear Differentiation on the Accent of Design Education

Based on the definition of design by NASAD and abet the main differences between design in design schools and engineering schools can be summarised as below:

- Industrial design's emphasis is on use and function is focused towards the users, leading to a user centred design approach to design.
- Industrial design also gives importance to the aesthetics of the final result (product or object)

- Engineering design's emphasis is on use from the point of view of function drivers (mechanical, electrical and electronics, structural, etc.)
- Engineering design education lays importance on optimising the function drivers to efficiency, manufacture, cost.

Womarld [4], Eggink [5] and many others tend to show a clear difference in industrial design education requirements from engineering design education as well.

7.2 Anomaly of Sorts in Practice

In studying the curriculum of the design programmes engineering schools in many parts of the world, one could believe that principles and processes of industrial design would also be taught. Where does this lead to in terms of the industry understanding of design? How does one understand relationship between 'fuzzy front end' aspect represented by industrial design and the 'analysis, synthesis and optimisation' approach of engineering design?

8 Mapping the Curriculum

Table 1 compares the curriculum between typical industrial design and engineering curriculum (nearest to engineering) placing five attributes namely, core skills, core knowledge, core studio/hands on, additional knowledge, capabilities.

It is apparent from Table 1 that for either programme to offer attributes from the other, some of the important core elements of the original programme need to be dropped. This leads us to the question of how rigorous would the integrated 'industrial/product design engineering' course be, in terms of justifying a curriculum that has both the accents of design? While a direct answer may not be possible, an indication of the challenges of such integration maybe possible through the visual mapping of typical curriculum based on Table 1, as shown in Fig. 1.

Figure 1 visually positions courses along subject areas in the X axis and focus (or intensity) of the courses on the Y axis as proposed by the author. Engineering courses are depicted as having a breadth ranging from science to application while design courses have a breadth ranging from art to application. One can clearly see from this map that engineering design harnesses science through technology to apply to real world situations while design harnesses art through humanities to apply to real world situations. Both the schools seem to overlap at the application level, with engineering reaching out to humanities and design reaching out to technology. As per this model, engineering courses are centred on technology while design courses are centred on humanities, and perhaps, social sciences. The challenge in developing any hybrid programme, then, is to find ways to bring

Table 1 Comparison of typical curriculum

Attribute	Industrial design	Engineering (related to design)
Core skills	Sketching/freehand drawing	Detailed level technical drawing CAD/CAE
	Model making	
	Visual communication techniques	
	Technical drawing/CAD/CAID Photoshop, illustrator skills, etc.	
Core knowledge	History of art, design and society	Math/physics/chemistry
		Mechanics of solids/machines
		Fluid mechanics/hydraulics
	Theory of design/design methodology/design research	Thermodynamics/thermal engineering
	Design elements/aesthetics	Machine element design/systems Design/part and component design
	Human factors/ergonomics	
		Analysis/optimisation
	Interaction/user experience	Materials/manufacture
Core studio/hands on additional capabilities	Product design (up to 6 courses)	Intermediate projects
		Capstone/final year project
	Conceptual design	Industrial engineering
		Operation management
	Form studies	Project management
	Minor projects	Project report, presentation project report viva voce
	Final year project	
	Marketing/product planning	
	Project management	
	Project report, multimedia presentation	

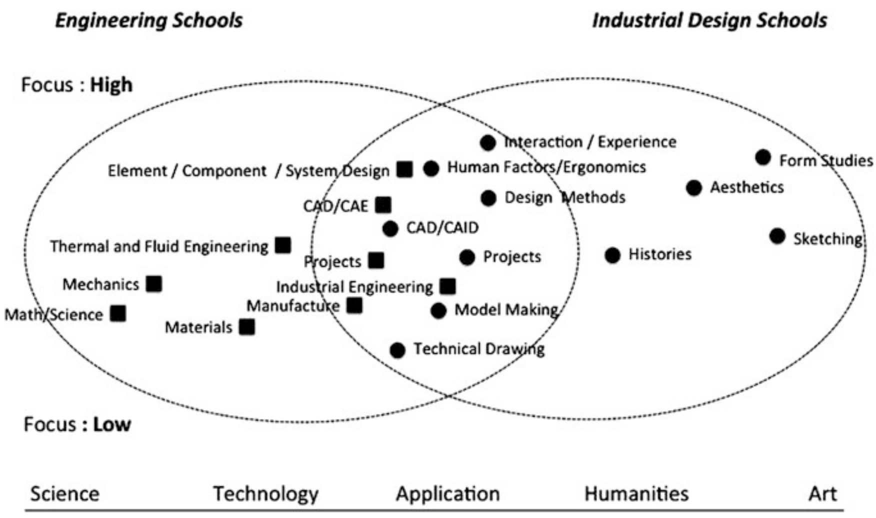


Fig. 1 Visual mapping of curriculum. ■ Engineering courses. ● Design courses

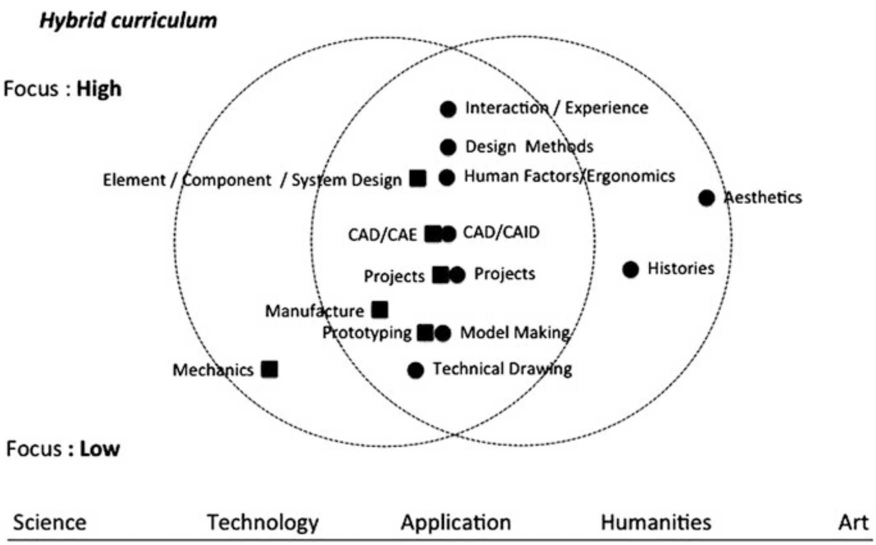


Fig. 2 Visual mapping of a possible hybrid curriculum. ■ Engineering courses. ● Design courses

subjects related to both together without losing the overall relevance of the courses.

One possible scenario for a hybrid curriculum is shown in Fig. 2, which depicts a four-year professional (hybrid) design programme. This curriculum compromises on two important elements of a typical design curriculum, namely sketching

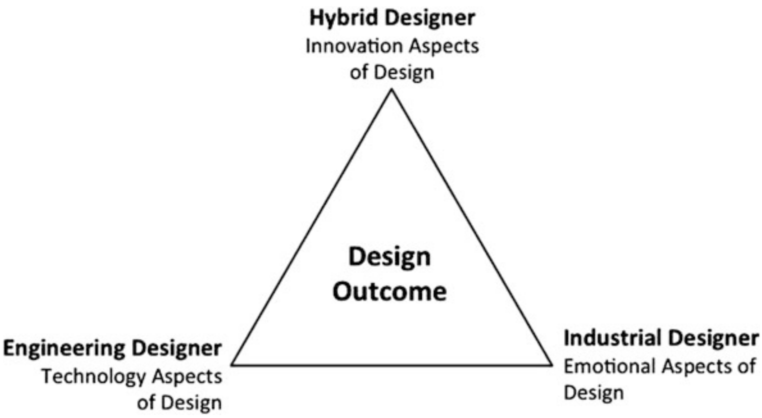


Fig. 3 Contribution zones of designers

and form studies as core subjects. This also has taken out engineering fundamentals in math/science and technology courses on thermal and fluid engineering. In other words, subjects that are fundamental/foundation to both have been removed. While it can be argued that basics of these subjects can be introduced under subjects termed foundation studies or electives, what is missed out is the rigour at which they were taught under traditional/classical curriculum of engineering or design. The end result of such hybrid curriculum could be graduates who have solid process and project knowledge who may not have sufficient skill or knowledge in making decisions on form and other aesthetics related issues as well as not be able to fully utilise the domain knowledge required in mechanics or thermal, fluid engineering, etc. The positive result of such hybrid curriculum would be the designers who will excel in managing projects whose fundamentals of engineering and art have been clearly defined. These hybrid designer-engineers could fit well into situations where decisions on design have to be made 'on the fly' at mass manufacturing centres which are far away from the origin of design, such as in China or Vietnam. They would have strong application knowledge and project management skills together with sufficient peripheral knowledge in areas related to art and engineering to make such decisions.

Is hybrid curriculum, then, be the new trend in design education? While the hybrid designer-engineer will figure prominently in the design of new products, the author feels that fundamental decisions related to the emotional side of a product (which require art, humanities and social sciences) will still be influenced by designers from the classical design schools, while fundamental issues related to engineering and technology applications will still come from design engineers from the traditional school of engineering. Figure 3 depicts possible zones of contribution by graduates/designers from the three curriculums. In presenting this model of contribution, the author's intention is to point out different products require different levels of focus. Furniture, ceramics and personal products such as watches, spectacles and jewellery require higher level of involvement in art and emotion. In such instances designers from a classical school of design would play dominant roles in the determining the final outcome of the product. Similarly, products such as precision instruments, engines and motors require engineering designers to play a dominant role in the design of such products. Products requiring new paradigm in user experience and application of technology such as smart phones and tablet computers benefit from inputs from designers originating from hybrid curriculum. There would be exceptions to this, especially in smaller companies perhaps, where one designer plays all three roles.

9 Discussions

The intention of this paper was to understand the curriculum of design degree programmes offered by schools of engineering and schools of design before visually mapping the two curriculums to compare them. This map gives a clear idea of the focus of each of these curriculum and allows for identifying possibility of establishing a hybrid curriculum, as has been established by several institutions around the world. The author highlights through this paper, that such hybrid programmes may compromise on the subjects/topics which are fundamental to engineering courses and which form the foundation for design course. In doing so design outcome may lose on fundamental principles of engineering and attention to visual aspects of design. At the same time, hybrid designers could play a prominent role as ‘innovators’ especially in products requiring new paradigms in user experience and technologies.

This paper, by outlining the three possible curriculum that produce designers with different focus and accent to their dominant roles in design, presents the importance of consideration of the human (designer) aspect in design research. It may be stated that designer, environment and process form the eco-system for effective design outcomes that show relevance through their success in the market place. The designers, in turn, are products of the different curriculum that produced them in the first place.

Acknowledgments This paper has drawn many of the curriculum and subject information from the websites of the various universities and institutions mentioned. Steps have been taken, as much as possible, to present information, which are up to date. The author wishes to place on record, his gratitude, for the availability of such information, to those universities and institutions that are mentioned in this paper, as well as those which are not mentioned in this paper whose information has been important in presenting ideas depicted herein.

References

1. DymHeywood J (2005) Engineering education: research and development in curriculum and instruction. Wiley, USA. ISBN 13 978-0-471-74111-4, ISBN-10 04-471-74111-6
2. Industrial Design Society of America (IDSA). (2010) ID defined. http://www.idsa.org/

3. Templeman E, Pilot A (2011) Strengthening the link between theory and practice in teaching design engineering: an empirical study on a new approach. Int J Des Educ 21:261–275
4. Womarld PW (2011) Positioning industrial design students to operate at the ‘fuzzy front end’: investigating a new arena of university education. Int J Des Educ 21:424–447
5. Eggink W (2009) A practical approach to teaching abstract product design issues. J Eng Des 20(5):511–521

A National Academic-Industrial Research Program with an Integrated Graduate Research School

Göran Gustafsson and Lars Frenning

Abstract ProViking® is a successful Swedish twelve-year research program in product development and production. Rather than to stimulate the emergence of new companies, it aims at strengthening the existing Swedish industry by producing scientific results at the highest international level and Ph.D.'s for work in the industry. ProViking® comprises a large number of research projects, jointly run by universities and industrial companies, and a national graduate school which provides courses for the Ph.D. students that work in the projects. The total ProViking® budget is close to 110 M€, of which 43 M€ is supplied by the Swedish Foundation for Strategic Research and the rest by the industrial project partners. Since the program started in 2002, forty-one different research projects have so far resulted in several hundred conferences and journal papers. Some fifteen patents have either been granted or have applications pending as a result of the research, and almost one hundred Ph.D.'s have graduated.

Keywords Research · Program · Industrial · Graduate · School

G. Gustafsson (✉)
Department of Product and Production Development, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden
e-mail: gorang@chalmers.se

L. Frenning
PPU-ProViking, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden
e-mail: lars.frenning@proviking.se

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_89, © Springer India 2013

1 Introduction

Sweden is a small but highly industrialized country with many successful international companies. The increasing global competition in the last few decades in particular has however forced an increased emphasis on the development of new and better products as well as faster, cheaper and more efficient and environmentally friendly methods to conceive of, develop, design and produce them. In addition, the vast majority of the Swedish international companies were founded on the basis of inventions and innovations in the late 1800s and the early 1900s, so there was and still is also a strong consensus across the national political borders that Sweden needs to nurture its small and medium-sized enterprises (SMEs) in order to create conditions which helps more of them to grow into large companies.

The background for what will be presented in this paper was therefore a strong desire to stimulate in particular the development of Swedish SMEs, and to do this through academic-industrial cooperation which would even better than before utilize the knowledge and competence in the domestic universities to further improve Sweden's international industrial competitiveness.

The ProViking® research program [1], which was launched in 2002, is an effort to strengthen the Swedish industry through a large number of research projects which involve academic as well as industrial partners with the intention that they shall produce useful scientific results at the highest international level. In addition, an integrated graduate school shall educate Ph.D.'s that are interested in and have backgrounds that are suitable for industrial rather than academic careers.

Previous papers on ProViking [2, 3] have mainly discussed aspects of ProViking's national graduate research school, and how that institution has developed over the years. This paper presents both parts of the ProViking program, i.e. the research projects and the graduate school. The first author is the Director of Studies of the ProViking National Graduate Research School and the second author is the Program Director of the entire ProViking research program. They have both held their positions since the start of the program.

2 The ProViking Research Program

2.1 Two Phases

ProViking is the result of expressed Swedish industrial needs for long-term research in the area of product development and production. Before and shortly after the turn of the last century there existed several different national research programs with or without integrated graduate research schools which aimed at strengthening various parts of the Swedish industry, or support it in several ways. Two of them were the Swedish Engineering Design Research and Education Agenda, ENDREA [4], and PROPER. Both included graduate schools. ENDREA focused on engineering management and product development while PROPER was dedicated to production research.

In the early 2000s however, the Royal Swedish Academy of Engineering Sciences, IVA [5], assembled the most important domestic stakeholders in the entire field of product realization to talk about what ought to follow ENDREA, PROPER and some other programs. The hearings and intense discussions with both industry and academia resulted in a new approach to the national industrial research: a broad program dedicated both to product development and production research, and with an integrated graduate research school, aimed at increasing the competitiveness of the Swedish engineering industry in general. Universities and companies should work together in the projects and produce research results at the highest international level. The doctors from the graduate research school should have knowledge and experiences that would make them suitable for industrial careers. Finally, ProViking, as the program was later named, should boost existing companies rather than stimulate the advent of new enterprises.

The ProViking program was launched in 2002. With its very wide coverage it has come to incorporate not only ENDREAs and PROPERs fields, but it extends beyond them. ProViking has from the start been financially supported by the Swedish Foundation for Strategic Research, SSF [6], and the total budget for its twelve years is around 110 M€. Of this sum, SSF directly supports the participating universities with 43 M€ while the remaining and larger part of the funding is provided by the industrial project partners in the form of cash, in kind (work) and other resources.

ProViking was initially planned as a six-year effort, and SSF established close coordination with VINNOVA [7] and the Knowledge Foundation [8], two other domestic research financers in the same field. However, towards the end of that period, in 2007, ProViking's scientific achievements were evaluated by four invited academic specialists from Canada, Denmark, Germany and Hungary, and their report showed such good results from both the research projects (see Table 1) and the integrated graduate school that SSF decided to extend ProViking by another six years. This was another sign of success since SSF normally only finances efforts that are limited in time to six-year periods. The two ProViking periods are somewhat overlapping and according to the plan the extended program expires at the end of 2013.

Table 1 Success of the ProViking1 research projects on a five-point scale, as assessed by the ProViking Scientific Council in 2007. (The non-integer numbers are due to split scores.)

Score		Number of projects
5	Excellent	3,5
4	Very good	7
3	Good	7
2	Fair	0,5
1	Poor	0
Total number of projects		18

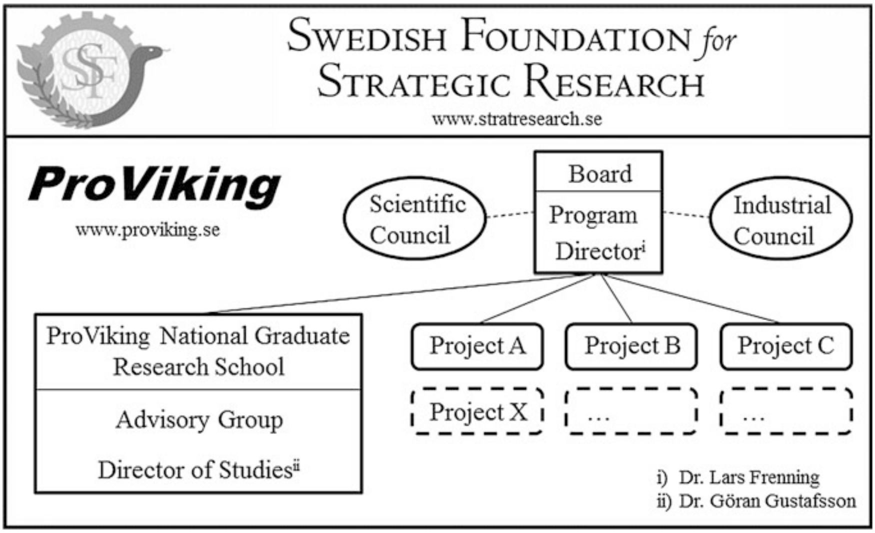


Fig. 1 Organization of the ProViking research program

The ProViking research program is governed by a Board with representatives from universities as well as industry. To assist them and the Program Director there is a Scientific Council with researchers from international universities which assesses applications for new projects, and an Industrial Council which provides advice on the industrial relevance of ideas and proposals for research projects. The integrated ProViking National Graduate Research School which will be described later in the paper has its own governing board in the form of an Advisory Group that supports the Director of Studies. Figure 1 shows the organizational structure of the ProViking program which has remained almost unchanged for a decade.

ProViking is also one of the founders of The Swedish Production Academy (Sw. Svenska Produktionsakademien), an organization of academics with professional interests in production. It supports cooperation in production research and production education and has an ambition to be an influential partner in this area. There are plans to create a corresponding organization for product development professionals. With an aim to boost the production knowledge in the domestic industry as well as in academia, ProViking has also both headed and largely funded an IVA project titled Production for competitiveness.

2.2 The Research Projects

The first phase of the program, ProViking1, in 2002–2007, involved eighteen different research projects. The second phase, ProViking2, which runs in 2008–2013, comprises twenty-three projects. All of these have and have had a focus on industrial development and/or manufacturing in Sweden in order to produce new concepts, theories, methods, tools and work routines that can strengthen the Swedish industry. The areas of interest are ideas, product development, design, production, product support, maintenance, end use and recycling, all in a life-cycle perspective. Some projects can be considered as commercially high-risk ones, since they have involved very novel ideas and complex technology.

The ProViking projects can all be categorized as applied research projects in the sense that the research questions that they deal with have been suggested as well as formulated by the industry, and not by university researchers. They vary in both length and amount of money allocated to them, but they all involve academic *and* industrial partners/institutions. Although SMEs are of particular interest, also large companies take part. Most of the projects have far more industrial participants than the minimum two, which of course reduces the cost for each of them. From the universities senior researchers as well as Ph.D. students take part, and foreign post docs have also been involved in some cases.

In addition to the several hundred conference and journal articles that have been published to report the scientific results from the ProViking research projects, the outcomes are also presented at yearly Result Days in selected cities all over Sweden. These are open to everyone interested since the policy of the Swedish Foundation for Strategic Research is to make public all results from the research projects that it finances. The idea behind the Result Days is also to give other companies than those directly involved in the ProViking projects opportunities to meet the researchers in person and discuss with them. As a complement to the Result Days, and as an alternative for those interested but who cannot attend, ProViking has also in collaboration with several other actors developed the Result Center^{TM} [9]. This is a meeting place on the web for all those involved in Swedish product development and production research which contains information about companies and institutions as well as individual researchers and ongoing research projects, ProViking's and others.

Since some of them are still running, there has yet been no evaluation of the ProViking2 projects. In all about fifty different companies and organizations were involved in ProViking1 though, of which twelve were SMEs. Of the in total eighteen ProViking1 projects, three focused on management, eight on production and seven on design, and the success rate of them is shown in Table 1. It is believed that the comparatively high scores, with part of one project rated fair and the rest better or *considerably* better, is due to the fact that each problem is worked on by people with different knowledge and background from industry and academia in cooperation. This creates very productive and intellectually challenging environments where the results exceed the sums of the individual contributions. On the educational side this is of course very positive also for the Ph.D. students who do their research in ProViking projects. They get the best of both industry and academia, and they develop an understanding of industrial research which makes it natural for them to look for careers not only in universities but also in companies.

As examples of very concrete and useful outcomes from the ProViking program it can be mentioned that during ProViking1, six patents came out of the eighteen projects. In ProViking2, five patents have so far been granted on basis of research results from the twenty-three projects in this phase, and another four patent applications are pending decision. It should then be noted that a Swedish patent is only granted for an invention that has a certain “innovation height”, which means that it is substantially different from and better than anything that is hitherto known, and that it is also useful in practice.

Some ProViking projects have resulted in very interesting and novel applications. One example is a project to develop a new way to build an electric motor. The magnetic parts of today’s standard motors consist of stacks of thin steel plates with layers of insulation between them, but with the new method, one such part is instead cast in one piece made of a soft magnetic moldable composite. The new material is a good magnetic conductor at the same time as it has the mechanical properties of a very strong polymer. Motors which are made in this way are not only cheaper to make than the standard ones, they also have higher efficiencies than what comparable existing designs have.

Another project is devoted to the problem of corroding surfaces in fuel cells. One way of protecting these surfaces is to gold plate them, which is obviously a very costly technique. The project studies how a new material, which is not only cheaper but also increases the life of the plates as well as the efficiency of the fuel cell, can be applied to reach the best overall result.

In a third ProViking project a method has been developed for automated disassembly of scrapped LCD screens, the yearly number of which is on the rise. Instead of incineration, which is the present and from an environmental point of view far from ideal alternative ending for these devices, the process makes it possible to recover not only harmful substances from them but also components which can be reused to build new and different products.

Efficient induction heating is the subject of a fourth project, which has demonstrated that remarkable energy savings are possible at the same time as the cycle time can be reduced, and several other projects are devoted to the development of various simulation techniques. Besides these there are more than 30 other finished or ongoing projects which deal with many other problems.

Although the intention behind ProViking is and has always been to strengthen *existing* domestic companies, as a bonus some new enterprises have also emerged based on the results from a few of the research projects.

2.3 The ProViking National Graduate Research School

Already at the beginning of the first ProViking phase a graduate school was set up to organize courses for all Ph.D. students who were somehow to become engaged in the ProViking research projects. The purpose was and still is to produce researchers with industrial as well as academic competence for work in the industry. This is in contrast to traditional Swedish graduate education, which has rather tended to prepare the students for academic research careers.

All Ph.D. students who do research in and are financed by ProViking research projects, also part-timers, are members of the ProViking National Graduate Research School. Besides these, the school has also attracted a large number of other Ph.D. students who want to take part in its activities. If a student is doing research in a subject that fits in with ProVikings profile, he/she is usually admitted. A clear sign that the school is very attractive is the fact that of today's about 105 member students, the vast majority belongs to the second category, i.e., they are not associated with ProViking projects and have themselves asked to become members. 25 % of the students in the school are industrial Ph.D. students.

It should be mentioned that it is the students' home universities which confer the Ph.D. degrees on them. ProViking only provides projects to do research in and its graduate school offers courses that the students need to take to be able to graduate. At the time of writing this article, 97 students have received their Ph.D.'s during the time when they belonged to the ProViking National Graduate Research School.

The graduate school has an Advisory Board which consists of representatives of the major research universities (senior researchers/teachers), the industry and the Ph.D. students. The board assists and advices the Director of Studies on the course program and the other activities in the school.

2.3.1 The ProViking Course Program

A Swedish Ph.D. program is four years long, full time, and of that time the student typically devotes one year to course work and spends three years doing research and writing the thesis. (This balance can vary somewhat between different universities, and between different research subjects in the same university). Not long ago Swedish Ph.D. students usually took their courses at their home university, but during the last two decades this has changed so that many students now also take courses at other universities, often within the framework of some type of graduate school.

The ProViking National Graduate Research School organizes and finances courses at all major Swedish research institutions. The exact number of courses as well as their topics is constantly discussed. Both vary over time to cater to the needs of the students, which are in constant change as students graduate and leave the school and new students with other research interests enter. Courses are not duplicated, i.e. there are no two ProViking courses with the same content at two different universities, so students who need to take a particular course therefore do so at the university which offers it, which may not necessarily be their own. It has therefore become completely natural for the students during their Ph.D. programs to take courses at several universities, for some even in other countries.

The present course program contains three courses which all students have to take. The survey course in product realization, which covers all stages from perceived problem or product idea via design, production and use to retirement, serves the purpose to give all students a common view of the process that a product undergoes during its life, and of how industry works in these stages. The other two mandatory courses are on the theory of science and oral presentation and scientific writing, respectively. Besides these there are five different themes, each with a number of different courses. Four of the themes are design theory and development methodology, leadership and organization, materials science and production processes and systems, and the fifth comprises courses that do not fit into any of the other four themes. The students choose at least two courses among those in the themes.

The courses cover a wide area of subjects, which is both natural and necessary since the ProViking projects extend across so many different technical subjects. As mentioned before, the graduate school caters not only to the students which work in the ProViking projects and consequently have very different backgrounds and research interests, but also to many other engineering Ph.D. students who have joined at their own initiative. The latter tend to be an even more heterogeneous group than that which consists of students in ProViking projects.

With a geographical distance of 1,200 km between the universities with ProViking students that are the farthest apart, the ProViking courses cannot be organized and run in the same manner as local courses usually are, i.e. with lectures a couple of hours every week. Instead they are organized as 3–4 gatherings of several days in a row, with periods in between when the students, as they do most of the time, study at their home universities.

This way of organizing courses is advantageous in at least three ways:

- Each course is run by the university which is best at it, so the students perceive a course quality which is in general higher than it would otherwise have been
- Specialization and shared work among the universities (since essentially the same course is given at one institution instead of repeated at several) reduces the total national cost for education
- The gatherings give the students tremendous opportunities to meet and learn to know colleagues from other universities and develop personal networks, which is expected to lead to more cooperation and business when in the future the students will have assumed influential positions in the industry.

The ProViking course work for an individual student amounts to about half of the total course work needed for the student to get his/her Ph.D. The exact requirements vary not only between universities, but can differ also between scientific subjects in the same university. The total work for a Ph.D. in terms of hours is nationally standardized though, so a university or scientific subject which requires a lower amount of course work for a Ph.D. has correspondingly higher expectations on the research work and the doctoral thesis.

All ProViking courses are free of charge for the ProViking students themselves since the graduate school pays the universities for the education that they provide. The courses are however open also to engineers from the industry, and *they* have to pay fees if the course-giving university so decides. Professional engineers are very welcome to take the ProViking courses, not primarily because they improve the course economy but since our experience is that the course quality increases with their presence. Interviews with students and engineers who have taken the same course together confirm that both groups benefit from studying together with each other. The students are in general more updated on modern theory than the engineers are, which sometimes in practice makes them somewhat of assistant teachers in the courses. The engineers, on the other hand, have a vast collective practical experience that the students lack, for obvious reasons. This is of course also of value to the country. Not only do in this way the time and money spent produce a greater amount of collective learning than would otherwise have been the case, but engineers and students also get to know each other, which stimulates future contacts and cooperation between them.

The ProViking course with the largest proportion of engineers is one in Lean Product Development, a philosophy for how to do PD work which is presently very popular both in universities and in the industry. This was originally a course for professional engineers organized by the Chalmers School of Continuing and Professional Studies, which was later, and very successfully, opened also to Ph.D. students.

2.3.2 Other Activities in the Graduate School

The graduate school has a yearly three-day gathering for the Ph.D. students, when among other activities the group visits several industrial companies. The last gathering in May 2012 took place in a very SME-dense part of Sweden, where eight ongoing ProViking projects were presented to invited local industrialists. This was a success, since the immediate reaction from the industry people was that the results from four of the projects would be directly applicable in local producing factories.

The ProViking students can apply for scholarships from the graduate school to conduct part of their Ph.D. program at a university or other qualified research institution abroad. The length of a stay can vary from about a month up to a full academic year, and the intention is that it should widen the student's horizons by giving him/her the opportunity to study and do research in an environment which is different from the one at home. Some twenty students have so far applied and received scholarships to go to as different countries as England, France, Germany, Switzerland, China, Australia, Brazil, Canada and the United States. Most of the students have been doing research at universities, but quite a number also in industrial companies. After having returned to Sweden, they have written reports on their stays which have been published on the graduate school's homepage to stimulate other students to also consider spending some study time abroad.

3 Discussion

It is apparent from the "lessons learned" in the ENDREA program, as stated in its final report [4], that ProViking is reaping the fruits of having been preceded by other efforts at establishing national graduate schools. It was not easy in the beginning for ENDREA to get accepted by the academic advisors, but that has not been a problem at all for ProViking.

One advantage of having a graduate school of ProViking's size is that it is relatively easy to assemble large enough groups of students to actually be able to run courses. The inevitably heterogeneous background of the students—in relative terms, of course—sometimes works the other way too, so that there are fairly few students who are interested in some of the courses. But if they had not taken part in a national school they would have belonged to even smaller groups at their home universities.

What is seemingly most appreciated by the students is the opportunities they get to meet fellow students from other universities and to develop their own networks. They are also positive to the frequent contacts with engineers from industry that they get in courses, in projects and during other activities like Result Days and the yearly three-day gatherings.

The companies who take part in the ProViking projects are in general very satisfied with the research results that they get, and they also appreciate the opportunities to work closely together with Ph.D. students in the projects, which is a good way of getting to know prospective employees. ProViking has a good reputation in the industry and is always welcome, which is in turn a great asset to the school when it comes to organizing study visits in courses and during the yearly gatherings.

4 Conclusions

Since there is no previous domestic and national effort like ProViking, neither in scope nor in terms of budget, it is difficult to compare it with other programs. In some ways it resembles ENDREA, but it has a much wider scientific scope, larger budget and longer time frame. ProViking's industrial results in terms of faster, better and more economic products and processes and more competitive companies are also largely, for commercial reasons, confidential information. However, judged from the volume of published research results from the projects, the number of patents and produced Ph.D.'s, as well as the expressed appreciation of the industrial partners and the positive outcome of the assessments, it seems fair to say that ProViking, with its integration of research and education and wide scope, is and has been a very successful research program which can be a model for future efforts.

5 The Future

The second and, as it seems, final phase of the ProViking program is now nearing its end. In 2012 the Swedish Foundation for Strategic Research adopted a new strategy which during the foreseeable future excludes further financing of technical research of the type that is carried out in ProViking, as well as financing of national graduate research schools. At the time of writing this paper, the possibilities for a second extension of the research program by SSF therefore look bleak. Many ProViking projects are already closed and according to the present schedule the last courses in the graduate school will be run in late 2013. The universities in ProViking have therefore commenced discussions on how to act if the whole research program comes to an end then. If that is the case, there is a readiness and strong interest among them to try to get support from some other financer to allow at least the activities in the graduate school to continue. Now, when already several generations of Ph.D.'s have graduated from national research schools like ENDREA, PROPER and ProViking, it seems completely natural to everyone involved that this is how the national graduate education in engineering subjects should be conducted also in the future.

Acknowledgments The support from the Swedish Foundation for Strategic Research and its encouragement to publish results and experiences from the ProViking program's research projects and national graduate research school is greatly appreciated.

References

1. ProViking® (2012) www.chalmers.se/hosted/proviking-en/. Accessed 6 Oct 2012
2. Frenning L, Gustafsson G (2007) A national graduate research school in product realization. In: International conference on design education (ConnectED 2007), University of New South Wales, Sydney, Australia, 9–12 July 2007
3. Gustafsson G, Frenning L (2010) A national graduate research school with close industrial collaboration. In: The 6th international CDIO conference, École Polytechnique, Montréal, Canada, 15–18 June 2010
4. ENDREA Final Report (2012) Swedish Foundation for Strategic Research (SSF), 8 Mar 2004
5. The Royal Swedish Academy of Engineering Sciences (2012) www.iva.se/en/. Accessed 6 Oct 2012
6. Swedish Foundation for Strategic Research (SSF) (2012) www.stratresearch.se/en/. Accessed 6 Oct 2012
7. VINNOVA (2012) www.vinnova.se/en/. Accessed 6 Oct 2012
8. The Knowledge Foundation (2012) www.kks.se/om/SitePages/In%20English.aspx. Accessed 6 Oct 2012
9. Result Center™ (2012) www.resultcenter.com/?lang=en. Accessed 6 Oct 2012

Future Proof: A New Educational Model to Last?

Mark O'Brien

Abstract This paper will discuss the research, introduction, development and delivery of a recently established Masters of Arts suite of programmes. This ambitious Cross-disciplinary programme now comprises of 22 named Masters awards, taught in mixed disciplinary cohorts with multiple entry points. It draws students from across the world and represents a unique structural format within the UK Art and Design education sector. The paper will examine the experience of the delivery to the first cohorts and consider the strengths and weaknesses of the model suggesting recommendations for continuing improvement in the provision of highly flexible cross-disciplinary taught Masters provision.

Keywords Curriculum development · Cross-disciplinary · International

1 Introduction

The School of Art, Design and Architecture (SADA) at the University of Huddersfield (UoH) comprises of approximately 2,000 students and staff across 3 Departments, Art and Communication, Fashion and Textiles and 3D Design and Architecture. It is a well equipped and resourced School occupying 3 prominent locations on the central campus in Huddersfield. Historically the majority of provision has been and remains at Undergraduate level, however, in the last 4–5 years there has been a significant increase in the provision of both Postgraduate Taught (PGT) and Postgraduate Research (PGR) students as well as significant

M. O'Brien (✉)
The University of Huddersfield, Queensgate, Huddersfield HD1 3HD, UK
e-mail: m.a.obrien@hud.ac.uk

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_90,

developments in the general research profile and capacity within the School. Although PGT provision had existed within the School at various times during the previous two decades this had diminished in size to only 2 small courses and some franchised provision overseas by 2007/2008. A recently recruited senior management team for the School embarked on a series of new initiatives including the development of PGT Masters provision. The research and documentation was developed by a team of subject specialist staff drawn from across the School, which was validated to commence in January 2009. In September 2008 a Postgraduate Academic Leader was appointed with a variety of duties including the establishment and management the new provision.

2 UK Background and Context

The interest in and examples of cross-disciplinary initiatives have been widespread over the last decades, however, there has been a particularly keen interest within the design and creative industries sectors in recent years. One of the main catalysts for this interest was the publication of Sir George Cox's *Review of Creativity in Business* [1], known as the Cox Review. This set out the need to embed creative capabilities at the heart of the UK's competitive positioning within a global economy.

He called for:

> Business people who understand creativity…and who can manage innovation; creative specialists who understand the environment in which their talents will be used and who can talk the same language as their clients and business colleagues; and engineers and technologists who understand the design process and can talk the language of business.

The report encouraged universities to create 'centres of excellence […] that specialise in multi-disciplinary programmes encompassing both postgraduate teaching and research.' The focus would be on Masters level programmes which would 'bring together the different elements of creativity, technology and business', enabling students from different backgrounds and with varying levels of industrial experience to work together.

The outcome, said Cox, would be:

> executives who better understand how to exploit creativity and manage innovation, creative specialists better able to apply their skills (and manage creative businesses) and more engineers and scientists destined for the boardroom.

Many universities in the sector had already been engaging in the development of new courses and research centres with varying levels of collaboration with other disciplines. Over 30 of these were brought together in 2006 when the Design Council set up a Multi-disciplinary Design Network, supported by the Higher Education Funding Council for England (HEFCE) and the National Endowment for Science, Technology and the Arts (NESTA), which 'aimed to facilitate the sharing of knowledge and best practice across universities, to improve curriculum design and assess the impact of these new programmes' [2].

The network was never intended to be exhaustive and it recognised that other similar activities were taking place within the sector (such as at Huddersfield), it did however, include the highest profile and best resourced examples of collaborative multi-disciplinary activity. Eight of these were brought together as a series of case studies [3]. They included probably the two most reported: Design London, a collaboration between Imperial College Business School, Imperial College Faculty of Engineering and the Royal College of Art and the Centre for Creative Design (C4D) a partnership between Cranfield University and the London College of Communication, University of the Arts London. Both programmes were listed in the Business week top 30 global Design courses (2009).

2.1 Definitions and Terminology

Various terminology has been used to describe cross-disciplinary practice in UK universities without reaching any agreed definitions. As the authors of the Design Council reports [2] note 'despite more than 40 years of cross-disciplinary practice in universities there is still a lack of precision about what the terms 'inter-disciplinarity', 'multi-disciplinarity' and 'trans-disciplinarity' actually mean'.

Citing earlier work (McEwenet al. 2008; Lawrence and Despres 2004) the authors use the term 'multi-disciplinarity' to describe a situation involving the co-operation of disciplines in which the disciplines themselves remain unchanged. Inter-disciplinarity they suggest would involve an attempt to 'integrate or synthesise perspectives from several disciplines' [2] and trans-disciplinarity would transcend or involve a transgression of disciplinary norms.

The courses devised at UoH are probably closer thought not wholly consistent to the definition Inter-disciplinary. The courses although mostly of an Art and Design nature draw content and some students (MA Fashion Management, MA International Design, Marketing and Communication) from non-design backgrounds, and within the module content there is material from other academic disciplines although delivered in and Art and Design specific manner. The chosen term used at UoH has always been 'Cross-Disciplinary' representing the disciplines within Art and Design: Fashion, Graphics, Interiors etc. and recognizing the changing nature of these disciplines and the benefits of learning from practices elsewhere, as well as providing input, content and thinking from across other academic disciplines.

3 Background and Course Development

The research and development of the original courses took place during 2007/2008 The, then new MA developments emerged from the existing MA culture in the School of Art, Design and Architecture and were evolutionary in nature, building on the experience of previous MA's at Huddersfield. Academic and industry professionals were widely consulted spanning the art and design industry, educational models both current and historic were referenced internationally to inform the rationale.

The following issues and objectives were identified in 2007/2008:

- The School of Art, Design and Architecture has grown considerably during the last 12 years from approx 450 students to now approx 2,000.
- During this period we have developed clusters of degrees in 10 subject areas and we have positioned ourselves as a school at the business/professional end of the spectrum.
- We have established a solid foundation of collaborative programmes and centres which over the years have been more academically and financially beneficial to the school.
- However, we have made little effort to establish a significant strong international recruitment profile.
- It is now an opportune moment to build upon the solid undergraduate base and move more coherently and strategically into postgraduate provision.
- (Internal report).

3.1 A New Art and Design Thinking

The original ethos of the courses was to 'promote a 'new art and design thinking' and the emergence of new art and design professionals whereby students will develop heightened creative analytical skills combined with business skills,' 'Key among these is 'employer engagement' [4]. It was and still is felt that, 'Masters students now need to develop a much wider skills set including: business acumen, art and design management skills, multi-disciplinary skills, art and design initiative and leadership, alongside philosophical and intellectual attributes'. The original courses aimed 'to offer an environment, which celebrates and interrogates the blurring of subject boundaries where for example fine artists can influence and work with fashion designers and vice versa.' (Internal report).

The courses were designed to respond to growing needs of internationalization of the curricula, global markets and the importance of creativity aligned to commerce. The future of postgraduate art and design education was seen to be moving to such commonalities within multi-disciplinary approaches. The MA programmes constitute the need for a common cross-disciplinary postgraduate delivery and as such has been specified to create common research collaborations. This was not dissimilar to PGT developments elsewhere in the sector (Nottingham Trent University, Manchester Metropolitan University, University of Northumbria) many Universities have promoted collaborative and shared provision within Art and Design often from a philosophical and pedagogical position allied as in the case at Huddersfield with a pragmatic response to reduced recruitment, a withdrawal of external funding (European Social Fund, ESF) and the need to provide efficient delivery models.

3.2 Initial Provision

The first cohort of students (Circa 20) were recruited in January 2009 to the original 8 programmes in a suite named the, 'Cross-disciplinary Masters in Art and Design'.

- MA International Graphic Design Practice
- MA International Design Marketing and Communication
- MA International Fashion Design
- MA Textiles
- MA Spatial Design
- MA 3D Digital Design
- MA Fine Art
- MA Digital Media

The 8 courses shared a series of generic educational aims in addition to three course specific aims for each named award and represented an ambitious spread of disciplines to be taught in a cross-disciplinary, collaborative format.

The common aims were:

- To enable graduates and professionals from varied and international backgrounds to further develop, demonstrate and apply autonomous skills in research, analysis and practice through a structured programme, which integrates scholarly, business, creative perspectives and processes.
- To provide students a unique cross-disciplinary, cross culturally and collaborative flexible environment in which personal and professional ambitions can be achieved through independent and teamwork.
- To provide the opportunity for students to develop a perceptive and acute appreciation and application of the importance and significance of innovation and entrepreneurship by becoming art and design practitioners who also have the ability to challenge and innovate at a business and society level.
- The stimulation of an inquiring, imaginative, analytical, intellectual and creative approach encouraging independent judgement, strategic decision making and

critical self-awareness leading to advanced knowledge and practice within art and design.

- To promote the relationships between theory and practice as fundamental for lifelong skills together with knowledge transfer and a creative application to further practice or scholarship.

Towards the end of the first delivery a significant number of changes were made to the documentation however, this related mainly to the assessable submissions and team provision as well as a move to more generic module specifications within the specialist provision. The original ethos, aims, learning outcomes and philosophy of the courses was retained and 3 new awards were added:

- MA International Fashion Management
- MA International Fashion Promotion
- MA Costume

3.3 Impetus for Change

The original courses commenced in January 2009 as the delivery to the first cohort. The rationale in choosing January over September was largely due to pragmatic considerations related to the initial validation schedule. It was felt that student demand was greater for September start programmes, the vast majority of Art and Design Masters provision is September start. However, over the two initial intakes (January 09 and 10) a good relationship had started to develop with International agents and it was felt that a move to September only start would damage the continuity of these evolving relationships. Also it was felt that the overall market would be greater with 2 potential intakes. Hence the decision was taken to accept Cohort 3 in September 2010 and cohort 4 in January 2011. Cohorts 3 and 4 were taught in entirely separate groups whilst research was undertaken to look at models of delivery that might enhance efficiency and provide alternatives in terms of student choice.

Research in the sector showed that there were only 27 taught Masters programmes nationally in Art and Design with dual or multiple-entry including the 11 at UoH. The only other major provider was Northumbria University with 10 courses all the others being dispersed at a variety of institutions frequently involving elements of Distance Learning. A variety of outcomes were considered, the final model chosen included two distinct routes which involved joint teaching of cohorts as mixed groups: a 12 month September start course which commenced in September 2011 (cohort 5) and a 16 month January version commencing in January 2012 (cohort 6).

3.4 Designed Outcomes

3.4.1 Full-Time 12 Month (September Start)

The September start version of the courses resembles the standard taught format within the sector, 3 terms of study ending in a 60 credit major project. On closer examination however, it has some divergence from conventional programmes. As cohorts from each entry point are taught together (5 with 6, 6 with 7 etc. see Fig. 1) the modules taken by September start students in their terms 1 and 2 have to be non-sequential in nature as January start students will undertake these in the reverse order. To facilitate this there is an extended and intensive Induction module for the first four weeks of the courses.

3.4.2 Full-Time 16 Month with Professional Engagement (January Start)

As can be seen from the model (Fig. 1), the January start version of the courses is undertaken over 4 terms (16 months). Students complete the same 180 credits as the September start students with the addition of a 20 credit 'Professional engagement' module to be completed at some point between Easter and October for a minimum of 5 weeks equivalent study. The module can be undertaken by

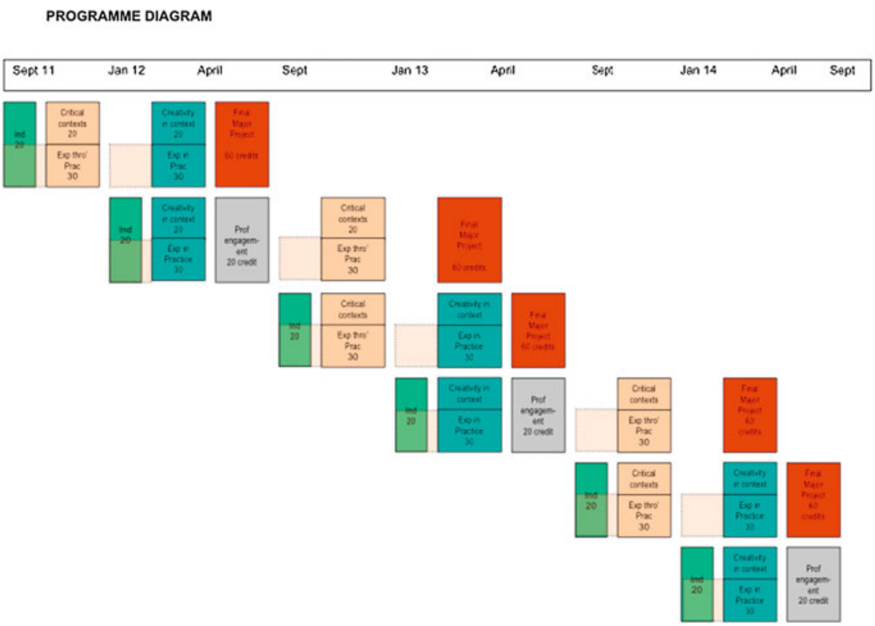


Fig. 1 Course diagram with multiple entry points

project or by placement/internship however, extensive efforts have been made to ensure that it cannot be offered or 'sold' as a guaranteed placement. The option is proving popular in International markets and also provides differentiation from the September version. Students passing the module in addition to the other modules receive a 200 credit 'with Professional engagement' degree award.

4 Delivery Experience

The experience of Full-time delivery is limited but positive. Students have reacted well to integration with new cohorts and have found the experience of meeting new cohorts as refreshing and rewarding. The student mix and interaction is positive as the courses always have 'old' students whenever a new cohort enters. There are therefore excellent opportunities for both formal and informal student mentoring.

4.1 Lessons, Experience and Recommendations

4.1.1 Non-sequential Delivery

The course consists of two main types of modules, as can be seen from Fig. 1, there are 2 'Context' modules and 2 'Exploration' modules. The 'Context' modules are primarily theory based, taught in mixed cohorts with some team elements. These can be delivered in a non-sequential manner, they contain different content from each other and students have become familiarised with many of the learning and assessment strategies from the Induction module.

The 'Exploration' modules are the 'subject' modules taught largely on a 1:1 or in small groups by Course Leaders and other subject specialist staff. The modules are generic across the 11/22 courses. The non- sequential nature of this learning does vary by course, in some courses it is sequential, students build from one project to the next, leading to their final Major Project, however, they do benefit from the interaction with students on 'other' parts of the same course. Because much of the delivery is 1:1 it is possible for students to build their learning in a sequential manner however, the longer term efficiencies required suggest that this is an issue that will need to be revisited.

4.2 Cross-Disciplinary Delivery

The courses are ambitious in the range of provision, from theory (Fashion Management) to Fine Art, some are quite technical (3D Digital Design) some very specialist (Costume). As a spread it is on occasion difficult to provide material that is of interest to all and also material that is essential to some but only very small numbers. A range of materials have been developed to enhance this cross-disciplinary delivery and have been largely well received however, there is feedback from both students and staff about relevance to individual requirements and the efficiency of delivery of specialist teaching to occasionally very small groups.

Much of the shared delivery and assessment is by team projects, this has evolved during the experience of delivering the courses, initially projects were fully cross-disciplinary with no two students in a group being on the same course. However, whilst this is still generally the case in the Induction module, for subsequent modules students have been clustered with students on related courses which has proven to be more successful and popular. As numbers increase (currently 35) increased clustering of delivery and material will continue. Modules are also supported by cross-disciplinary seminars, these are intended to be discursive and participatory in nature. These have been successful with the initial cohorts however, as the courses continue to develop this is evolving in response to student requests, seminars are a balance of delivered content as well as discussion.

4.2.1 Part-Time Delivery

Initial cohorts did contain part-time students and although delivery was never simple, it was possible to integrate students attending one day per week and completing the course over a 28 month period. Although numbers were small there were instances of high student achievement and satisfaction. However, once the current version of the courses was introduced in September 2011 the PT experience has suffered. The block delivery of the Induction module and subsequent impact on other modules has made part-time delivery very difficult and the decision has been made to withdraw provision. Delivery had always been challenging and economically questionable however, the PT students did bring fresh perspective and professional experience to the student body. Students interested in part-time study are now encouraged to apply to MA/MSc's by Research and are still welcome to attend taught sessions across all courses.

4.2.2 Integration of International Students

The nature of the student body has evolved during the evolution of the courses, becoming increasingly International in nature, drawing students from all the major continents of the world. This adds an interesting and welcome dynamic. The courses have been designed to provide an International perspective and to represent the realities of a global economy. One of the greatest assets of the courses in this respect is the range of international and cultural experience within the student body itself. The benefits of bringing students together into a larger community also enhance this, in a mixed group of 35 or more students there will usually be over 10 nationalities represented.

5 Conclusion

Although the courses have only recruited students for just under 4 years, this has involved delivery to 8 separate previous and ongoing cohorts (by January 13) and hence a notable learning experience. The courses have undergone significant amendments during this period and have been revalidated externally (December 2011) and subject reviewed externally (February 2012). It is felt that the courses have now developed a degree of maturity and stability; a model has been developed to facilitate the efficient delivery of multiple courses across a wide range of disciplines within the School with dual entry points. The central lessons to be drawn from this experience, of interest to academics and institutions considering cross-disciplinary and/or multiple entry delivery are manifold. Central amongst them however, would be to: consider with care the blend of programmes to be clustered, to examine the feasibility of further 'sub' clustering and the balance between the 'sub' and the main cluster. Multiple entry points can bring enhanced benefits to both recruitment and the student experience, although the associated complexities raised above do need to be acknowledged.

This is a unique model within UK Masters provision in Art and Design. Although not without challenges given the complexity of the provision, the Course team recognise that the structure and nature of provision provides a flexible, rich and rewarding learning experience for students.

References

1. Cox G (2005) "Review of creativity and design in UK business" HMT, London
2. Design Council (2010) Multi-disciplinary design education in the UK. Report and recommendations
3. Design Council (2010) Multi-disciplinary design education in the UK. Eight case studies
4. Clews D (2008) Future proof—new learning in the creative and cultural industries, ADM HE

Talking Architecture: Language and Its Roles in the Architectural Design Process

Yonni Avidan and Gabriela Goldschmidt

Abstract Architects use language intensively along the design process. Students are often asked to talk about their concepts, which sets the verbal language as the main tool used by students for communicating information, in spite of the fact that the architectural act is conceived as visual/spatial. The study challenges the notion that language is inferior compared to visual representation, and places the verbal expression as an essential part of the design process. The study follows architecture students, whose verbal concepts during one semester were mapped in terms of consistency, variability and development. A correlation was found between the percentage of evolving concepts in the process and the final studio grade. Analyzing semantic networks of design processes showed a higher number of links between concepts for students with higher grades, supporting the argument that language has an important role alongside graphic products in the architectural studio.

Keywords Design process · Design education · Language · Verbal concepts

Y. Avidan (✉) · G. Goldschmidt
Technion—Israel Institute of Technology, Haifa 32000, Israel
e-mail: yonniavidan@gmail.com

G. Goldschmidt
e-mail: gabig@technion.ac.il

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_91, © Springer India 2013

1 Introduction

1.1 Language and Communication

Language is a means of communication which is used to transfer knowledge, ideas, feelings and other information through different sounds and signals that give them meaning [1]. In the human language there is a limited number of vowels and constants, which constitute all the words and determine their pronunciation. In linguistics it is customary to attribute the term language to a system of signs and symbols that are subjected to syntax. The symbols themselves are meaningless; the syntax is what gives them meaning when they are in a certain context [2]. "The meaning of each expression does not constitute another simple projection of the author's intent, instead it is comprehended in the relation between the creator of the expression, the language it is stated in, the discourse it takes part of, and the understandings of the readers/listeners who interpret it" [3, pp. 20–21]. According to the authors, between the subject of the expression and the recipient there are at least two mediating factors—the language as a collection of meaningful symbols and the discourse as a social action of exchange of words and the creating of meaning. This idea is identical in essence to the ideas of the philosopher and architect Wittgenstein [4] who sees the language as an assortment of tools which work in different ways. The meaning of a word is set according to the way it is used and its location in a sentence. Therefore, it is possible to sort a group of words in new ways according to new sets of rules, thus gaining new readings of the same words, which receive different meanings [5]. This concept is most relevant to the learning process in the architectural studio, where the design language is built through concepts that have certain initial meanings butare given a new expression. As a result their meaning changes [6].

1.2 Language and the Design Process

Architects use language intensively along the design process, both as students and as experts [7]. Words help architects to express and explain their ideas to others, which is essential in teamwork, common among designers [8]. Students are often asked to talk about their concepts in design reviews, which sets verbal language as the main tool used by students for communicating information, in spite of the fact that the architectural act is, by definition, physical. What roles do words play in the architectural design process? Are there special elements in the spoken language that place it as a design tool along with graphic representations? What is the point of talking about architecture?

The design process, much like language is "a way of communicating ideas. Both can be considered cultural expressions or cultural communication" [9, p. 224], hence the proposal to examine these two as sharing a common structure. Oak [10] claims that design is intertwined with dissociation and interaction between participants, who create together an understanding of the object. In speech, evaluation is also apparent and as a result a student can change his or her mind if he or she chooses to do so. According to Oak, the nature of a conversation is not only the creation of concepts for its participants for the purpose of understanding, appraisal or using what is said; the conversation effects directly the future appearance of the designed object.

Dong [11] defines design itself as a language. In his research "The enactment of design through language" he contemplates the true role of language in the design process. He takes issue with the popular opinion that the language is subjected to the visual representation and in most cases functions as an accessory, an addition to the design itself which assists solely in negotiation. In his opinion, the language has an essential role in portraying the design, beyond the representation or the verbal description of the architectural act. He defines three executive parameters, through which the language portrays design:

(1) *Aggregation*, an arrangement of concepts, accumulated ideas and experience which are built over time along with the designers' personal experience.
(2) *Accumulation* of concepts, creating new representations from the collection of knowledge items.
(3) *Appraisal* of concepts.

These parameters allow to the design process to run its course and be brought to fruition through the use of language. An example can be found in Schön [12, 13] who describes the teacher Quist and his student Petra achieving congruence in the process of creating the design concept through words. Reflective design as defined by Schön is a process where in the designer responds during reflection in action, by understanding the problem and disassembling it into action strategies. Dong explains this as progressing towards a clear design concept, which is built from "cycles of convergence and divergence" [11, p. 11].

Schön [12] claimed that language reveals the ways in which we think and perceive reality. One cannot think of a new concept, only create new compositions and new relationships; therefore developing concepts and replacing one concept with another is highly important.

The purpose of this research is to examine the ways in which architecture students integrate verbal concepts in the different stages of the design process. The study challenges the definition of language as subordinate to visual representations, and argues that language is an integral part of the design process and can reflect its potential alongside visual artifacts.

2 Methodology

In this study, two studio groups were selected randomly from a total of eight groups in the third semester of Architecture studies, a total of 23 students. This selection was intended to widen the sample and diversify the range of design processes; the process was the same in both groups. All participants were informed about the research goals and procedure in general terms only, in the first meeting of the semester. The students were observed at work on their individual projects for 14 weeks, from the beginning of the semester, in regular classes and presentations, including the final presentation that marks the end of the design exercise. Class routines were not interfered by the research, as researchers took part only as non-participating observers.

Most of the material for the analysis came from the conversations between the teachers and the students (desk critiques), which were recorded and transcribed in order to glean verbal concepts from. The researchers mapped the students' concepts over time, as expressed by them verbally, in terms of consistency, variability and development. Conceptual maps of their design processes were examined and correlated with the students' final studio grades, given by the studio teachers. Semantic networks [14, 15] were also generated, which allowed tracing the different connections among verbal concepts, and comparing the semantic networks of the different students.

3 Research Definitions

3.1 Consistent Concepts

Students often express repeatedly topics which they find exciting and inspiring to work with along the semester. Concepts that were mentioned more than once in a specific design process were defined as consistent concepts, and were marked as such in the concept charts that were generated for each of the research participants. Figure 1 shows an example of a construction of the concept chart of a single design process. Every new concept that is mentioned by the student is documented in a new row, under the column representing the sequential number of the class. In class 2 for example, the student discussed with the teacher three verbal concepts ("different Places", "layers" and "public path"). In the following lessons the student kept on mentioning two of those three concepts (verbal concepts no. 2 and 4), while the verbal concept "layers" (no. 3) was dropped and therefore it is not considered as a consistent concept.

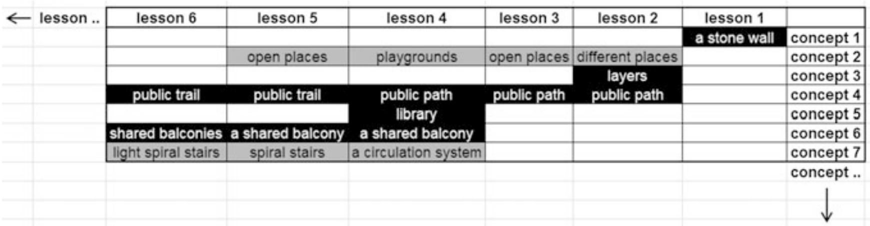


Fig. 1 An example of a concept chart (partial)

3.2 Evolving Concepts Versus Unchanged Concepts

Evolving concepts are verbal ideas that developed along the process. They are represented by gray bars (see Fig. 1), while black bars indicate unchanged verbal concepts–permanent ideas which have not evolved throughout the design process. For example, verbal concept no. 4 is an unchanged concept–one can notice that although the student has mentioned this concept constantly, it remained verbally unchanged as it was called "Public Path/Public Trail". On the other hand, verbal concept no. 2 was defined as an idea that has evolved from "Different Places" through "Open Places" and into "Playgrounds" (lessons 2, 3 and 4 respectively).

3.3 Semantic Networks and the Design Space

The design space in which the student's project is developed is a dynamic psychological-intellectual realm created by both the teacher and the student. "It is used to identify the design problem and to facilitate the development of the design project. It places the imagined environment in a workable context, linked in reality" [16, p. 325]. The language of the design space is assembled from both visual and verbal components. And defines a shared 'database' as an infrastructure for communication. Wendler and Rogers [16] define five acts that can create the design space:

(1) *Specifying*—identifying processes that will lead to intended outcomes to surface.

(2) *Witnessing*—recounting personal experiences and expectations in the studio environment.

(3) *Structuring*—organizing processes, goals, objectives, perceptions and expectations.

(4) *Visualizing*—visual information, written and verbal communication.

(5) *Sharing*—structuring information that is seen as relevant by all parties.

In this research, Semantic Networks which were assembled from the teacher-student conversation protocols during the semester represent the design space of each of the participants. The semantic network's structure is composed of Nodes—verbal concepts mentioned by the student, and Connections between them. Figure 2 is an example of a semantic network characterizing a design space of a single student's process. This semantic network differentiates among three types of verbal concepts: Main Verbal Concepts (see Fig. 2, legend) represent ideas that the student defined as primary, and that led to 4 or more other ideas. In the design process described in Fig. 2 the student had 3 main verbal Concepts. The second node type is Conceptual Ideas, the student's "design wishes" that do not achieve a physical (spatial/visual) expression, followed by the last component of the network—the Design Acts, an actual architectural elements designed by the

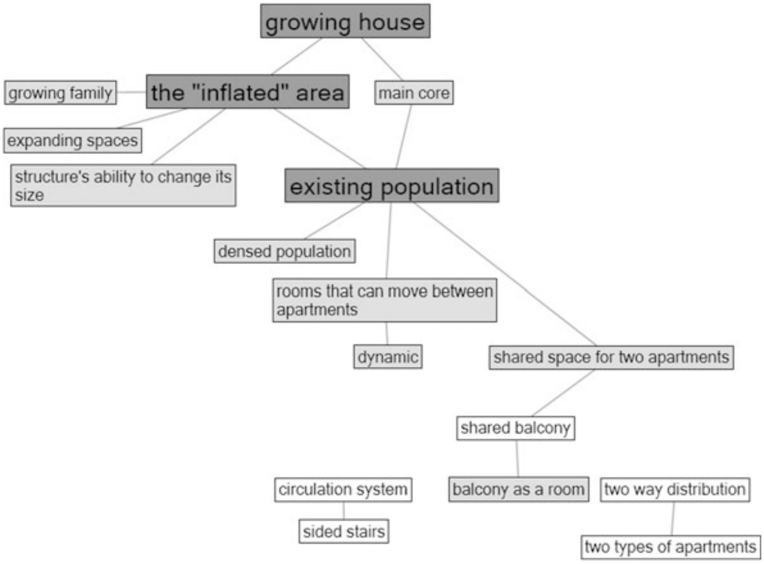


Fig. 2 Semantic network as a design space. *Legend dark gray* background: main concepts; *light gray* conceptual ideas; *white* design acts

student. In the example given in Fig. 2 the student decides on several Design Acts: shared balcony, two types of apartments, etc.

The semantic networks draw the boundaries of the space in which the student chooses to work, while the teacher can broaden, challenge and change those boundaries, allowing the student to use this new information first as a new analysis area, and afterwards as an integral part of his or her personal design space.

4 Results and Discussion

The study found an $r = 0.537$ correlation between the proportion of consistent concepts and the studio final grade, meaning that the more students adhered to their ideas along the process, their accomplishments in the studio were higher, as shown in Fig. 3. Figure 4 shows that the lack of ability to develop concepts throughout the process led to poor results. In addition, an $r = 0.626$ correlation was found between the final studio grade and the proportion of evolving concepts—ideas that developed along the process (see gray bars in Figs. 3 and 4). Similar to Schön's proposition [12], design processes wherein one concept was transformed into another by developing and enhancing existing verbal concepts, as well as continuous concepts along the design process, were rated higher at the end of the semester. As a result from these findings, an $r = 0.704$ correlation was found between the proportion of the combined total of consistent concepts and

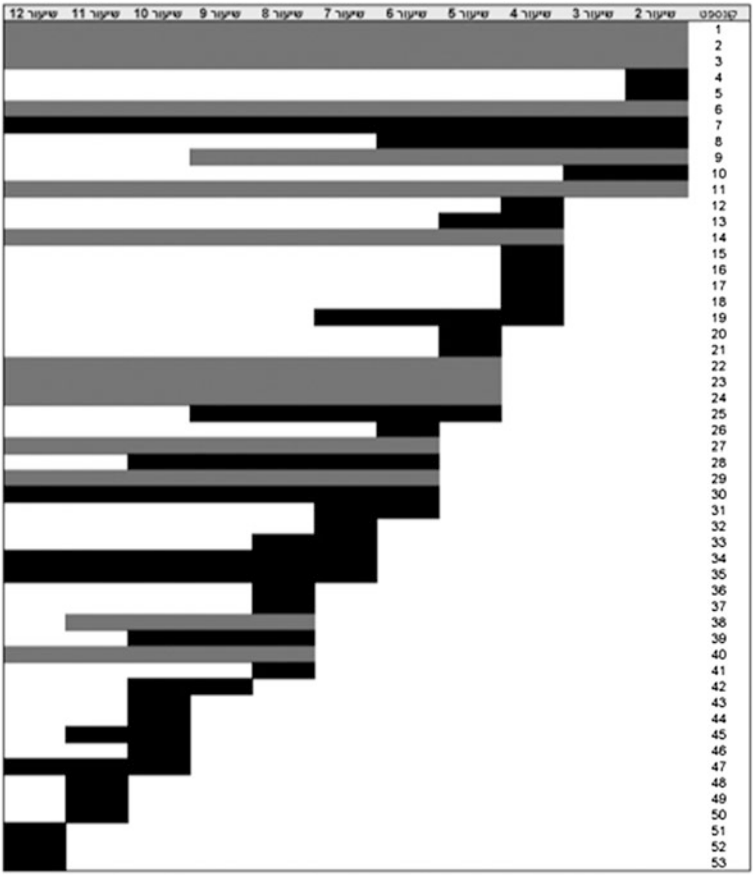


Fig. 3 Concept chart of a student graded 95. *Legend gray bars* evolving concepts, *black bars* unchanged concepts

evolving concepts. This indicates that designers who entertained a wide range of ideas during the semester, could develop them into new verbal concepts, which expanded and enriched their design process.

The charts generated from the students' design processes differ from one another not only in the number of consistent or evolving concepts. The charts' graphic characteristics such as length and slope can also shed some light on the quality of students' processes. In this research no correlation was found between the total number of the verbal concepts (represented by the charts' lengths) and the students' studio grades. Although in the examples given above the concept chart of a student graded higher is in fact longer, Fig. 5 shows a design process with a large number of verbal concepts, double the average number of verbal concepts of the entire group examined. In spite of the fact that the student had many ideas, most of them did not evolve nor were they carried over to the next class. As a result, the

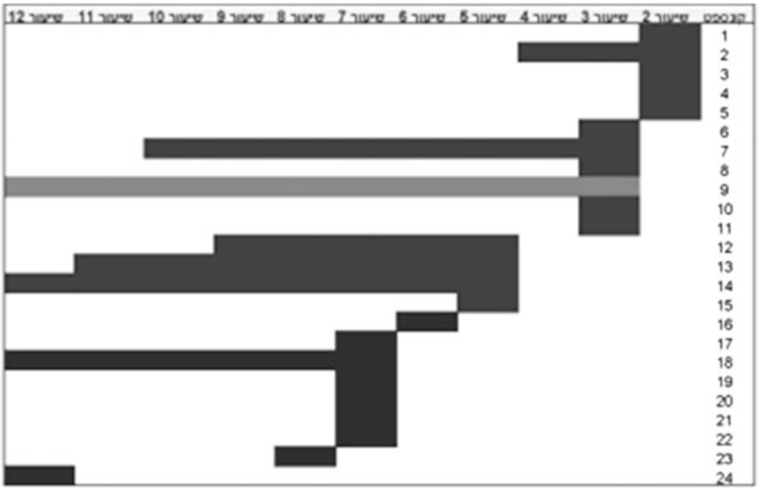


Fig. 4 Concept chart of a student graded 70. *Legend gray bars* evolving concepts, *black bars* unchanged concepts

student's grade, 70, was the same as the grade awarded to the student whose concept chart, shown in Fig. 4, includes significantly fewer ideas.

In addition, Fig. 5 demonstrates a chart with an acute slope, a prevalent quality in the design process, defining a process with clusters of Local Ideas that do not continue to the following class (see Fig. 6). On the contrary, a moderate slope of a chart stands for a design process that is rich with continuous concepts which, as mentioned earlier, this research takes to be a more successful design process (See Fig. 3).

As mentioned earlier, a semantic network analysis enabled to examine the connections between verbal concepts in the design process, as well as to define different kinds of concepts.

Comparing networks showed a higher number of links among concepts and therefore a more solid framework for students with higher studio grades, while low-graded students were characterized by a more disassembled structure of their networks (See Figs. 7 and 8, respectively).

Additional research findings shows an $r = 0.874$ correlation between the proportion of conceptual ideas at the beginning of the semester (class 2, top of a network) and the verbal concepts that were added in the same class. This reinforces the understandable notion that at the beginning of the semester architecture students explore and build their primary conceptual inventory. Referring to this data, an $r = 0.469$ correlation was found between the proportion of conceptual ideas in the final presentation, at the end of the design process (bottom of a network) and the studio final grade. These findings strengthen the importance of the presence of a solid and varied conceptual inventory for design that is being held until the later phases of the process.

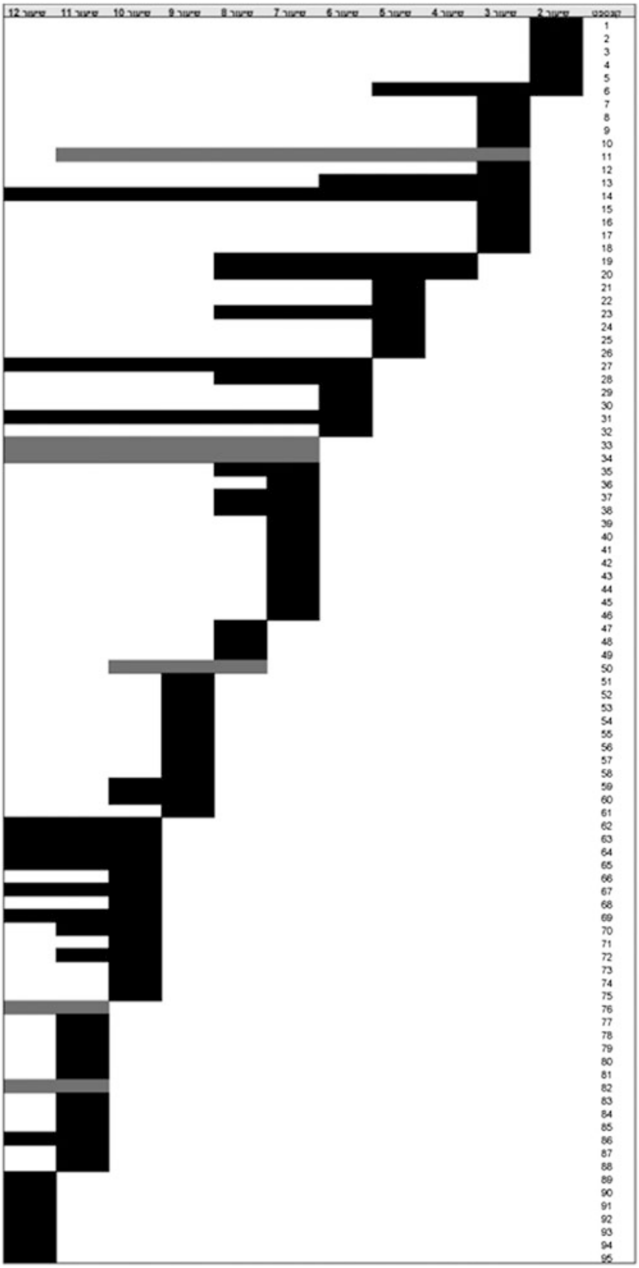


Fig. 5 Concept chart with an acute slope

Fig. 6 Detail of the chart demonstrating clusters of local ideas

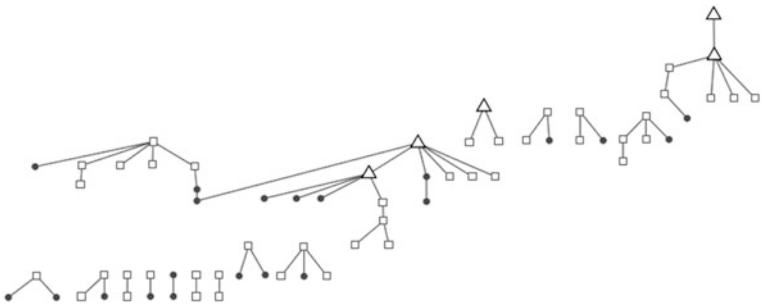
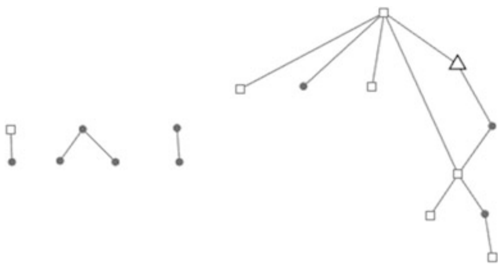


Fig. 7 Semantic network of a student's process graded high. *Legend triangle* main verbal concepts; *square* conceptual ideas; *black circle* design acts

Fig. 8 Semantic network of a student's process graded low. *Legend triangle* main verbal concepts; *square* conceptual ideas; *black circle* design acts



5 In Conclusion

The findings of this study support the claim that verbal language has an important role alongside graphic products in the architectural studio. Although this research followed only the verbal concepts that were obtained from the students, a clear connection between the verbal 'database' of a specific design process to its quality has been shown. A correlation between these two indicates that even though the teacher does not follow the students' verbal ideas consistently, his or her general assessment of the students' achievements also include their verbal choices.

Pinker [17] argues that the idea of which language is identical to thought is a common absurd: one knows the familiar feeling of searching for the right word for a specific thought or an idea. For this to happen, a conceptual realm between internal and external representation (expression) has to exist. This conceptual space also contains the endless possibilities of one thought as it transforms and changes into a chosen word. Most designers execute these bidirectional movements between internal and external representations hastily, as they make progress in the design process. It is proposed that meticulous choices of words defining the designers' wishes may lead to a more satisfying result. Furthermore, the progression of a search for accuracy will construct and expand the design space. Understanding its dimensions can "promote effective communication, so that each individual can better "see" what another "sees"" [16, p. 333].

Verbal concepts are varied and unlimited. This research distinguishes between two types of verbal concepts, characterizing the design process; while a conceptual idea can be used as an endless platform for developing other ideas, a design act is intended as an examination of the original idea and stands as its physical representation, which can result in another conceptual idea or design act. Other categorizations of verbal concepts can be established in order to reveal other design process structures, inferred from verbal concepts.

The architectural studio teaches its students design methods by using professional language and visual tools, but it cannot explore and review all verbal concepts, leave alone determine which ones have the ability to lead to a better design product. Nevertheless, developing and enhancing verbal motivators among architecture students may provide them with new insights that would refresh their processes and, ultimately, lead to better results.

Acknowledgments The Authors would like to thank the students and teachers in the faculty of Architecture and Town Planning at the Technion who participated in the research for their appreciated cooperation.

References

1. Ruse C, Reif JA, Levy Y (eds) (1988) Oxford students' Dictionary. Kernerman Publishing Ltd and Lonnie Kahn & Co. Ltd, Tel Aviv
2. Goldschmidt G, Litan-Sever A (2011) Inspiring design ideas with texts. Des Stud 32(2):139–155

3. Shalsky S, Alpert B (2007) Ways of writing qualitative research: from deconstructing reality to its construction as a text. Mofet, Tel Aviv
4. Wittgenstein L (1953) Philosophical investigations. Basil Blackwell Ltd, Oxford
5. Chomsky N (1978) On the biological basis of language capacities. In: Miller GA (ed) Psychology and biology of language and thought. Academic, NY
6. Vygotsky L (1997) Thought and language. MIT Press, Cambridge MA
7. Wong J (2010) The text of free form architecture: qualitative study of the discourse of four architects. Des Stud 31(3):237–267
8. Poggenpohl S (2004) Language definition and its role in developing a design discourse. Des Stud 25(6):579–605
9. Swierczek DJ (1985) Style as a language of design. Des Methods Theor 19(1):218–225
10. Oak A (2011) What can talk tell us about design? analyzing conversation to understand practice. Des Stud 32(3):211–234
11. Dong A (2007) The enactment of design through language. Des Stud 28(1):5–21
12. Schön D (1983) The reflective practitioner: how professionals think in action. Basic Books, NY
13. Schön D, Wiggins G (1992) Kinds of seeing and their functions in designing. Des Stu 13(2):135–156
14. Sowa JF (1991) Principles of semantic networks: explorations in the representation of knowledge. Morgan Kaufmann Publishers, San Mateo CA
15. Jackendoff R (1990) Semantic structures. MIT Press, Cambridge, MA
16. Wendler V, Rogers J (1995) The design life space: verbal communication in the architectural design studio. J Architectural Plann Res 12(4):319–335
17. Pinker S (2011) The language instinct: how the mind creates language. Shalem, Jerusalem

Cross-Disciplinary Approaches: Indications of a Student Design Project

H. Hashemi Farzaneh, Maria Katharina Kaiser, Torsten Metzler and Udo Lindemann

Abstract Cross-disciplinary approaches are adopted in technical product development for a number of reasons, including the improvement of the product quality and the reduction of time to market. However, the positive and negative effects of cross-disciplinary approaches such as cross-disciplinary teams or biomimetics are controversially discussed. In this work, we perform a case study with architecture and mechanical engineering students using biomimetics to gain insights to effects in a threefold cross-disciplinary project. The results indicate possibilities for improving cross-disciplinary team projects.

Keywords Cross-disciplinary team work · Biomimetics · Collaborative design

1 Introduction

Adopting a cross-disciplinary approach in technical product development is supposed to have a number of positive effects: a more profound problem understanding, higher quality of solutions and a shorter time to market are examples [1, 2].

H. H. Farzaneh (✉) · M. K. Kaiser · T. Metzler · U. Lindemann
Institute of Product Development, Technische Universität München, Boltzmannstraße 15, 85748 Garching, Germany
e-mail: hashemi@pe.mw.tum.de

M. K. Kaiser
e-mail: kaiser@pe.mw.tum.de

T. Metzler
e-mail: metzler@pe.mw.tum.de

U. Lindemann
e-mail: lindemann@pe.mw.tum.de

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_92,

A cross-disciplinary approach can be conducted in different ways. One approach is to set up cross-disciplinary product development teams in order to develop a product for a task related to both disciplines. An example is a product for heating, ventilation, air conditioning and refrigeration (HVACR): both architects and engineers can contribute with their discipline-specific knowledge to the development. Another approach is to use information from different disciplines for inspiration. This is the case in biomimetics: the designer uses nature or results from biological research as inspiration for solving a technical task.

What are the effects if both these approaches are combined, i.e. a cross-disciplinary team uses information from another discipline? Understanding the effects of this combined constellation can give implications for supporting cross-disciplinary teams working on a cross-disciplinary project.

In this work, we explore the effects of cross-disciplinary approaches in a case study conducted with five cross-disciplinary teams consisting of 23 students of mechanical engineering and architecture collaborating in a biomimetic product development project. A particular focus lies on the comparison between the internal views of the participating students and the achieved outcome of the team work. To start with, this paper gives an introduction to literature on cross-disciplinary teams and biomimetics. Then, we describe the detailed proceeding of the case study. In the following section the internal views are presented. They are then compared to the outcome of the teamwork. In conclusion, this exploratory study shows positive and negative effects of cross-disciplinary approaches.

2 Literature Survey: Cross-Disciplinary Approaches

This section gives an introduction to literature on cross-disciplinary teams and on biomimicry, an approach to use information from biology to develop technical products.

2.1 Cross-Disciplinary Teams

From an industrial perspective, working in teams aims at synergy effects and information exchange to enhance productivity. In this context, teams are defined as temporary work groups solving problems, developing solutions or fulfilling tasks within the framework of a superordinate target [3]. Cross-disciplinary-teams consist of individuals possessing knowledge from different disciplines. According to the above understanding that one goal of teams is to “exchange information”, the individuals can contribute with their heterogeneous information achieving a higher productivity. However, research on diverse teams including cross-disciplinary teams has resulted in contradicting conclusions. Mannix and Neale [2] reviewed psychological research on diversity in teams and found that the negative effects prevail in the majority of research contributions. They propose theories such as the self-and social categorisation approach. According to this theory individuals categorise others and have expectations based on this categorisation. This increases the tendency to develop stereotypes about individuals belonging to a different "category" [2]. In contrast, conflicts and confrontation can also have positive effects. Stempfle and Badke-Schaub [4] state that cognitive confrontation is necessary for creativity. Kurtzberg [5] observed that diverse team develop a higher number of ideas even though the individual team members feel less creative.

2.1.1 Biomimetics: Using Information from Different Disciplines

Engineers as well as architects are continuously searching for new solutions for their technical and design tasks in order to develop new, creative solutions. Nature offers a large repository of biological systems which can provide analogies or inspiration. Therefore, biomimetics are recommended as a creativity method [3]. Accordingly, Nachtigall [6] defines biomimicry as "learning from the design-, process- and development principles of nature". Still, applying biomimetics can pose a number of challenges due to the cross-disciplinary nature of the approach. Coming from different disciplines, mechanical engineers, architects and biologists use different models and terminologies [7]. This entails challenges for the search for biological inspirations and analogies as well as for their transfer to technical and design solutions. A number of researchers have focused on these challenges and developed approaches to support the biomimetic search and transfer: as to biomimetic search, databases of biological systems have been built [8–12]. Another research focus is on natural language analysis to map biological and technical terms [7, 13, 14]. The transfer of biological analogies to engineering and architecture is also addressed by Sartori et al. [8] using the SAPPhIRE approach to model both biological and technical systems. Other researchers propose development procedures specifically designed for biomimetics to facilitate the transfer [9, 10].

3 Combined Cross-Disciplinary Approach

In this work, we study a combined cross-disciplinary approach in product development involving three disciplines: a team consisting of individuals from two disciplines and a task focusing on these two disciplines for which information from a third discipline is required. The aim is to integrate information from the three disciplines to improve the development of a product. This threefold cross-disciplinary constellation discloses a number of questions:

- What are the effects of the cross-disciplinary team and how do they use information from the other discipline?
- What is the impact on the outcome of the project? What is the contribution of the three disciplines to the outcome?
- Which indications for a support of a project in this threefold constellation can be deduced?

We approach these questions with the case study described in the following section.

4 Case Study: Cross-Disciplinary Student Teams Developing a Biomimetic Concept for a Shell Construction

In this case study, teams consisting of students of architecture and mechanical engineering develop a biomimetic concept for a shell construction. 23 students participate in 5 cross-disciplinary teams. The teams consist of four to six students of which one or two are mechanical engineering students. This team constellation is due to the task *developing a shell construction,* which is considered mainly architectural but requires knowledge from mechanical engineering to ensure the technical functionality.

The students were guided and supervised jointly by members of the Institute of Shell Constructions from the Faculty of Architecture and the Institute of Product Development from the Faculty of Mechanical Engineering. Lectures focusing on shell construction, technical product development and biomimetics introduced the students to the project. In the first 2 weeks, the teams performed a literature research on biological systems which were used as inspiration for shell constructions. Then, within 7 weeks, they developed concepts for shell constructions addressing a chosen issue such as ventilation or lighting conditions. They tested and presented their concepts by models and prototypes. There was a mid-term presentation after 4 weeks and a final presentation after 7 weeks.

To capture the internal view of the students, they filled out six questionnaires. The questionnaire at the beginning of the project was aimed at capturing the students' previous experiences and their expectations. During the project there were four questionnaires to record the development of the teams: before and after the literature presentation, at mid-term and before the final presentation. After the final presentation a last detailed questionnaire was used for a retrospective view on the project. To deepen the understanding gained from the questionnaires, semi-structured interviews with five of the students were conducted. For the interviews we chose two teams and interviewed one mechanical engineering student and one or two architecture students per team.

As to the outcome of the project, we regard the final presentation of the concepts. The focus lies on the contribution of each discipline to the outcome.

The internal observations are compared to the outcome and discussed to analyse effects of the cross-disciplinary product development teams in combination with the use of information from another discipline. We conclude with the indications of the case study with regards to the questions presented in Sect. 3.

5 Internal View of the Students

We use the questionnaires and interviews with the participating students to analyse their internal view on the cross-disciplinary team work (Sect. 5.1) and the bio-mimetic approach (Sect. 5.2). In the following, due to limited space, we present only the most distinct results of the analysis of the questionnaires and additional insights gained in the interviews.

5.1 Cross-Disciplinary Team Work

The results are divided into the topics: *team-performance* and its development during the project, *positive and negative aspects of the cross-disciplinary team constellation*, *tasks of the individual students* and the perceived *importance of the cross-disciplinary team constellation.*

5.1.1 Team-Performance

Figure 1 shows the students' evaluation of their team's performance and its development during the project. This evaluation was designed according to Metzler and Shea [15]. The students could evaluate on a scale between a *dys-functional team* (0) to a *functional team* (4) to a *high performance team* (8). Figure 1 displays the average values per team. Since some students did not fill out all questionnaires, the number of students varied from 16 to 23.

The first time the students evaluated their team's performance was in the second questionnaire before the presentation of the literature search (week 2). The other questionnaires were filled out after the presentation of the literature search (week 3), at mid-term (week 6), before the final presentation (week 9) and after the final presentation (week 10). The axis in Fig. 1 is therefore not proportional to the elapsed time. It can be noted that the average value per team varies from 3.75 to 7.25 throughout the whole project. It has to be added that the minimum evaluation by one student in one questionnaire is 2 (not displayed in Fig. 1). Still, it can be concluded that in general all teams considered their team functional or more. As to the development during the project, all teams except team 3 evaluated their team's performance higher at the end of the project than at the start. Team 3 evaluated their team's performance highest at the beginning of the project in comparison with the

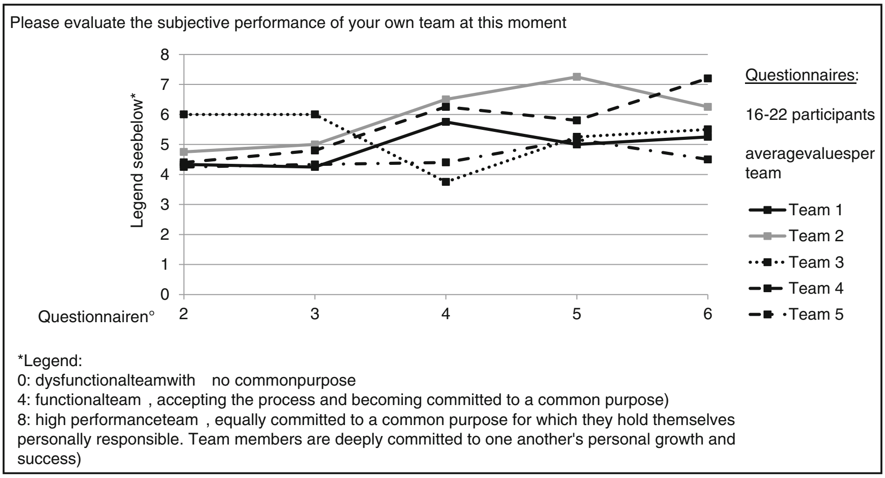


Fig. 1 Questionnaires: development of the team performance

other teams and lowest at mid-term. Towards the end of the project their evaluation of their team's performance increased.

5.1.2 Positive and Negative Aspects of the Cross-Disciplinary Team Constellation

In the questionnaires the students were asked for positive aspects in their team (*What contributes to the success of your team?*) and for negative aspects (*What causes difficulties in your team?*). The students could choose six options per question and suggest additional observations. Figure 2 shows the students' expectations at the start of the project (questionnaire 1) and their view at the end of the project, i.e. after the final presentation (questionnaire 6).

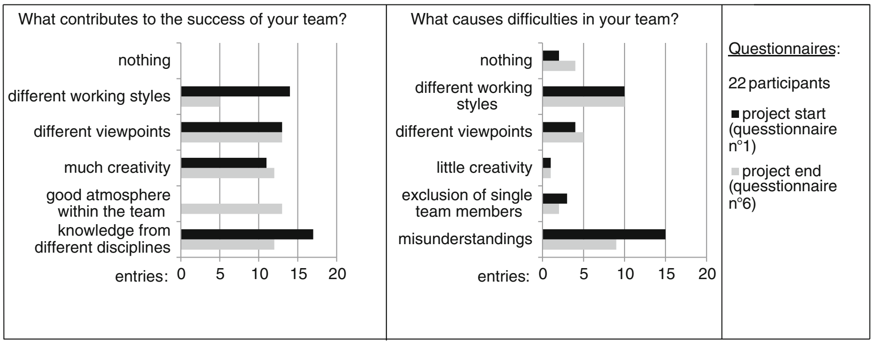


Fig. 2 Questionnaires: positive and negative aspects of the team work

As to the positive aspects, no student chose the option *nothing contributes to the success of the team*. Both at the start and at the end of the project, more than 10 students chose "different viewpoints" and "much creativity" as positive aspects. This positive view was sustained by a student in the interview stating that he gained awareness of the other discipline's viewpoint which caused him to leave his common patterns of thought.

At the start of the project, no student expected a "good atmosphere" as a positive aspect in a cross-disciplinary team. At the end of the project this option was chosen. 13 times which represents more than half of the students. They now perceived the good atmosphere as a factor in their team work even though they had not expected it.

At the start of the project the majority of the students (17) expected *knowledge from different disciplines* to be a positive aspect. At the end of the project the number of students choosing this option had declined to 12. This decline might be explained by statements from the interviews. In the interviews, three students stated that the technical ideas from the mechanical engineering students could not be pursued as far as they had wanted because of a lack of time. According to these three students the main contribution of the mechanical engineering students was their knowledge about systematic approaches in product development. On the other hand, they considered the architecture students more pragmatic, but less systematic.

Different working styles were expected to be a positive aspect by 14 students at the start of the project. At the end of the project solely five students chose that option.

With regards to negative effects, at the most five students chose *nothing*, *different viewpoints*, *little creativity* and *exclusion of single team members*.

Different working styles as a negative aspect was chosen by ten students at the start as well as at the end of the project. This view is sustained by two of the architecture students in the interviews. In their opinion, the architecture students were prepared to work more than the mechanical engineering students. One of them stated that "*architects accept iterations due to significant concept changes if the result can be improved*". The other one stated that "*when a model had to be finished, it was the architecture students who stayed and worked*".

Misunderstandings were expected at the start of the project by a majority of 15 students. At the end of the project the number of students choosing that option had declined to nine.

5.1.3 Tasks of the Individual Participants within the Team

Figure 3 shows the students' expectation about their individual tasks at the start of the project (questionnaire 1) and their view after the final presentation at the end of the project (questionnaire 6). The students could choose several options in the questionnaires. The answers of architecture and mechanical engineering students are shown separately to allow for a comparison.

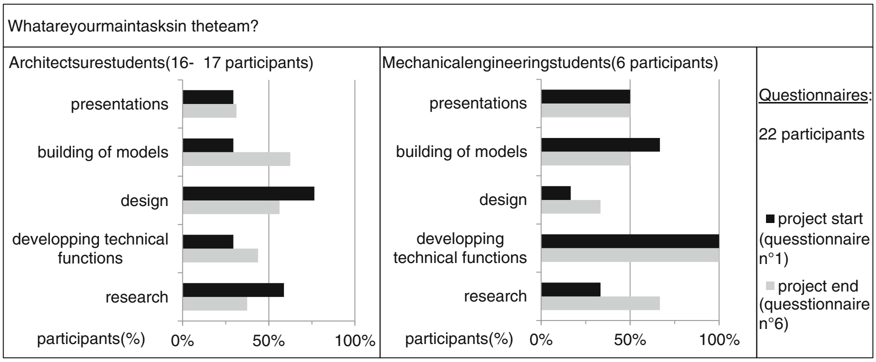


Fig. 3 Questionnaires: Tasks of the individual students within the team

At the start of the project more than 50 % of the architecture students chose *research* and *design* as their main tasks. The other tasks were chosen by about 25 % of the architecture students. At the end of the project, the rating of the task *building of models* had changed most: More than 60 % of the architecture students chose this option. In the interviews, one architecture students stated that he had expected the mechanical engineering students to be technical "tinkerers" who build a lot of models and prototypes, but was proved to be wrong during the project.

As to the mechanical engineering students, all of them chose *developing technical functions* to be one of their main tasks at the start and at the end of the project. Apparently, they felt this was their main responsibility, possibly because there were only one or two mechanical engineering students per team.

5.1.4 Importance of the Cross-Disciplinary Team Constellation

Figure 4 shows the degree of confirmation of two statements comparing the importance of the cross-disciplinary team constellation to the option to carry out the project with students from one of the disciplines. These statements were part of the questionnaire at the end of the project after the final presentation (questionnaire 6). The students could choose six options on a scale between one (not true) and six (very true). The options one to three therefore express declining disagreement with the statement, the options four to six show increasing agreement with the statement.

As can be seen in Fig. 4, the confirmation of the first statement (importance of cross-disciplinary team constellation) was high. The majority of both architecture and mechanical engineering students chose between four and six (very true) points.

With regards to the second statement, the result differs for the two disciplines: The mechanical engineering students all rather disagreed with the statement and

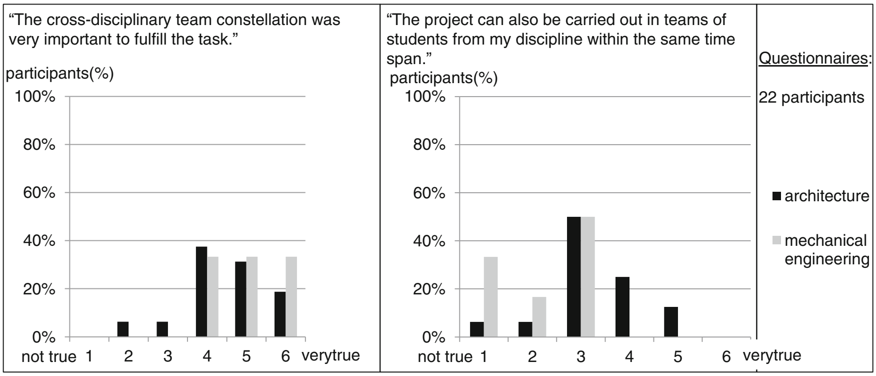


Fig. 4 Questionnaires: Importance of the cross-disciplinary team constellation

chose between one (not true) and three points. The majority of the architecture students chose between three and five points. This shows their tendency to see less importance in the collaboration with the mechanical engineering students.

5.2 *Biomimetics*

Figure 5 shows the evaluation of the students with regards to the influence of biomimetics on creativity and the importance of biomimetics for the task. This evaluation was part of the questionnaire at the end of the project after the final presentation (questionnaire 6).

As to the question "did you develop more creative ideas because of biomimetics?", students could choose on a scale between one (no more creative ideas) and six (much more creative ideas). About 60 % of the students choose five or six

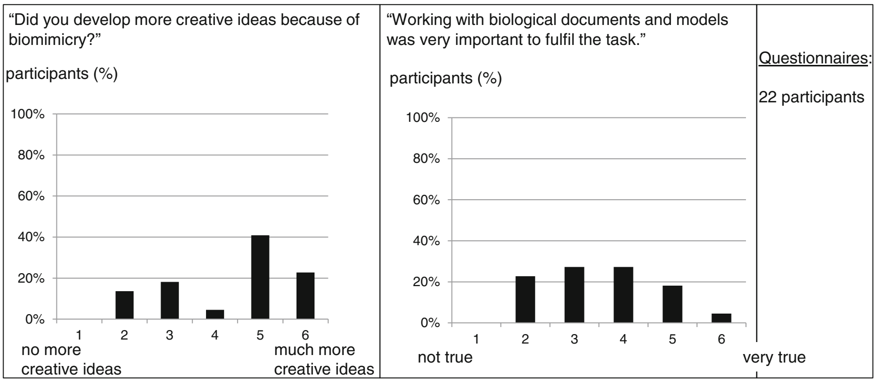


Fig. 5 Questionnaires: Biomimetics—creativity and importance

showing that the majority of the students believed to have more creative ideas due to biomimetics. This view was confirmed by four of the five interviewed students. One of the students stated that biomimetics had helped to disengage from existing solutions and to defer the feasibility of ideas. According to him, both fostered the development of more creative ideas.

To evaluate the statement *"working with biological documents and models was very important to fulfil the task"* students could choose on a scale similar to those in Sect. 5.1.4. About 20 % of the students evaluated this statement with two, three, four and five points respectively. This shows a moderate disagreement to a moderate agreement with the statement. Accordingly, in the interview one student stated that since the literature research on biological systems had been separated from the development of concepts they had not pursued ideas from that phase later in the project.

To sum up, a majority of the students were of the opinion that biomimetics triggered their creativity. On the other hand, almost half of the students did not think it was essential to fulfil the task. A possible reason for this is that they did not pursue a biomimetic idea until the end of the project, but solely used biology as an inspiration at the start of the project.

6 Comparison of the Internal Views with the Outcomes of the Project

For the final presentation, all teams prepared a presentation to show their final concept and its development. In addition they presented physical models of their preliminary and their final concept. We analysed this outcome of the project to assess the contribution of the three disciplines architecture, mechanical engineering and biology to the final concepts. Table 1 shows a short description of the final concepts and the contribution of the three disciplines. As can be taken from Table 1, all final concepts are predominantly architectural concepts as required by the task given to the student teams. In addition, all final concepts include elements from mechanical engineering. Either they are necessary elements to actuate the developed concepts (paraffin cylinders, electro-magnets, hydraulic cylinders) or additional elements to save or produce energy (water pumping systems, wind turbines). The third discipline, biology, on the other hand, is not directly visible in the final concepts, but the teams claim to have used biological systems as inspiration. Hill distinguishes between four different degrees of abstraction for biomimetics, of which using a biological principle as an inspiration is the most abstract one [9]. It can be concluded that in this case-study biology was abstracted to a high degree to serve as an inspiration.

In comparison with the internal views, the outcomes confirm the evaluation of the students to a high degree. As to the cross-disciplinary collaboration of architecture and engineering students, the final concepts confirm that both disciplines

Table 1 Final concepts of the teams

Team	Final concept	Architecture	Mech. eng.	Biology
1	Cooling and shading system for a building	Window blinds adaptable to different conditions during day and night	Water pumping system cooled during night-time in the window blinds through the building	The wings of beetles served as an inspiration for the folding of the window blinds
2	Shading system between the window panes	Ring elements connected via paraffin cylinders;they twist due to heat and change the shading conditions	Actuation of the elements via paraffin cylinders changing their length due to heat	Hairs of the old man cactus served as an inspiration to provide shading with thin elements that can be twisted to enhance their opacity
3	Cooling a building and producing energy	Façade leading the wind through the building (adaptive to the wind direction)	Wind turbines for the energy production	The den of the prairie dog served as an inspiration to use wind
4	Shading system between the window panes	(Un) folding elements to shade parts of the window	Electro-magnetic actuation of the window panes	Butterflies served as an inspiration to vary the geometry of elements
5	Shading system for a building	(Un) folding elements that are installed in front of the windows	Actuation of the elements via hydraulic cylinders	Mimosa serves as an inspiration for the folding mechanism

contributed and that the architectural part dominates. With regards to biomimetics, biology served as an inspiration, but the teams detached themselves from the biological systems when developing their concepts.

7 Conclusion, Discussion and Outlook

This work can provide a few starting points for further research. It cannot provide generally valid answers because of the limited number of teams and participants and the number of additional influences characteristic for such a case study. In the following, the indications of this work with regards to the questions of Sect. 3 are presented:

- What are the effects of the cross-disciplinary team and of the use of information from the other discipline?

As to the cross-disciplinary team, the positive aspects prevailed, as the students affirmed a positive influence of different knowledge and viewpoints. The main negative aspect was differing *working styles*. With regards to biomimetics, the teams perceived a positive effect on creativity but did not unanimously perceive a high importance for the project.

- What is the impact on the outcome of the project? What is the contribution of the three disciplines to the outcome?

Both architecture and mechanical engineering contributed to the outcome. Biological systems were not transferred or copied but abstracted and served as an inspiration.

- Which indications for a support of a project in this threefold constellation can be deduced?

To support the cross-disciplinary team work, this case-study indicates that a support of the teams to understand the working styles of the other discipline can be beneficial. In this case study teams used biomimetics on a highly abstract level. This is not necessarily negative, but if a more direct use of biomimetics is requested, measures for support can be beneficial. Possibilities are the inclusion of biologists or providing more support for the transfer of biological systems to architecture and mechanical engineering.

Acknowledgments The authors want to thank the participating students and Prof. Dr.-Ing. Tina Wolf and Dipl.-Ing. Philipp Molter from the Institute of Shell Constructions for their support.

References

1. Kleinsmann MS (2006) Understanding collaborative design. Ph.D. Thesis, Technical University Delft
2. Mannix E, Neale MA (2005) What differences make a difference? the promise and reality of diverse teams in organizations. Psychol Sci Public Interest 6(2):31–55
3. Lindemann U (2009) Methodische entwicklung technischer produkte, 3rd edn. Springer, Heidelberg
4. Stempfle J, Badke-Schaub P (2002) Thinking in design teams—an analysis of team communication. Des Stud 23(5):473–496
5. Kurtzberg TR (2005) Feeling creative, being creative: an empirical study of diversity and creativity in teams. Creativity Res 17:51–65
6. Nachtigall W (2002) Bionik—Grundlagen und Beispiele für Ingenieure und Naturwissenschaftler, 2nd edn. Springer, Heidelberg
7. Kaiser MK, Hashemi Farzaneh H, Lindemann U (2012) An approach to support searching for biomimetic solutions based on system characteristics and its environmental interactions. International design conference (Design2012), pp 969–978
8. Sartori J, Ujjwal P, Chakrabarti A (2010) A methodology for supporting "transfer" in biomimetic design. Artif Intell Eng Des Anal Manuf 24:483–505
9. Hill B (1997) Innovationsquelle natur: naturorientierte innovationsstrategie für entwickler, konstrukteure und designer. Shaker, Aachen
10. Gramann J (2004) Problemmodelle und bionik als methode. Ph.D. Thesis, Technical University Munich
11. Löffler S (2009) Anwenden bionischer konstruktionsprinzipe in der produktentwicklung. Ph.D. Thesis, Technical University Carolo-Wilhelmina
12. Asknature (2012) http://www.asknature.org, extracted 2012/07/20
13. Cheong H, Shu L, Stone RB (2008) Translating terms of the functional basis into biologically meaningful keywords. In: Proceedings of the ASME IDETC/CIE
14. Vandevenne D, Verhaegen P-A, Dewulf S, Duflou JR (2012) Automated classification into the biomimetics taxonomy. International design conference (Design2012), pp 1161–1165
15. Metzler T, Shea K (2011) Lessons learned from a project-based learning approach for teaching new cognitive product development to multi-disciplinary student teams. IDETC/CIE, Washington

Reflecting on the Future of Design Education in 21st Century India: Towards a Paradigm Shift in Design Foundation

Indrani De Parker

Abstract This research-in-progress is an attempt to establish the need for a paradigm shift in design education. The research also investigates aspects that need to be rooted and nurtured in the foundations of design education appropriate in the 21st century India. 'Design Foundation' or 'Basic Design', as it was referred to in early design education has come a long way since its origins at Bauhaus and its further evolution at Ulm and Basel. In the nascent period of design, which primarily involved industrial design, the work was focused on physical products including textiles and graphics. Today, however, to be relevant to contemporary society, designers need to work on complex issues that are interdisciplinary and much broader in scope. 21st century design education needs to be able to apply design and develop strategies to solve real issues and not just look at 'good form'. There is also visible shift from client-driven projects towards a more reflective 'issue based' design education that strives for more socially inclusive, locally/glocally/globally relevant solutions. It is becoming very important in design education to include political, social, economic and ecological discourses in a collaborative and trans/multidisciplinary way thus enabling a conceptual understanding of issues at stake as well as 'intangibles' like values, social responsibilities, empathy, humility and local/global relevance. Relevant design solutions seem to have shifted from 'Form Based' Design to 'Issue Based' Design. Design today is complex and large scale, and design education needs to address major issues. Design education needs to change, yet still retain its essential character. It needs to encourage trans-disciplinary thinking in students to better understand human beings and their needs, understand the economics underpinning issues and

I. De Parker (✉)
Industrial Design Centre, Indian Institute of Technology Bombay, Mumbai, India
e-mail: indranideparker@gmail.com

I. De Parker
366, Sector 'A' Pocket 'C', VasantKunj, New Delhi 110070, India

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_93, © Springer India 2013

the technological requirements of solving problems. An extensively documented case study was conducted to illustrate collaborative learning in design education for students of a Foundation Program, using urban–rural connections as an example. The study documented collaborative activities among educators, students, crafts persons, professionals business entrepreneurs and so on, in constant search for ways to improve learning, increase student involvement and maximize human interaction, establishing the rural context in design education.

Keywords Design foundation · Design education · Paradigm shift · Issue base learning · Collaborative learning · Rural–Urban connect

1 Background

Design Foundation or the Foundation Program of most design curricula has evolved from a need that was originally perceived at Bauhaus and Ulm as an introduction to 'elements and principles of design' and 'design thinking and action'. There is a need to revisit the traditions of design learning and try to understand the role played by basic design and see how it should be woven into the process of inducting new entrants into the realm of design thinking and action.

1.1 The Bauhaus and the HfG, Ulm Heritage

Modern design education originated during the industrial revolution where craft traditions and apprenticeship processes through which design used to be practiced, was steadily replaced by industrialization. The first school to formally create a series of assignments within a curriculum to introduce students to formal design education was the Bauhaus in Germany. Set up in 1919, post World War I, the Bauhaus was a creative center that was home to some of the greatest design thinkers of those times. The founders of the Bauhaus tradition identified those qualities that needed to be nurtured in an art and design student, both in the form of skills and sensibilities as well in their conceptual abilities and attitudes when dealing with materials and the real world of design action [1].

The Hochschule fur Gestaltung (HfG) Ulm, emerged as a continuation of the Bauhaus experiments in design education under its former students, Max Bill. However under the leadership of Tomas Maldonado, it's focus veered from a foundation in art to science and society. The faculty, comprising eminent teachers and thinkers across disciplines, experimented with design education and documented the results in a series of 21 journals published between 1958 and 1968. This research, theory building and sharing had a lasting impact on design education including design teachers in India [2].

The closing down of the HfG Ulm in 1968 saw the scattering of its faculty and students across the world, all steeped in the Ulm ideology of public good with design theory and action. This resulted in significant action on the ground in the form of new design education in Latin America by Gui Bonsiepe, in India by Sudhakar Nadkarni and H Kumar Vyas and in Japan by Kohei Suguira, besides the numerous other influences in Europe and the USA that continue to this day.

1.2 Inherited HfG, Ulm Heritage and Influence of Pedagogy in India

In India, modern design education began in the late nineteenth century with the opening of schools in architecture and art (commercial and fine art). On the request of the then Prime Minister Jawaharlal Nehru, Charles and Ray Eames' 'India Report' initiated Industrial Design practice and education in the post independence period. Charles Eames who had drafted the guidelines based on which the National Institute of Design (NID) was founded, had spent some time at HfG Ulm. In spite of the focus on Eames' report on Indian design tradition and sensibilities, the design education programs in India, like in many other countries, actually borrowed its pedagogy and thinking from Bauhaus as well as HfG Ulm school tradition.

This influence continued at Industrial Design Center (IDC), which was setup in 1969 at the Indian Institute of Technology Bombay (IITB) in Mumbai and later Department of Design (DOD) at IIT Guwahati, where the first and the only undergraduate program in design in India. Many early teachers at NID, IDC and DOD were trained in the same school. This deep-rooted connection between HfG Ulm and many design schools even today, influenced thoughts, ideas, philosophy and hence the Foundation Program.

Prof Trivedi [3, p. 9] notes in his article, Sarvodaya—Betterment of All, "One of the propositions put forward by the HfG, Ulm in its founding philosophy was that the quality of human life can be bettered by improving the quality of the man-made environment. But that alone would not be enough." He also quotes Tomas Maldonado who wrote in Ulm 2: "Man exists not only to utilize objects and even less—as they will make us believe nowadays—to consume products. But man will constantly be confronted with the intentional and unintentional demands of his consciousness. And these demands cannot be satisfied by soundly designed consumer goods alone".

2 Homogenization in Design Foundation Education

In September 2010, NID organized a conference in Kolkata (in collaboration with Goethe-Institut/Max Mueller Bhavan, HfG-Archive Ulm & IFA, Stuttgart (Institute for Foreign Cultural Relations, Germany), 'LOOK Back—LOOK Forward: HfG Ulm and Basic Design for India', where it shared, after fifty years, its curriculum through an extensive documentation of the work of the students of their Foundation Program. Surprisingly, students from different institutions, (such as National Institute of Fashion Technology (NIFT), Delhi; Pearl Academy of Fashion, Delhi; IILM School of Design, Gurgaon, Institute of Apparel Management (IAM), Gurgaon and Indian Institute of Craft Development (IICD), Jaipur), produced work similar to that of NID which has a rich heritage and infrastructure spanning five decades. This observation is based on an extensive photo-documentation of the works of the students of Foundation year of the mentioned design schools over a few years and demonstrates a certain homogenization that exists in design schools today. The profiles of the students defer significantly, but this similarity of work among students of across various design schools is apparent and could be attributed to the pedagogy followed, repeated and replicated over decades, which may, warrant a re-look at the current learning process.

3 The Current Design Paradigm

In the early days, the main of focus of industrial designers was form and function, materials and manufacturing. Today, design is the dutiful servant of technological, economical and political interest in almost every area of manufacturing and construction. This design paradigm includes not only products of consumption but also today's housing which is informed by and designed within a vision driven by short-term economic goals [4].

> Design was summoned to absorb the shock of industrialization, and to soften its devastating consequences upon the cultural web, in other words, to make industrial products culturally, socially, economically, symbolically and practically acceptable. Esthetics was then its privileged rhetorical tool, followed by ergonomics in the mid-twentieth century and semiotics in the late-twentieth century. But its most unique field of activity has remained the material product. Findeli [5, p. 15], emphasis as per original)

Most design schools in India have been stand-alone enterprises (or institutions). Classical industrial design is a form of applied art, which requires deep knowledge of forms and materials and skills in sketching, drawing, and rendering. The new areas, on the other hand, are more like applied social and behavioral sciences and require understanding of human cognition and emotion, sensory and motor systems, and sufficient knowledge of the scientific method, statistics and experimental design so that designers can perform valid, legitimate tests of their ideas before deploying them [6].

However, the issues are much more complex and challenging, in the current context. The current programs in India expect students to offer services to very diverse requirements. How does one train a student to design for global village as well as real villages in India as the demands of the global companies are very different from the demands of the villages in India?

4 The Paradigm Shift in Design

Findeli defines a paradigm as 'the shared beliefs according to which our educational, political, technological, scientific, legal and social systems function without these beliefs ever being questioned, or discussed, or even explicated [5].'

> The need to perceive concepts differently, to reframe our approach to complex systems, is a reality that we must reckon with and which requires new pedagogical methods. Rather than simply focus on passing on knowledge, then, it is necessary to develop thinking methods that will generate new knowledge. Moreover, these methods need to lead us to better solutions not only for business but for humanity and the planet as a whole. Peinado and Klose [7], emphasis as per original).

4.1 New Paradigms for Design Practice

The modern practice of design has been the model for design education since the days of the Bauhaus. Defined as an object centered process, the traditional goal of design has been to produce an artifact or environment that solves a problem.

> For academic programs arising from the arts, the beauty and humanity of such objects or environments are important. For programs arising from the sciences and engineering, usability and efficiency are paramount. And in between are the social sciences, where the issues of culture and social interaction reside. The distinctions within each of these disciplines are not simplistic, but the research paradigms they represent for producing objects and environments clearly have different value systems and methods, and historically, they have argued for very different curricular paths at the graduate level. The demands on design practice in the twenty-first century, however, are significantly different from those of the past, suggesting that these paradigms may require re-examination [8].

- Increasing complexity in the nature of design problems
- The transfer of control from designers to participants
- The rising importance of community
- The necessity of trans-disciplinary, collaborative work

The complex scale of problems, diversity of settings and participants, and demand for adaptable and adaptive technological systems argues for work being done by interdisciplinary teams composed of experts with very different modes of inquiry. How such experts collaborate as peers and the roles design can play in mediating collaboration present new opportunities for designers. The paradigm shift in the focus of the design process from objects to experiences demands new knowledge and methods to inform decision-making. It broadens the scope of investigation beyond people's immediate interactions with artifacts and includes the influence of design within larger and more complex social, cultural, physical, economic, and technological systems.

India, in this context, has a unique opportunity, to innovate a new kind of design education at the exact moment when four new NID (National Institute of Design) campuses have been announced. Thakara [9] elaborates, "India is not alone in needing to innovate new educational models. On every continent, outside its Big Tent—on the edge of the clearing—exotic new species of design and business education are emerging. These new schools and courses have names like Yestermorow School, Deep Springs College, Kaos Pilots, School of Everything, Social Edge, Deep Democracy, Center for Alternative Technology, Schumacher College, Living Routes, Gaia U, Crystal Waters, Horses Mouth, WOOF, The Art of Hosting. These 'outliers' (not mainstream universities) are where the real innovation is happening—in terms of content, form and business model. Few designers, few policymakers, and few entrepreneurs, have even heard of these places. But they are significant, for me, because they meet the requirements of these new times. They can be the competition—or the collaborators—for design education in India and beyond."

A trans-disciplinary approach broadens the 'objective' of design and rising complexity of contexts requires new multidisciplinary knowledge. Design students need to experience the benefits of working with others with the components of design being central.

4.2 Collaborative Learning in Design Education Today

Collaboration is a process in which two or more people or organizations work together in an intersection of common goals—by sharing knowledge, learning, and building consensus. Structured methods of collaboration encourage introspection behavior and communication. These methods specifically aim to increase the success of teams as they engage in collaborative problem solving.

Advocates of collaborative learning claim that the active exchange of ideas within small groups not only increases interest among the participants but also promotes critical thinking [10]. Quoting Johnson and Johnson [11], Gokhale argues that there is persuasive evidence that cooperative teams achieve at higher levels of thought and retain information longer than students who work quietly as individuals. The shared learning gives students an opportunity to engage in discussion, take responsibility for their own learning, and thus become critical thinkers.

Designers (i.e. the experts who have been specifically trained in design thinking and design knowledge) need to face systemic changes that are driven by a growing number of actors. These actors together can generate wide and flexible networks that can be collaboratively conceived, developed and generate sustainable solutions. The paradigm shift in design today changes the position and role of professional designers.

Traditionally, designers have been seen and have seen themselves as the only creative members of interdisciplinary design processes. In the emerging scenario this distinction blurs, and they become professional designers among many non-professional ones. However, this does not mean that the role of design experts is becoming less important. On the contrary, in this new context, design experts have the crucial function of bringing very specific design competence to these co-designing processes. That is, they become process facilitators who use specific design skills to enable the other actors to be good designers themselves. Manzini [12, p. 11], emphasis as per original)

Thus design schools can play a significant role in the emerging scenario and, generate new models and ideas in education to map the paradigm shift. Today's design problems exist at the level of systems and communities, and are too big and too complex for any single discipline to address. Collaborators need to be from fields as diverse as anthropology, cognitive psychology, computer science, business, social policy, etc. Current strategies of design education need to evolve to prepare students to address the interdisciplinary demands of complex, system-level problems.

> We are in the midst of a slow, but insistent shift in how we teach, assess, and organize our classrooms. After centuries of fixating on the solitary student's singular progress, we are currently experiencing the rise of a radical emphasis on collaborative, team-based learning. This is not just a slight course correction but has the potential to be a major shift of paradigm. This transformation poses profound challenges to the basic tenets of our educational system while it also forces teachers and administrators to invent new and novel ways to assess student progress and organize their curricula. We can no longer afford to wait for an Einstein to help us. Working effectively in groups and across disciplinary boundaries will be a key survival skill in the 21st century (James Hunt, Director, the Experimental Graduate Program in Transdisciplinary Design at Parsons)

[13].

5 Rural-Urban Synergy

It is more important now than ever before to make the connect between the rural and urban in design education. It is critical to create collaborations engaging in a more holistic approach to design, which includes all other actors and stakeholders both rural and urban, especially when today's design scenario exists at the scale of systems and communities; huge and complex.

> In India, on one hand, we are privileged to have a large rural base of people with agricultural and artisanal skills and a huge diversity of knowledge, tools materials and experiences. In the march towards a mostly Western, industrialized model of development much of this indigenous knowledge resource is being lost. Design skills could be used to trigger new imagination, propose daring new scenarios, which build on what people know and empower them to become partners in shaping their destinies. On the other hand, Indian industry and services are maturing rapidly. Indian corporations are becoming multinational. To remain competitive in the global marketplace, industry must respond to new sets of challenges from users who are seeking more than usefulness and usability. They are looking for emotional connectedness, commitment to green values, transparency, fair use of labor and so on. (Vision First, 2011, emphasized as per original).

Design discipline in India has been attempting to address the conflict between the need to rapidly modernize, need to promote economic development to tackle poverty and the need to minimize the effects of economic developments on traditional culture. Caught in this conflict, design schools in India have been walking a tightrope, balancing between international design approaches and those rooted in local issues and tradition of India. Globalization has exacerbated this conflict, forcing us to question the validity of the tightrope walk, particularly in design education [11].

5.1 Collaborative Connect Between the Rural and Urban in Design Education: A Case Study

An extensively documented case study was conducted to establish these complex urban–rural connections in design education. The key for designers today is to understand the stakeholders and how they are connected through the web of stakeholder networks. The study also documented collaborative activities among educators, students, crafts persons, professionals business entrepreneurs and so on, in constant search for ways to improve learning, increase student involvement and maximize human interaction, establishing the rural context in design education.

The underlying premise for collaborative and cooperative learning is founded in constructivist epistemology. Johnson et al. [16] have summarized these principles in their definition of a new paradigm of teaching.

> First, knowledge is constructed, discovered, and transformed by students. Faculty create the conditions within which students can construct meaning from the material studied by processing it through existing cognitive structures and then retaining it in long-term memory where it remains open to further processing and possible reconstruction. Second, students actively construct their own knowledge. Learning is conceived of, as something a learner does, not something that is done to the learner. Students do not passively accept knowledge from the teacher or curriculum. Third, faculty effort is aimed at developing students' competencies and talents. Fourth, education is a personal transaction among students and between the faculty and students as they work together. Fifth, all of the above can only take place within a cooperative context. Sixth, teaching is assumed to be a complex application of theory and research that requires considerable teacher training and continuous refinement of skills and procedures (p1: 6)

The action research method was adapted for this study. The objective was to integrate collaborative learning in design education, particularly for design foundation. This case study, presents the learning and experience of design students as a collaborative activity and show how it can happen effectively and successfully between the urban and the rural actors. Students were encouraged to develop the capacity to design for the unexpected.

The learning opportunities, which foster the above, were created in such a way that they operate on four levels, which are not discrete, linear or sequential. Taken together they enable experiences, which stimulate genuine understanding of complex relationships and processes.

The collaborative experiential learning layers are:

- Looking, listening and being
- Exploring, thinking and assimilating
- Questioning, experimenting, making and questioning
- Connecting, collaborating and co-creating.

The course 'Issues & Perspectives in the Craft Sector, is orchestrated by Ms Lakshmi Murthy. A professional Communication & Ceramic Designer, and Design Educator, she has been conducting this course since 2005 with refinements every year in context to the present needs and future projections. This module has been extensively documented for the past two years by the author, at the Indian Institute of Craft Design, Jaipur, Rajasthan, India, as part of the in progress research. The module stimulates the students's curiosity and encourages them to experience the synthesis within the craft sector, social sector, business and design. The Case Study is presented in form of a booklet.

6 Conclusion

India as an emerging market has grown rapidly, thus giving rise to both aspirations and anxieties about the potential socio-economic and environmental repercussions. This has thrown up new opportunities, both in the rural and urban spaces for designers, entrepreneurs, activists, policy-makers, investors, and so on. Design could focus on developing dynamic and flexible innovation systems, through which all actors collaborate to create and develop, options which encourage sustainable lifestyles and inclusive prosperity. Design students need to experience the benefits of working collaboratively with others with the components of design being central. A trans-disciplinary approach broadens the 'objective' of design and rising complexity of contexts requires new multidisciplinary knowledge.

Future design schools could follow a model of participatory and collaborative design education. The research attempts to establish that there has been a paradigm shift in design. Given this shift, it stresses the need for a concurrent and corresponding shift in the design pedagogy, most critically at the design foundation.


COLLABORATIVE CONNECT BETWEEN THE RURAL AND URBAN
IN DESIGN EDUCATION: A CASE STUDY
Issues & Perspectives in the Craft Sector
Collaborative Learning Between...
Assimilating Critical Issues in Design Education
Methods, Medium and Activities that Foster an Understanding of the Collaborative Connect between the Rural and the Urban
AN INTRODUCTION TO UNDERSTANDING COMMUNITIES
Ice Breaking Activity
Addressing Fears and Articulating Expectations
Awakening of Five Senses
Understanding the First Steps of Issues and Perspectives
day
one
EXPERIENCING, ASSIMILATING AND LEARNING
Discourse on Issues and Perspectives
Introspection of Self in Tandem with Issues of the Village Craft Sector
Experiencing the Village Craft Sector and Collecting Information
day
two


UNDERSTANDING ISSUES AND PERSPECTIVES IN THE CRAFT SECTOR
day three
WORKING WITH HANDS THINKING WITH HANDS
day four
UNDERSTANDING SOCIAL ISSUES IN THE CRAFT SECTOR
day five
Issues of Concern in Design Education Today
Issues and Perspectives in the Craft Sector in India Today

References

1. Ranjan MP (2005) Lessons from Bauhaus, Ulm and NID: role of basic design in PG education. Design education: tradition and modernity. Scholastic Papers from the International Conference, DETM 2005. National Institute of Design. Ahmedabad
2. Ranjan MP (2011) Nature of design: the need for nurture in India Today. What design can do—Conference. Amsterdam
3. Trivedi K (2003) Sarvodaya—Betterment of all. Page 9, ICSI Dnews
4. Fuad-Luke A (2002) Slow theory: a paradigm for living sustainably, design by development. MIT/Srishti School of Art and Design, Bangalore
5. Findeli A (2001) Rethinking design education for the 21st century: theoretical, methodological, and ethical discussion. Des Issues 17(1):5–17 (Winter 2001)
6. Norman D (2010) Why design education must change. Core 77 design magazine & resource. Viewed July 2012 http://www.core77.com/blog/columns/why_design_education_must_change_17993.asp
7. Peinado A, Klose S (2011) Design innovation: research-practice-strategy, researching design education, symposium proceedings, researching design education, 1st international symposium for design education researchers, Cumulus Association//DRS SIG on Design Pedagogy, Paris
8. Davis M (2008) Why do we need doctoral study in design? International Journal of Design vol. 2 (3). www.ijdesign.org
9. Thakara J (2011) Doors of perception: what kinds of seed. Viewed July 2012, http://wp.doorsofperception.com/next-skools/what-kinds-of-seeds/
10. Gokhale A A (1995) Collaborative learning enhances critical thinking. J Technol Edu 7(Fall):1
11. Johnson RT, Johnson DW (1986) Action research: cooperative learning in the science classroom. Sci Child 24:31–32
12. Manzini E (2011) Design schools as agents of (sustainable) change: a design labs network for an open design program, symposium proceedings, researching design education, 1st international symposium for design education researchers, CUMULUS Association//DRS SIG on Design Pedagogy, Paris
13. Hunt J (2012) Collaborative learning. Viewed July 2012, Posted: 05/24/2012 5:25 pm http://www.huffingtonpost.com/jamer-hunt/collaborative-learning_b_1543999.html
14. Vision First (2010) About creating design competencies in India.Viewed July 2012, http://issuu.com/visionfirst/docs/visionfirstproposal110212
15. Athavankar U (2005) Globalization and the new mantra of design education for India. Design education: tradition and modernity. Scholastic Papers from the International Conference, DETM 2005. National Institute of Design, Ahmedabad
16. Johnson DW, Johnson RT, Holubec EJ (1991) Cooperation in the classroom. Interaction Book Co, Edina

Design of Next Generation Products by Novice Designers Using Function Based Design Interpretation

Sangarappillai Sivaloganathan, Aisha Abdulrahman, Shaikha Al Dousari, Abeer Al Shamsi and Aysha Al Ameri

Abstract Several researches confirm that novice designers need to gain many abilities to perform like experts in the field. Design interpretation is a technique to analyze the working product and identify the functions performed by an artifact in the form of a function tree. This paper reports an investigation into the design of an Operating Table by novice designers and the use of Design Interpretation to gain abilities to perform like experts. The observations were made with respect to (1) Organized structure and cognitive action (2) Scoping and information gathering (3) Consideration of alternatives (4) Time spent on activities and tasks (5) gathering basic data (6) adaptive expertise and (7) procedural expertise. The results suggest that novice designers gain by carrying out design interpretation of the current generation when designing the next generation.

Keywords Design interpretation · Adaptive design · Next generation products

1 Introduction

A design expert is a person who has a comprehensive and authoritative knowledge or skill in the design area. A novice in the meantime is a person new to the field or activity. An expert therefore will normally have knowledge about the product, or at least sufficient ability to acquire the product specific knowledge needed, with ease. The novice on the other hand will have limitations in both product specific

S. Sivaloganathan (✉) · A. Abdulrahman ·
S. Al Dousari · A. Al Shamsi · A. Al Ameri
Department of Mechanical Engineering, United Arab Emirates University, 17555Al Ain, United Arab Emirates
e-mail: Sangarappillai@uaeu.ac.ae

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_94, © Springer India 2013

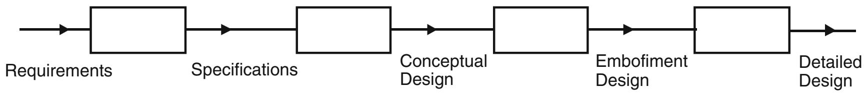


Fig. 1 Input output representation of systematic design process

and design domain knowledge. Ahmed et al. [1, 2] investigated the experienced and novice and conclude that (1) significant differences between them are present and the differences are noticeable in the early stages, and (2) supply of additional information expressed or used by the experienced designers is a credible way to support the novice designers.

Systematic product development starts with establishing the elements of a societal need called requirements and the process goes through the stages where specifications and conceptual, embodiment and detailed designs are being produced. From an input–output or black box visualization, requirements are the input and specifications are the output, specifications are the input and conceptual designs are the output and so on as shown in Fig. 1. Every product will have these in an explicit or implicit form.

Next generation products are improved variations of existing products. The variation may originate by having additional requirements, tighter specifications or/and better conceptual, embodiment and detailed part designs due the use of better insights and the usage of advanced technologies. The design of next generation products thus is not a new product development. Its development however has to follow a similar path of new product development from the point where the variation originates, but with better insight provided by the current generation.

Design Interpretation [3] is a technique where the embodiment of an existing artefact is extracted in the form of a parts tree and each operating condition is considered in turn to identify the functions performed by these parts or subassemblies. The functions are grouped into functional subsystems thus transferring the artefact from the physical domain to the function domain. The generated function structure of the existing product will give a better insight into the design of the current product. Whether Design Interpretation is a suitable means for novices to gather the initial knowledge needed to thrive in the design project is the research question and this paper reports an investigation into this question.

2 Literature Survey

Four aspects (1) expertise in design (2) comparison of novice and experienced in action (3) function based design and (4) design interpretation were seen as relevant and used in the investigation, and a brief review of the survey is given in the following sections.

2.1 Expertise in Design

If expert is an authoritative person in a subject, expertise is the basis of his credibility due to his or her study, training and experience in the subject matter. Cross [4] asserts that expertise is not simply a matter of possessing 'talent', but is the result of a dedicated application to a chosen field and without the dedicated application of the individual, levels of performance will remain modest. Chi [5] outlines, (1) excelling in generating the best solution (2) detecting and seeing features that novices cannot (3) spending a relatively more time analyzing a problem qualitatively, developing a problem representation by adding many domain-specific and general constraints to the problems in their domains of expertise (4) possessing more accurate self-monitoring skills in terms of their ability to detect errors and the status of their own comprehension (5) choosing appropriate strategies (6) using available resources efficiently and (7) retrieving relevant domain knowledge and strategies, as the characteristics of experts. Cross and Clay bourn Cross [6] note that experts take a systemic view of the design situation, choose to frame their view of the problem in a challenging way, and draw upon first principles to guide both their overall concept and detailed design.

2.2 Comparison of Novice and Experienced in Action

Several researchers have carried out comparative studies on how novice and experienced designers carry out design tasks. For instant Kavakli and Gero [7, 8] reports that the expert's cognitive actions are clearly organized and structured while there are many concurrent actions that are hard to categorize in the novice's protocol. They also found that the expert's cognitive activity and productivity in the design process were three times as high as the novice's. Based on these results, they present the view that the expert's structured and organized cognitive actions lead the expert to a more efficient performance than the novice.

Atman et al. [9] report their findings on comparison between student and experienced designers under the categories (1) problem scoping and information gathering (2) project realization (3) consideration of alternative solutions (4) total design time and transitions and (5) solution quality. They found that experts spent significantly more time on the task overall and in each stage of engineering design, including significantly more time in problem scoping. The experts also gathered significantly more information covering more categories. Results support the argument that in problem scoping and information gathering there are major differences between advanced engineers and students.

Ahmed, Wallace and Blessing [1, 2] in their research used observations, discourse analysis and interviews to identify differences between novice and experienced designers. Their findings from observations can be summarized as 'experienced designers consider several more related data and information when considering an issue than a novice'. In the discourses the novice designers' questions fall under the categories of (1) obtaining information (2) how to calculate (3) terminologies and (4) typical values. The supporting interviews among others identified that experienced designers knew which issues are important. They concluded that there is a significant difference between the experienced and novice and the difference is noticeable in the early stages. The main support for novices suggested by them is the additional information expressed or used by the experienced designers.

Robin et al. [10] report the work of Hatano and Inagaki which divides the expertise into (1) adaptive and (2) procedural types. Characteristics of adaptive expertise are inventing new procedures derived from expert knowledge to solve novel problems, a tolerance for ambiguity, fluidly adapting to new situations, performing minor variations in procedural skills and examining their effectiveness in a new context, engaging willingly in active experimentation and exploration, and being sensitive to internally generated feedback such as a surprise at a predictive failure or being perplexed by alternative explanations of a phenomenon. In contrast, characteristics of routine expertise include technical competence in solving familiar problems quickly and accurately yet only modest competency in solving novel problems, tendency to solve problems based on past solutions, highly standardized procedural skills, unwillingness to risk varying the skills, and having a preference for strategies that ensure quicker solutions over strategies that promote seeking alternative solutions.

2.3 Function Based Design

Establishing the function structure in systematic design process was first introduced by Pahl and Beitz [11] and the method has been adopted by other design text books as well [12]. Function Analysis has gone through several developments since then. For instance Ullman [13] outlines a hierarchical function structure as part of his design process and Andreasson [14] forwards Function Means tree as a method to establish conceptual designs. For this research it is sufficient to use the hierarchical function structure as outlined by Ullman.

2.4 Design Interpretation

Design Interpretation [3] is a technique aimed at establishing the function structure of an existing product in the absence of technical and design data of a product. It is achieved in three steps (1) process description (2) extraction of the parts tree and (3) establishment of the function structure. The first step is to operate the product and get familiar with the product to get a step by step description of the operation of the product. From the description the subassemblies and parts responsible for various actions are identified and a parts tree is established. The objective of the parts tree is the derivation of the function structure and as such an appropriate level of abstraction is decided. A similar technique called 'Product Teardown' is described by Otto and Wood [15]. It employs a procedure called Subtract and Operate Procedure, SOP for short, where the product is systematically dismantled, one by one, to identify the functions performed by each subsystem or part.

3 Formulation of the Study

The study was conducted by making observations on a group project lasting sixteen weeks by a group consisting of four undergraduate students in their final year. The students were expected to complete a conceptual design as their deliverable and in that sense it is a real life project and not a controlled experiment. Interim presentations, reports, log book and frequent interactions with the supervisor are the records that were developed and used in the study. The objective is mainly to understand the students' thought processes and identify whether design interpretation is the right means to support them.

Findings from the literature survey which formed the basis for formulating the study is given in Table 1. It shows seven areas in which the experienced designers do much better than the novice. The transition of a novice into an expert needs development of the novice in these areas. The research question therefore is 'Whether Design Interpretation assists novice designers to gather ability in (1) Organized structure and cognitive action (2) Scoping and information gathering (3) Consideration of alternatives (4) Time spent on activities and tasks (5) gathering basic data (6) adaptive expertise and (7) procedural expertise'.

4 Description of the Work

The task in this project is to develop a conceptual design of a surgeon's operating table for use in operating theaters and the students were given a very brief description of the product. The first activity was to gather as much information as they can from the net and write details on a log book. Weekly meetings were held with the supervisor. After the first week and visiting a lot of sites the students managed to write only a couple of lines on the log book. In one student's own words 'I have visited several sites but I do not know what is important and what I have to write in the log book'. During the second week the students were introduced to the systematic product development process as outlined by Ulrich and Eppinger [12]. Contacts were made with a local hospital and a visit was made. Two engineers explained and demonstrated an operating table used in the hospital. The students were given ample opportunity to ask questions and to take as many photographs as they would like. The visit lasted about an hour and a half. The

Table 1 Basis of formulating the study from literature survey

Characteristic	Findings from the literature
Organized structure and cognitive action	Experts excel in this and get better results while the novices lack the ability and struggle
Scoping and information gathering	Experts spend a lot of effort in defining the scope of the problem and in gathering information
Consideration of alternatives	Experts explore alternative solutions or width first approach while novices take a depth first approach
Time spent on activities and tasks	Experts spend considerably more time in activities and tasks by considering different perspectives in detail while novices plunge into the details straight away
Basic data 1. Obtaining information 2. How to calculate 3. Terminologies 4. Typical values	Experts have standard methods and intuition to gather these data efficiently while this is the major constraint for novices
Adaptive expertise	Experts thrive in this due to their past case studies and the structured methodology while novices struggle a lot in this area
Procedural expertise	Experts again perform better in this because of their ability to choose right domain of knowledge for the task

numbers of questions asked were limited and excepting one student even the number of photographs taken was also small. The students could not even express their understandings among themselves with a standard terminology.

By this point design interpretation was introduced to the students and they carried out design interpretation of a hydraulic trolley to learn the technique. The photographs were systematically studied after that while trying to establish a function structure. It was felt that the details collected from the hospital were inadequate and a second visit was arranged. The visit lasted for about two hours and the students had more time on their own with the product and they took several photographs. There was only one engineer and the students asked several questions. Following the visits the students carried out systematic analysis of the photographs taken trying to understand the functionality of the parts and assemblies. In the meantime they became conversant with the systematic product development method by Ulrich and Eppinger [12]. They divided the operating table into ten sub-sections as shown in Fig. 2 together with two additional sub-sections the hydraulics and electricals.

With this division they could establish the functions performed by each of the subsystems and a function tree was formed as shown in Fig. 3.

By this time the students were comfortable with a standard terminology and design process model. Following the design process model outlined by Ulrich and Eppinger they established a Mission statement, recorded Customer Verbatim and formed target specifications. The group was ready for conceptual design. Then they realized that they could only think about the table for which they have carried out the design interpretation. A third visit to the hospital was arranged. There they

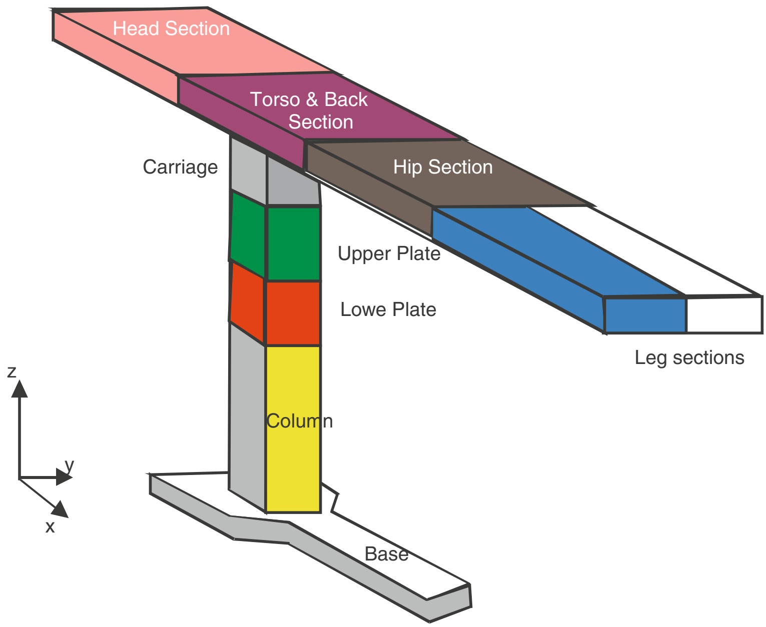


Fig. 2 Sub-sections of an operating table

saw different operating tables. The visit lasted for about two hours and the students were very busy discussing the functionality of the different tables with the engineer and were effectively carrying out design interpretations. Though no documents were made it was a thorough job with the usage of specific terms for sub-assemblies and parts. They could formulate a generic description for the operating table as ‘an operating table is constituted with a flexible bed section carried on a shuttle which has the capabilities to (1) adjust the height (2) tilt the bed about the x axis (3) incline the bed about the y axis and (4) keep the various sections of the bed at different angles. It has minimum foot area so that other equipment and monitors can be brought to the vicinity without difficulty’ [16]. With this definition and understanding the students were able to develop a CAD model of conceptual operating table as shown in Fig. 4.

5 Analysis and Discussion

Organized Structure and Cognitive Action: The project started with no structure and direction though the students knew about the generic design models and stages in the design process. Adopting the design model by Ulrich and Eppinger gave a definite direction. However the lack of product knowledge was evident in the early stages and in many meetings the common question was ‘what shall we do next?’.

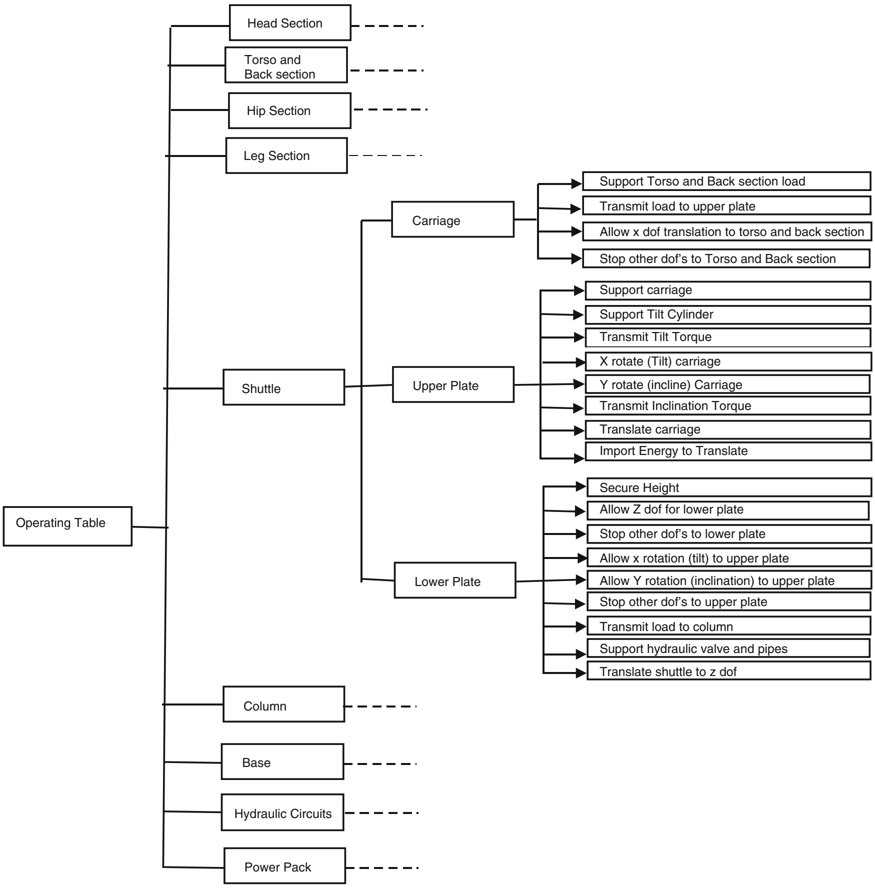


Fig. 3 Part of the function structure

The observations by Ahmed et al. were clearly evident. Design interpretation was not an easy task for them. But they had several pictures, especially those taken during the second visit. After working hard they established the Function Structure. With the function structure in place and the design model to follow the students started to progress well and this suggests that Design Interpretation helped them to structure the work.

Scoping and Information Gathering: Identifying 'what is needed and where to find them' was a difficult task for the students. Product descriptions, leaflets and manuals, health department directives, clinical requirements expressed by the engineers in the hospital and machine elements including the electronics, power and hydraulics were some of the areas visited by them. The situation changed considerably with the establishment of the function structure. It gave them a direction to narrow down and focus the search.

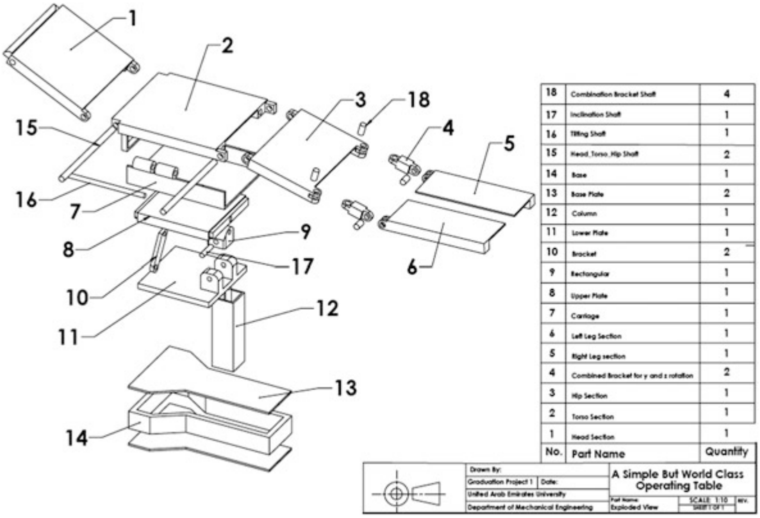


Fig. 4 CAD model of the conceptual operating table

Consideration of alternatives: This had two phases. After establishing the function structure the students tried to generate concepts and all what they could do was reproducing the table they analyzed supporting some kind of design fixation. However the situation changed dramatically when they analyzed different designs. The students were able to come up with different concepts. This is an area that needs further investigation.

Time spent: Time spent on the project increased as time went on. But it is difficult to say whether it was due the pressures exerted by the deadlines or by better insight into the problem.

Basic Data: Design Interpretation definitely had an effect on this area. The dominant one was the establishment of the standard terminology. This enabled them to have intellectual discussions with the engineers in the hospital during the third visit. They could obtain 'ball park values' for various parameters and identify information elements they should search for.

Adaptive Expertise: Though the mind's databases for past case studies of the students were limited, their interpretations of the functionality of the different tables during the third visit suggest that they recall the interpreted design of the first table. This suggests that design interpretation helps to structure designs for mind's database.

Procedural Expertise: No specific evidence was found to support or reject help from design interpretation. However it is worth pointing out that function structure helps to identify knowledge components needed for providing different functions.

5.1 Discussion

Design Interpretation is aimed at establishing the function structure of an existing product. In this project however its use as a tool to gain the abilities lacking in novice designers is being assessed. The observations were made passively while the students were working for a different target. In this sense it is an assessment of the technique on a real project but in an uncontrolled fashion. The results suggest that Design Interpretation helps novice designers to gain the abilities they lack when designing the next generation products. However the observation is based on a single project. Detailed investigation with more projects is needed to make a firm decision on usefulness of Design Interpretation.

6 Conclusions

Observations on the design and development of this moderately complex product suggest that Design Interpretation of the current generation product helps novice designers to gain the skills possessed by expert designers in the following areas, when designing the next generation product.

1. *Organized structure and cognitive action*: Product specific knowledge provided by Design Interpretation helped the students substantially to think of the product as a collection of ten subsystems and organize their thought process along those lines.
2. *Scoping and information gathering*: Design Interpretation broke the overall problem into subsystems and this enabled the search for the relevant information needed for the design for example the body mass distribution to design the bed sections.
3. *Consideration of alternatives*: This had two phases. In the first, design fixation played a major role. But after looking at different products, the fixation eased and they generated concepts where casting, welding and bolting were the main manufacturing processes.
4. *Time spent on activities and tasks*: Time spent on the work increased as time went on but it is not clear whether it is due pressure or due to the nature of design.
5. *Gathering basic data*: The main contribution by Design Interpretation in this area was the establishment of standard terminology. It made them confident and pro-active in collecting data and engaging in discussions with professionals in the area.
6. *Adaptive expertise*: Design Interpretation helps to add items to the mind's data base.

This paper describes the observations made on a single group of students in an uncontrolled setup. Though they provide interesting observations the conclusions can only help to formulate hypotheses. Further investigations on multiple projects in a controlled setting are needed to confirm this observation or otherwise.

Acknowledgments The authors wish to acknowledge their gratitude to the maintenance department of Tawam Hospital in UAE and Professor Yousef AlHaik and Dr AbdelHamid Mourad of UAEU for their intellectual contributions.

References

1. Ahmed S, Wallace KM, Blessing L, Moss M (2000) Identifying differences between novice and experienced designers, design for excellence. In: Sivaloganathan S, Andrews PTJ (eds) Proceedings of the engineering design conference 2000, professional engineering Publishing, Bury St Edmunds, Suffolk, pp 97–106
2. Ahmed S, Wallace KM, Blessing LTM (2003) Understanding the differences between how novice and experienced designers approach design tasks. Res Eng Des 14:1–11
3. Mendis MV, Sivaloganathan S (2000) Design interpretation: a methodology for adaptive design, the Journal of the institution of engineers Sri-Lanka. May 2000. Won the best paper award for the year 1999/2000
4. Cross N (2004) Expertise in design: an overview. Des Stud 25(5):427–441
5. Chi TH (2006) Two approaches to the study of experts' characteristics. The Cambridge handbook of expertise and expert performance, Cambridge, pp 21–29 (Chapter 2)
6. Cross N, Clayburn Cross A (1998) Expertise in engineering design. Res Eng Des 10:141–149
7. Kavakli M, Suwa M, Gero JS, Purcell T (1999) Sketching interpretation in novice and expert designers. In: Gero JS, Tversky B (eds) Visual and spatial reasoning in design, key centre of design computing and cognition, University of Sydney, Sydney, pp 209–219
8. Kavakli M, Gero JS (2001) The structure of concurrent cognitive actions: a case study on novice and expert designers. Des Stud 23(1):25–40
9. Atman CJ, Adams RS, Cardelia ME, Turns J, Mosborg S, Saleem J (2007) Engineering design processes: a comparison of students and expert practitioners. J Eng Educ 96(4):359–379
10. Adams RS, Turns J, Atman CJ (2003) What Could Design Learning Look Like? In: Design thinking research symposium VI, Sydney
11. Pahl G, Beitz W, Schulz H-J (2007) Engineering design: a systematic approach, 3rd edn. Springer, London
12. Ulrich K, Eppinger S (2011) Product design and development, 5th edn. McGraw Hill, New York
13. Ullman D (2003) The mechanical design process, 3rd edn. McGraw-Hill, New York
14. Andreassen MM (1998) Conceptual design capture, keynote paper. In: Sivaloganathan S, Shahin TMM (eds) Proceedings of the engineering design conference '98, Professional Engineering Publishing, Bury St Edmunds, Suffolk, pp 21–30
15. Otto K, Wood K (2006) Product design. Tata McGrawHill, India
16. Abeer A, Aisha A, Aysha A, Shaikha A (2012) Design and development of a simple but world class operating table, graduation project report, Department of Mechanical Engineering, United Arab Emirates University, UAE

Changing Landscapes in Interactive Media Design Education

Umut Burcu Tasa and Simge Esin Orhun

Abstract The recent advancements in networking technologies and tools are causing different transformations in the modes of communication and the design of products, which mostly is in direct relationship with the discipline of interactive media design. Having based its curriculum on project design courses for varying media, Department of Interactive Media Design in Yildiz Technical University was established in 1997 and gave its first graduates in the academic year of 2002/2003. Reflecting the effects of the spreading of media technologies in the way the students approach to design process and products, we believe that the graduation projects of the last decade have great potential to delve into the changes in the digital media landscapes. This research analyses this potential in parallel with the real-life design implementations in media technologies and a McLuhanian media theory, in terms of the dynamics of content flow and the reconfiguration of user relationship with the content.

Keywords Interactive media design · Media ecology · Design education

1 Introduction

"We shape our tools, and thereafter our tools shape us" [1].

The transformative effect of technologies and media has long been debated by scholars from different disciplines.

U. B. Tasa (✉) · S. E. Orhun
Department of Interactive Media Design, Yildiz Technical University,
Istanbul, Turkey
e-mail: utasa@yildiz.edu.tr

S. E. Orhun
e-mail: sesin@yildiz.edu.tr

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_95, © Springer India 2013

Media ecologist Neal Postman drew attention to the ecological nature of technological change, underlying its power in changing the whole relationships and the root structure within the system, instead of just adding a new value to the system [2]. According to Lanier, a technologist himself, technologists, by changing the ways we connect to ourselves and to the others, directly manipulate our cognitive experiences; so it is impossible to work with computing technologies without getting involved in "social engineering" [3].

Activity theorists had long ago argued how consciousness of a human being is shaped through the "actions" that are being done [4]. If "we are what we do" as the activity theorists argue, we should consider the artifacts and tools all around us, by which our activities are mediated. In a recent article philosophy professor Andy Clark points exactly to this fact, as he argues embodied cognition and the fact that cognitive processes are products of not only neurological activities of brain, but also the complex interactions between the brain, the body and the "designed" environments that we live in [5].

While these arguments can be exemplified more, we argue that they become ever more crucial when it comes to the recent advancements in media and communication technologies. These ubiquitous and pervasive tools of technological design become more and more intimate to our daily lives and to our bodies day by day. And they not only "upgrade" our present activities with faster, more convenient and more efficient ones, but also create their own "needs" to the novel activities that they bring into our lives [6].

This invasion and transformation of new technologies have been occurring most intensely among young generation. That is why in this research, we intend to track how this invasion has transformed the mindset of our graduate-to-be students—both as the direct experiencer and the very designer-to-be of these media, in order to be able to take the picture of the change in the digital media "landscapes".

2 Background of the Analysis

In this research we analyzed 86 graduation projects developed, defended and succeeded in Interactive Media Design Department of Yildiz Technical University of Istanbul, from 2002/2003 to 2011/2012. In the analysis, we used Marshall McLuhan's forecasts on the changing trends due to the changes in media as a framework. We have not taken these forecasts as a priori true statements; rather the study has been conducted as a two-way test. On one hand it is a unique test of McLuhan's theories among a group of next generation of designers. On the other hand, McLuhan's theories provided us a framework to analyze the mindset of this group. The main purpose of the project has been to reveal possible future projections of how media has been changing and transforming.

2.1 Interactive Media Design Education

Interactive Media Design Department (IMD) of Yildiz Technical University of Istanbul was established in 1997 and began accepting undergraduate students in the academic year of 1998/1999. The department gave its first graduates in the spring semester of 2002/2003.

The focus of the department has changed from Communication Design to Interaction Design in due time, which affected the approach in graduation projects. In today's perspective, Interactive Media Design discipline and designers have great potential to set the basis for the new coming services and products. As the idea of innovation gets stronger, creativity becomes more valuable than ever. In the curriculum, the students are expected to work on a specific design problem and/or specific technology in each of the preceding project courses. In the graduation projects on the other hand, they are asked to generate a creative solution for a design problem that they have discovered themselves. While in the first years they were also expected to implement their design and they were motivated towards game design, since 2006 we try an alternative approach to generate more innovative works through the stages of the briefing, conceptualizing, planning and executing processes of the projects, with more emphasis on the conceptualization so that the practical impossibilities of execution shall not restrain innovative ideas from being developed [7].

2.2 Timeline of Interactive Media Industry

When we analyzed the projects, we came up with the clear observation that there is a paradigm shift in the graduation projects of the last decade around the year 2007. This is not only a projection of the change in educational approach at the department, but also due to the advancement in real-life media implementations. It should be noted that when in 1998, the first group of students was accepted to the department, only a minority of them had mobile phones, Windows 98 had just been released, and the only way to connect to the Internet was via dial-up.

During 2000s, we have witnessed a great leap not only in the pace and capabilities of these communication technologies that we use in daily life, but also in the spread of them among young people. However, it was especially after 2004 that the seeds of some groundbreaking media tools were planted. Facebook, Flickr and Google's Print Project were launched in 2004, followed by Youtube and novel Google services such as Google Earth and Google Books in 2005, and Twitter and Wii in 2006, the year when "You" were selected as the person of the year by Times magazine. With 2007, the most significant year in the short history of the projects, iPhone was out with built GPS inside. In 2008, the first Android powered phone was in market together with the street view display in Google Maps. These utmost mobile devices and services paved the way for millions of applications;

including location based ones as well as the use of touch screen and gestural technologies; and other hand-held devices like iPad, and gestural game consoles like Kinect for Xbox in 2010. The pace of the change itself has an ever increasing acceleration that makes it very difficult to keep track of the changing landscapes in the use of information technologies and communication media, however we can at least say that *gestural interfaces*, *ubiquitous connectivity*, *socializing through digital media*, *collaborative content creation*, *a shift of focus to user experience*, and being surrounded by an increasing *abundance of digital information* have been some of the "gifts" of these groundbreaking media of the last decade.

2.3 McLuhan's Projections Adapted

While it is rather clear and trivial to track the reflections of changes in the industry and in our educational approach on student projects, the changing landscape of the graduation projects has the potential to reveal more for the future, which we intend to uncover through a reading and comparison of McLuhan's visionary projections on media.

Philosopher and media theorist Marshall McLuhan is mostly well known for coining the statement "the medium is the message" and the term "global village". The theories that he developed on media and communication especially in 1960s have been among the most debated and referred theories in the field of media studies. While his "prophetic" visions of "Electric Age", may be argued to be controversial from many aspects, a specific reading on his media approach turned out to be very inspiring and promising for this research.

McLuhan evaluates the history of humankind in three ages namely Tribal, Mechanical and Electric Age. These ages corresponds to specific mentalities, rather than being chronological and successive periods. The mentalities shaping these ages are determined by the way people relate to the media and technologies, which are extensions of men that which result in a distinctive understanding and experience of life. In this manner McLuhan contemplates on a significant number of media from language to TV (which was the "new" media of his time) and on how these media have changed the human perception through altering "sense-ratios" and how even further transformed the experience of life. The first great transformation is the de-tribalization of Tribal Man by the 3000 years of mechanical and fragmentary media and technologies of Mechanical Age, such like phonetic writing, print, clock, assembly line, car and so on. This is a transformation that has already taken place in Western world and has given birth to the "modern man". And it is a transformation that has been carried over to tribal men of the other worlds via colonization and modernization. As the second collective transformation, he prophesies the "re-tribalization" of modern life by Electric media and technology, which is introduced with the electricity and the following communications media from telegraph and telephone to TV [1]. During this re-tribalization process, McLuhan suggests many paradigm shifts to occur presented in Table 1.

3 Methodology

Through a list of qualities as a checklist, each graduation project has been investigated in a historical perspective according to the paradigm shifts presented in Table 1.

These qualities questioned the existence or non-existence of customization; the structure, the nature and organization of the content, of the media, of the tasks, and of the activated senses; the existence or non-existence of social interactions, social responsibility and use of social media. Due to format restrictions we cannot present here further details but only a limited number of examples from student projects.

It should be noted that our intention has been revealing the possible trends underlying media innovations and opening these to discussion, rather than proving a quantitative hypothesis. In that manner, considering the highly qualitative nature of the data, any statistical data are only used as a clue to detect and present the changing trends.

4 Results and Discussion

Through the analysis of the projects, which we have accomplished utilizing -but not limited by—McLuhan's forecasts listed in Table 1 as a framework, we have

Table 1 The Process of Re-tribalization in the transition from Mechanical Age to Electric Age

Mechanical age	➔	Electric age
Mass-production	Re-tribalization	Customization
Mechanization		Information
Typographical and mechanical		Metaphorical and iconographical
Pyramidal hierarchy		Mesh structure
Centralization		De-centralization
Lineal and deterministic		Non-lineal and in-deterministic
Division and specialization of tasks		Integration and unification
Homogeneous and uniform		Heterogeneous mosaic mesh
The dominance of visual sense		Synesthetic and all-inclusive
Visual and abstract media		Tangible and organic media
Isolated individuality		Connected collectivity
Abstraction of space		Contextual spatiality
Fragmentation		De-fragmentation

reached some trend changes clearly manifest and in parallel with the milestones of the media industry and our educational approach.

These changes and discussions among them have been compiled in six compact arguments; namely “A shift to subjectivity”, “Kingdom of information”, “Dissolution of rational structures”, “Back to heterogeneous nature”, “Appraisal of synesthesia and tactility”, and “Global embrace versus fragmentation”.

4.1 A Shift to Subjectivity

Freeing the students from the technological capabilities of present day and encouraging innovative thinking, contributed to the development of more sophisticated and creative projects during the second half of the decade. Before 2006, almost all the projects with minor exceptions are Game design projects implemented in Macromedia Flash for PC platform. With 2006, the proportion of Tool/Service design type of projects which are task-specific assistants and/or guides, based on a variety of technologies and platforms, starts to increase each term, taking over the majority by 2010, most of which are customizable according to user preferences.

Beginning from 2007, whether Tool/Service or Game design, the projects start to reflect a “media consciousness” and a focus on experience design. That is to say, they consciously use and reflect on the media, considering the possibilities of the used media in designing the user experience. By 2008, the proportion of these experience-centric projects reach majority. As a comparative example in games, the left screenshot in Fig. 1 is from the *Çukursaray Hidden Room* (2005) project by Seren Köroğlu, which is a typical Flash based survival horror/puzzle game. As for the *Bunker* (2011) project by Mert Uzer in the right screenshot of Fig. 1, as a more current game project, it is a location-aware augmented reality multiplayer game application designed for smart phones, where the social media (Twitter and Face book) activity of the user is an input to the game play and the user may come across with other users in physical reality. The designer of this project underlines

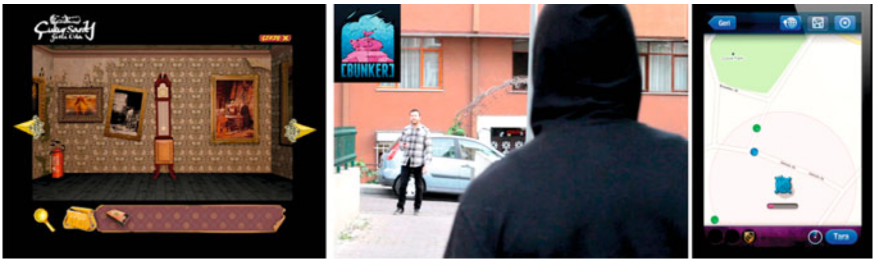


Fig. 1 Çukursaray Hidden Room (*left*) versus Bunker (*right*)

his intention to encourage people to engage in physical activity while staying connected to social media.

As another comparative example, in Fig. 2, the projects *Kördüğüm* (2012) (“Blind Knot” in Turkish, which is a phrase used for “complicated situations”) by Cansu Kaykaç, and *Finkles* (2011) by Cansu Taştan, respectively, are both examples of experience design projects. *Finkles* as a tangible medium prints a 3D tangible and organic form as output, which is generated by the random motions of the users during their play with the medium. The purpose is to give inspiration to designers. *Kördüğüm* as another tangible project on the other hand is a Tool/ Service, as well as an Experience design, which utilizes use of (textile) threads embedded with new technology as a novel interaction medium for visually impaired people. The aim of the project is to provide the visually impaired people a memorandum book where they can record and recall their memories. There is a shift from mass-produced “experiences” designed for all to customizable and personal experience centeredness, which was also foreseen by McLuhan. We can observe an increase in the subjectivity of both the designer in design process, and the user as s/he experiences the design.

4.2 Kingdom of Information

Although it was not McLuhan who coined the term “Information Age”, it was he who claimed that everything, including ourselves, is being translated into the form of “information” [1] in this age.

Since the invention of telegraph, the increasing abundance of information has started to become a part of the human life. That is why crossword puzzles and knowledge contests entered into our lives: to create contexts that all this information abundance makes sense [5]. The massive amount of applications being implemented for iPhone, iPad and other mobile devices is the continuation of this process. As for the student projects, beginning from 2007, information—be it design, transference, or processing of information—starts to become a major element in their design. Besides, a switch from the universal and abstract language of typography to the story-telling and contextual way of metaphorical and iconographical communication, as another projection of McLuhan, is also manifested especially in the design of this information in these student projects.

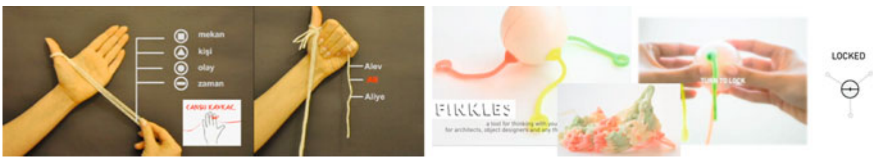


Fig. 2 Kördüğüm (*left*) versus Finkles (*right*)

4.3 Dissolution of Rational Structures

According to McLuhan, a linear, continuous, and deterministic structure and a central and pyramidal hierarchy between everything are the very nature of Mechanical Age, which is subject to dissolutions with the coming of Electric Age [1].

When we look at the course of projects, one of the pioneers, which indicate the upcoming paradigm shift, is an "interactive TV" design project from 2007. Although TV media itself was acknowledged by McLuhan as an example of "mosaic mesh" media, we have seen even further de-centralization of this media in due time [1]. The *Live Video Share and Interaction Platform* (2010) by Ömer Çıracıoğlu, a later gestural TV project is an example of this change. In this project the structure of TV media is totally turned upside down, with the inclusion of audience participation in the programs by broadcasting their own live videos, giving live feedback to the programs and by communicating directly with other audience.

4.4 Back to Heterogeneity

Division of tasks in the cycle of production and specialization among disciplines are another elitist and fragmentary face of Mechanical Age and modernization, while the specialized tasks and any other subject are supposed to be homogenous and uniform in themselves [1]. McLuhan suggests a unification and integration among tasks and disciplines, especially those of production, consumption and learning in Electric Age, and a heterogeneous mosaic structure instead of the uniformity that is diminishing [1].

This integration of tasks and disciplines instead of division and specialization, and a heterogeneous nature in the use of media are manifest in the projects around since 2007. For example, both of the projects in Fig. 3, *Live Video Share* (2011) and *Vibe Sense* (2011), include a unification of consumption and production, by inviting users to be active content creators. *Vibe Sense* (2011) by Meir Benezra is a project designed to strengthen the communication between the DJ and the audience in live music performances. Proposing a conceptual interactive ceiling, lighting and floor structure, the environment responds to the gestures and dance movements of the audience and translates them to the DJ in an augmented reality display. The audience learns through experience how their body feedbacks are communicated and responded, and thus begins to use this language to consciously communicate their musical requests to the DJ. This project not only combines the production, consumption and learning processes, but also integrates many different media from lighting to tangible and spatial media or to augmented reality in a heterogeneous manner.

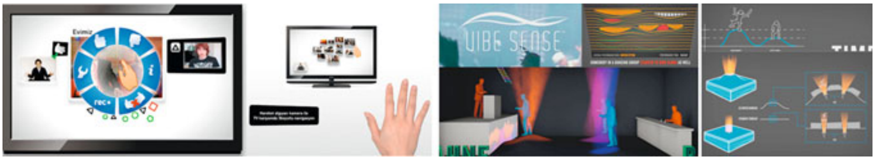


Fig. 3 Live Video Share and Interaction Platform (*left*) versus Vibe Sense (right)

4.5 Appraisal of Synesthesia and Tactility

The human senses and their "ratios" in the perception of reality is a discussion of great importance in McLuhan, who argues that the culture of Mechanical age is "visual", and sense of sight is a cool and detached sense [1]. Under the dominance of sight, the other senses like touch and smell, which are all-inclusive senses on the contrary to that of sight, and very crucial in the life of Tribal Man, loses their significance in Mechanical Age [1].

The prevision of the coming back of these underrated senses of tactile, audio and scent, in a synesthetic manner, are clearly manifest in many of the projects since 2007. While *Vibe Sense* (Fig. 3) translates motion into iconographical visual data, or *Kördüğüm* (Fig. 2) proposes sense of touch as a way to "write" down your memories, they both suggest all-inclusive and immersive experiences. Besides, in an increasing number of projects since 2007, we came across with the use of tactile and also "organic" material and media, such as ceramic or textile. For instance *Rina* (2012) by Özge Kantaroğlu (Fig. 4) is a conceptual interactive bond project, which is made from an electronics embedded textile, and is designed as an assistant for the traditional spring festival *Hıdırellez*. *Hıdırellez* is celebrated every May by thousands of people in a very crowded area where Balkan music and dances dominates the cultural atmosphere and many rituals from jumping over the fire to attaching tissues to the "Wish Trees" are performed collectively. Inspired by the handkerchiefs and neckerchiefs commonly used by Balkan musician and dancers and by the tissues attached to the Wish Tree, the student chose "textile" media as a communication, way finding, socializing and memorial tool. This project is an example of the tendency towards the use of tactile and also organic material in the overall projects.

Fig. 4 Rina: Interactive Cord

4.6 Global Embrace vs. Fragmentation?

Since 2008, the year when Facebook exploded in Turkey, the projects have started to consider social parameters increasingly. Some of the projects, like *Live Video Share*, *Vibe Sense* (Fig. 3) and *Rina* (Fig. 4), focused on designing social interactions. Some other projects like *Kördüğüm* (Fig. 2) started to consider social responsibility. And some projects went ahead and designed novel "social media" projects, such as *Peace Begins With You* (2008) by Ece Soner, a social media platform for peace activism on the web.

The clear shift from individual use to collaborative use among projects may also be regarded as a clue of the shift from the isolated individualism of Mechanical Age to the connected collectivity of Electrical Age [1]. However, this time, we abstain from claiming that this increase in the interconnectedness is a manifestation of the forthcoming "Global Embrace" that McLuhan anticipated.

"Fragmentation" or "segmentation" is the utmost critique directed towards not only to the Mechanical Age in McLuhan, but also to the whole modernization project in Deleuze [1, 8]. Whether the Electric/Information Age carries along this fragmentary nature of the Mechanical Age, or whether this nature is being transformed into a state of "Global Embrace" through new technologies, is an immediate question to answer.

On one hand, there are optimists such as artist and theorist Roy Ascott, seeing an embracing future in new technologies [9]. On the other hand other theorists, Sherry Turkle for instance, has strong claims that are based on interviews with hundreds of people, that new communication tools like social media and texting creates "connected but alone" people more than ever, along with the increasing risk of pathological communication disorders [10].

As it is not a trivial task to evaluate a design in terms of its "fragmentariness" in advance, we approached this problem indirectly in this research. The detachment of the human being from the rest of the life and from themselves, as a result of this fragmentation, begins with the abstraction of time and space [1, 5]. The notion of space as an abstract, detached, uniform, and quantifiable concept sets the very basics of de-tribalization of human [1]. "Contextual spatiality" thus points to an integrated relation of human to their spatiality. When we analyzed the projects, we see that beginning from 2007, an increasing number of them start to consider spatial information, through the use of location-aware, sensor, or ambient technologies. When we focus on the relationship between the user and the space, however, the observation is clear that it is never the *user* that is "location-aware", but the *media* itself. Space is also translated into the spiritual form of information, as McLuhan prescribes, and it is this information that the user is related to, not the space itself, which is most observable in augmented reality projects. Thus, we argue that, McLuhan's projections on Global Embrace, de-fragmentation and contextual spatiality, on the contrary to the previous projections, are not really coming into life yet.

5 Conclusion

Due to fast developments and adaptations that has been taking place in information technologies, there has been an increasing demand on the design of products, tools and applications, which however may not all be in favor of human beings. We believe that this changing landscape may be observed from the discipline of interactive media design as it provides a wide range of designs and innovations related with the ongoing advancements.

In this research we intended to delve into the mindset of gradute-to-be students of IMD of Yildiz Technical University, as they are potentially both the very subject and the future designers of the new media and technologies, which have a crucial transformational effect on the very experience of life. Thus our purpose has been not only to take a picture of the present situation of, but also to disclose and open to discussion any possible forecast for, the digital media landscapes.

The analysis not only showed an open connection between educational and industrial approaches and the course of the student projects, but also provided an experimentation of the paradigm shifts suggested by McLuhan. We concluded that there is a tendency towards *subjectivity*, *information hegemony*, *dissolution of rational structures* and *hierarchies of modernity* such as centralism and linearity, *a heterogeneous nature* where once divided subjects *converge and come together*, *end of uniformity*, and a *yearn for a synesthetic and tactile life experience*, which is in parallel with McLuhan's forecasts. The last observation is especially valuable, as it is different from the ongoing trend in industry. We came across with many projects in which the students consciously preferred not only tangible but also organic materials and media, which provide an all-inclusive sensual experience, having real textures and odor. This observation, we believe, can reveal two important outputs especially from the standpoint of product design. One is that, in the products that are being designed, technology should not diminish and substitute the organic and tactile practices of daily life, but should be integrated as an assistant to our daily and embodied experiences. That is why we believe the increasing research on embedding electronics media in organic material such as glass, textile and etc., will maintain a fruitful avenue.

There has been one remarkable output, which is in conflict with the McLuhan's theories, that we could not find true traces of the proposed shift from isolated individualism to "Global Embrace". While there is an ever increasing emphasis on social media, social interactions, social responsibility and inter-connectedness, among both real-life and student designs, there is also a strong debate going on whether this connectivity has been causing another type of detachment. We took the relation of human to their spatiality as the indicator in this debate, owing to the argument that the abstraction of space and losing direct contact with it is the first step in the process of fragmentation. We observed that although there is an increasing number of "spatial" projects, the spatiality in these are reduced to "information" again. If there is any awareness, it is not the *user*, but the *media* that is location-aware. In the demo video of the location-aware *Bunker* project in

Fig. 1, two "users" come across with each other within the game play but in a physical space, and they do not even greet each other.

We believe that, due to the great transformational effects of new media technologies, an ecological approach, which would consider all the related parties in their dynamic play holistically, is necessary both in the design of and the theory building on these media.

Acknowledgments We would like to thank our colleagues Adviye Ayça Ünlüer and Dr. Asım Evren Yantaç for their valuable support in collecting the necessary information from the departmental archive and to all graduates for their creative and wise works. This research would not be possible without them.

References

1. McLuhan M (1964) Understanding media. Routledge, London
2. Lanier J (2010) You are not a gadget: A manifesto. Knopf Doubleday Publishing Group, New York
3. Clark A (2012) Out of our brains. New York Times, New York
4. Norman D (2010) Technology first, needs last. ACM Interact 17:2
5. Postman N (1993) Technopoly: the surrender of culture to technology. Vintage, New York
6. Kaptelinin V, Nardi BA (2009) Acting with technology. The MIT Press, Cambridge
7. Brown T (2009) Change by design. Harpers Collins Publishers, India
8. Deleuze G, Guattari F (1987) A Thousand Plateaus: capitalism and schizophrenia, translated by brian massumi, University of Minnesota Press, Minneapolis
9. Ascott R (2003) Telematic embrace. EA Shanken (ed) University of California, California
10. Turkle S (2011) Alone together. Basic Books, New York

System Design for Community Healthcare Workers Using ICT

Vishwajit Mishra and Pradeep Yammiyavar

Abstract This paper presents a case study in the design of a mobile based community healthcare communication system within a larger health project named ASHA (Accredited Social Health Activists). The paper outlines the process of conceptualizing and modelling a health system involving community healthcare workers in a rural setting in India. The aim of the designed system is to enhance the efficiency of the field level community health workers in carrying out their prescribed work. The methodology involved, the identification of needs and problems as well as the development of the mobile based approach is outlined in this paper. It includes the initial design of the system up to the GUI and final working prototype run on a mobile. System analysis and information design principles were incorporated during the development process. Results of a limited testing of the design are also reported in the paper. The study reported includes findings from 8 village community healthcare workers and 3 doctors using the developed application. The targeted users were asked to evaluate the designed interfaces and information architecture in terms of their learn ability, ease of use, efficiency and adaptability. It was found that using the application reduced the cognitive load of the healthcare workers and assisted them in their work. The community healthcare workers were able to engage better with the rural people using this application.

Keywords Information system · Community system design · Qualitative research · Mobile based health monitoring system · GUI · Useability testing

V. Mishra (✉) · P. Yammiyavar
Department of Design, Indian Institute of Technology Guwahati, Guwahati, Assam, India
e-mail: vishwajitster@gmail.com

P. Yammiyavar
e-mail: pradeep@iitg.ernet.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_96,

1 Introduction

In the present age, the government is putting significant emphasis on fostering the health of people, especially in the rural areas. The rural health sector presents numerous diverse and challenging problems that are unheard of in the urban landscape [1–3]. Generally in developing economies like India, there is a scarcity of resources in terms of infrastructure as well as human resources. Most of the problems arise due to an acute lack of doctors and unawareness among people in rural India. This is clearly evident in the scenario considered in this paper [4–6].

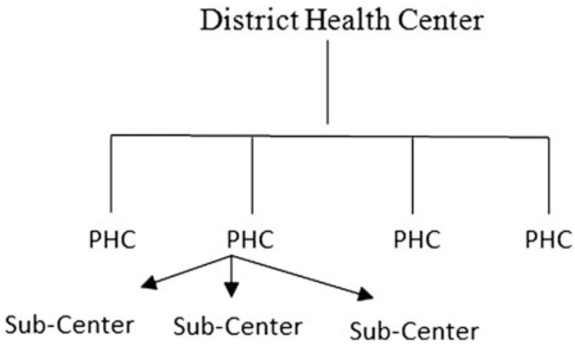
From the field study, it was found that in the present context of North Guwahati region in Assam, there are just four doctors in the Primary Health Centre (PHC) at College Nagar to cater to a population of around one lakh spread over 19 villages. In such a scenario, empowering the community health workers becomes an imminent task at hand to bolster the efficacy of the many health schemes promoted by government. The members of ASHA have been empowered by government through means of limited training, free mobile phones, pamphlets, brochures, informative books, a free radio and a free cycle [7, 8]. In this paper, we have tried to understand the current system as functional in the North Guwahati area in our locality and have tried to propose design interventions for the broader system to plug the prevalent loopholes. The focus has been on empowering the ASHA members, Auxiliary Nurse Midwives (ANMs), Anganwadis, and other multi-purpose health workers in their work through the intervention of Information and Communication Technology. The paper intends to explore further how the ASHA members and other community health workers can be empowered and assisted in their daily work and be integrated with the central health-care system through the means of an even efficient system and through the intervention of a mobile application utilizing the high penetration of mobile phones.

2 Current Scenario of Healthcare with Emphasis on North Guwahati, Assam

In the current situation, there is a District Health Centre in every district in the country. Besides this, there are some Primary Health Centres in each district, which come under the purview of the District Health Centre. To support these, there is one Health Sub-Centre in each village. The Sub-Centres come under the supervision of The Primary Health Centre (Fig. 1).

The focus of this study is the Primary Health Centre at College Nagar, in Kamrup District, and the Sub-Centres that come under its purview, especially the Moriyapati Sub-Centre at Amingaon, in North Guwahati, Assam. In the current system, there are 19 health sub-centres in the region between Amingaon and Bezara, in North Guwahati. There aren't any regular doctors assigned at the sub-centres, only community health workers work there, roughly 4 health workers at

Fig. 1 Existing hierarchy: *PHC* primary health center



every Sub-Centre. Once a week, a doctor from Primary Health Centre visits the Sub-Centres. The Primary Health Centre (PHC), located at College Nagar, North Guwahati, monitors these Sub-Centres. The population of this region is approximately 1 lakh. There are 4 doctors assigned in the PHC at College Nagar. Besides them, there are around 15 other health workers to assist them in their work at PHC. The working hours of the doctors are between 9:30 AM to 2:30 PM from Monday to Friday. Approximately 180 people visit the Primary Health Centre at College Nagar every day during winters. The number rises significantly during summer months. On every Wednesday, the doctors have to go to the Sub-Centres on field visits and immunization. On every Friday, the doctors go to villages to spread awareness and look after people in their area. Thus, as can be analysed from the routines of the doctors, there is significantly great work load on them. Besides the doctors, there are many community healthcare workers and a chain of ASHA members, one ASHA for approximately every 1,000 rural people in villages. The ASHA members receive payment on performance basis and there isn't any monthly salary for them [9]. Their major duties are to spread the messages of government health schemes to rural people and bring about awareness in them. However, majority of the tasks that ASHAs perform are limited to the areas of maternal health, immunization, family planning and first aid. Besides the ASHAs, there are Anganwadi Workers (ANW), who cater to the cognitive and development aspects of children less than 5 years of age in villages [9]. The Anganwadis' receive a paltry monthly salary. Although the tasks of ASHAs and Anganwadis are demarcated, the roles performed by them in villages are generally blurred [10]. The government has given the Auxiliary Nurse Midwives (ANMs) and ASHAs' a free mobile phone [11]. Although there is an eligibility barrier of being class 10 pass for becoming an ASHA but generally the norms are relaxed [10]. Respected women in their middle ages and widows are mostly preferred for recruitment to the ASHA program. "The situation of healthcare was significantly grim before the inception of National Rural Health Mission (NRHM) in the year 2006. But after the inception of NRHM in 2006 and the Accredited Social Health Activists (ASHA) program in 2008, the efficacy of the intended health schemes has improved significantly. There has also been significant improvement in the ratio of the number of ASHA members to the number of rural people and it is reaching the desired ratio of 1 ASHA member for every 1000 people in the villages [9].

3 User Survey

This survey was conducted with the intention to understand the problems faced by community healthcare workers in their daily life while performing their task. The usage characteristics and importance of mobile phone in their daily lives were also studied. The sample sizes are indicated in the table mentioned below. The findings from the survey are reported in the paragraph that follows (Fig. 2).

3.1 Problems Faced by Community Healthcare Workers

After studying the current scenario and interacting with the stakeholders concerned, i.e. the healthcare workers, doctors, rural people, and assessing the information present in literature and other secondary information sources, the following issues and problems were considered to be the most concerning.

- Little Training (only 23 days training in 12 months followed by mere 2 days of follow up every 2 months) [9]. After the training, the health workers were left on their own, they did not know whom to approach for doubts on their lessons. Also, since the books and pamphlets that they received after training sessions [9] weren't engaging and contained too much prose, the health workers generally did not read them.
- Inertia towards reading books and other written material. The Booklets and learning material given contains too much prose and is not engaging and one has to search sufficiently to gather information from books and there isn't any instant doubt removal facility.
- The Radio program that was aired for ASHA [12] members was too infrequent. It was aired only 4 times in a month. The health workers could not listen to the program again if they had missed a radio session once. Also, the members could not record the Radio sessions. Besides this, the information disseminated

Health Centre	District	State	Country	No. of Community Health Workers
Moriyapati Subcentre, Amingaon	Kamprup	Assam	India	6
Primary Health Centre, College Nagar	Kamrup	Assam	India	12

Fig. 2 User survey to asses needs of community health workers

through the ASHA Radio Program [12] was too generic in nature and only seldom catered to the demands of individual community health workers.
- The post cards given to ASHA members [12] was initially offering exciting prospects in terms of doubt clearance and query answering results, but this also reached stagnation since the answers through post cards took a lot of time to reach and till then the interest in the case was lost.
- The mobile phone given to the ASHA members and the free closed user group created by BSNL [11] is not used to its full capacity since the ASHA uses it only to make and receive calls. There isn't any integrated application to help them in their work.
- The village sessions that the ASHA organizes or the home visits made by them aren't very engaging. Besides, when an ASHA goes to check a particular patient, she generally does not know about the past patient history of that person. Also, even though most of the cases that come to ASHA concern maternal health, there isn't any checklist which ensures that the ASHA has covered all the necessary points while discussing it with a would-be mother.
- The health worker does not know what to do in case of a medical emergency as she has limited training. If the health worker can administer some basic first aid in cases of emergency, then it will be of great help in saving valuable lives.
- There are certain cases in which the ASHA goes to visit a particular patient and then she has a doubt in performing a particular task, say wrapping a band aid, or she is confused whether to feed the patient medicine A or medicine B for a particular ailment. In these situations, the ASHA cannot bring along her book with her and even if she brings, it will be a big embarrassment for her to look into it for solution. In these cases, the availability of a secondary learning resource to aid her was missing.

4 Context Diagram

Figure 3 shows all the entities involved to form the basic system and is termed as the Context Diagram [7]

A mobile service provider controlled by the health department will monitor the system. The rural people can send in their queries regarding health, appointments, etc. and the system will direct their queries to the community health worker in their locality. The health worker can register patients and send his/her data to the service provider, controlled by the health department. Health workers can also type in their queries or seek help in case of emergencies and the service provider can then connect the health worker to appropriate doctors who can assist them in their work. Health workers can also perform several other functions like learning their training lessons and taking self evaluatory tests sent by the health department.

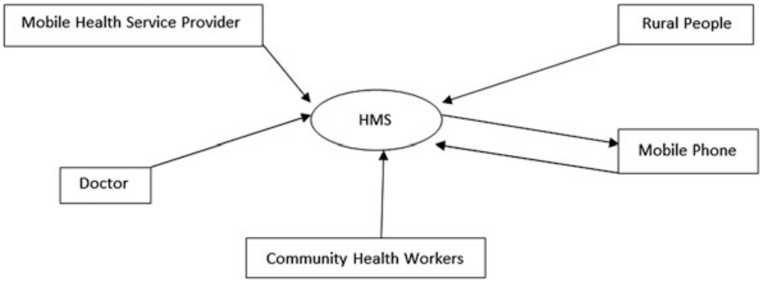


Fig. 3 Context diagram: *HMS* healthcare management system

They can send the result to the service provider, who can send it to doctors, who can monitor the community health workers progress over time.

5 System Modelling and Development

The detailed modelling of final designed system was done using Unified Modelling Language comprising of Use Case Diagram, Sequence, Relationship, and Activity diagrams among others [7, 13]. One of the several Use Case diagrams and Sequence diagrams is shown in Figs. 4 and 5. The sequence diagram depicts the sequence of interface interactions performed by a community health worker, given the tasks of selecting a mode of registration, searching for a patient who is already registered on the list, looking the patient's past history and finally counselling the patient.

5.1 Information Architecture

The information architecture (IA) of the application was designed keeping the system specifications in mind. The central aspects of the system, Registration, Learning Module, Notification, Self-Assessment tests, Important Contacts and Asking Doubts sections, were further detailed down. For example, within the registration section shown in the IA, one can choose from Children's Registration, Mother's Registration or General Registration, catering to other ailments which do not belong to the previously mentioned categories, like fever, diarrhoea, wounds, etc. This categorization was done since most of the patients that come to the health workers concern maternal and child health. Similarly, in the 'Learn' section, health worker has the option of learning lessons on various issues like Pregnancy, Family Planning, First Aid, Immunization, Hygiene, Nutrition, etc. In the notification section, the health worker can view messages and reminders sent to her from the health centre or rural people. The notifications from the health centre can be

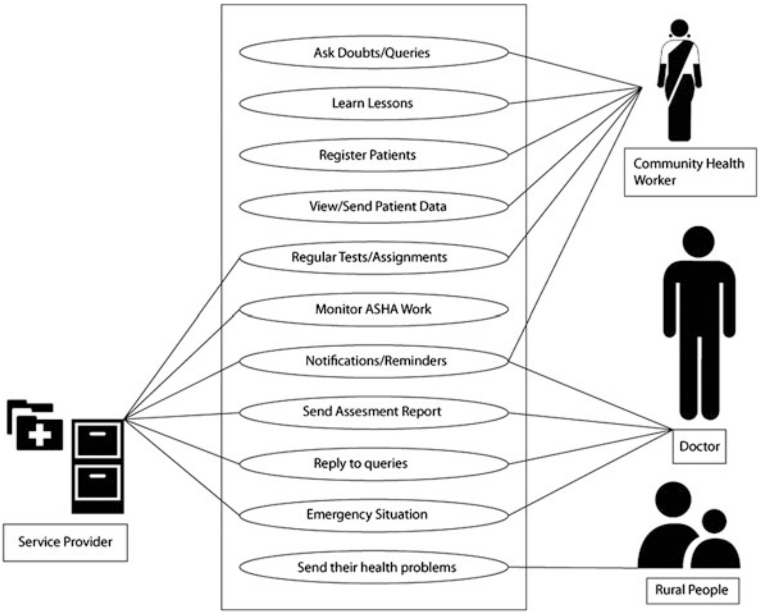


Fig. 4 Use case diagram

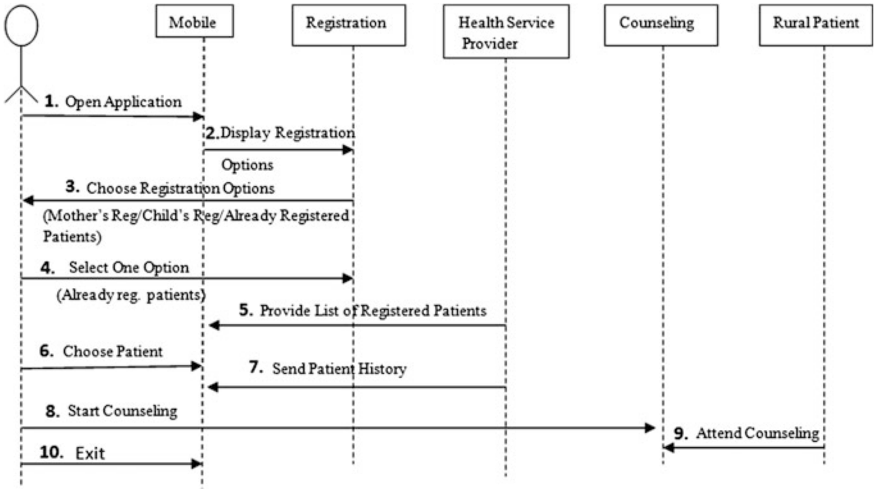


Fig. 5 Sequence diagram

regarding reminding the health worker about her home visits, or health check-up scheduled in the village, what items she should carry along with her, what lessons she has to revise in order to prepare herself for a particular task, etc. In the self-assessment or 'Test' section, the health worker can evaluate her knowledge of a

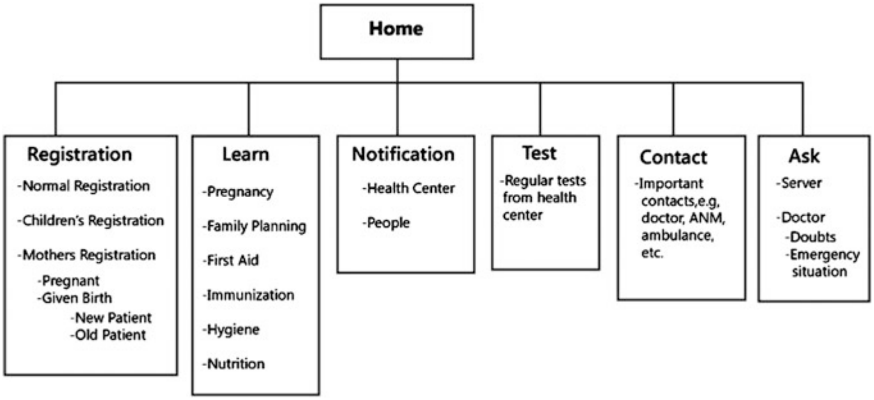


Fig. 6 Example of a basic information Architecture for the application

particular section by giving the predefined tests already loaded on her mobile application. The health centre monitoring the progress of ASHA can also send her tests to take. The answers to these tests are present in this section. In the 'Contacts' section, important contacts of all healthcare professionals and emergency numbers are provided. In the 'Ask' section, the health worker can send her doubts to the healthcare service provider, or in case of emergencies, for example, a large cut, snake bite, etc., she can send the photo of the affected part to a doctor, through the service provider, and slowly they can have a video conference where the doctor guides the health worker in emergency situations (Fig. 6).

5.2 Functions in the Mobile Application

Functions in the mobile application shown in Fig. 7.

6 Final Mobile User Interface Prototype Development

The prototype was developed using Adobe Flash CS 5.5 and Action Script 3. The specifications of the developed User Interface are as listed below:

Language Used: Hindi, Assamese
Voice Over: Hindi
Number of Icons: 6 on the first screen
Color Used: Color and Black and White both
Screen Size: 240 × 320 pixels
Software Used for Prototyping: Adobe Flash CS 5.5
Mobile Used for testing prototype: Dell XCD 28

Registration	• Registering a child → Options for registering a new born child or view patient data history of an already registered child • Registering a mother with maternal problems → Options for registering a new mother or view data of an already registered mother • General Registration for other illnesses like jaund ice, malaria, etc. Other options same as in the previous cases
Learning	• Pregnancy → Danger signs in pregnancy, correct breastfeeding techniques, nutrition, medication, etc. • First Aid → Large Cuts, Suffocation, Drowning, Snake Bite, etc. • Immunization • Family Planning • Cleanliness • Nutrition
Notification	• Notification from health center informing the health worker about village health day, her counselling sessions, patient visits, etc. and its time, venue and articles to be carried along with • Notification/requests from people. The mobile server will direct rural people's queries to the concerned ASHA in the village and then the health worker can look into the query
Evaluation/Tests	• Self-Assessment tests which the health worker can take to test her k nowledge on an any topic. For example, before an in house counselling session, the health worker may want to brush up her knowledge on danger signs in pregnancy and other maternal health topics • Tests sent from health center from time to time basis or before organizing a village health day/health camp. For e.g., before a malaria, pulse polio drive, etc., the health center can send some tests to the health worker over phone. The health worker in turn has to send her response and she can get a feedback. This way, she will be better prepared for her sessions and her efficiency will improve. • In case the health worker does not know the response to a question, she can discuss it with other health workers at sub center
Ask	• Send doubts/queries to mobile health se rver in case when she has a doubt or if she does not know about a health topic. • Send photo of affected area to doctor/ start tele-medicine, in case there is an emergency situation and doctor is not immediately available

Fig. 7 Table depicting functions in the mobile application available to the health worker

6.1 Features of the Developed Mobile User Interface

- Usable Information Architecture
- Easy Navigation
- Voice Over
- Notifications messages from health service provider
- Facilitates learning and self-assessment
- Easy registration of patients
- Enhanced engagement for both the health worker and her clients
- Checklist of important points to be followed

6.2 Final GUI on Mobile

Some screenshots of the final Graphical User Interface designed are shown below in Fig. 8. Wherever there is a voice over, the active loudspeaker button denotes it.

Fig. 8 Final GUIs

7 Testing

The first set of tests was done to understand the 'learnability' aspects of the proposed new GUI. Testing location was at North Guwahati, Assam, India. Total 8 community health workers were tested. The tests were carried out at health centres and at the residences of health workers. The user age group ranged between 37 to 46 years. Education level of the users was till class 10th. All the users had previous experience of mobile phone and they were using the free mobile phone that the government had provided them. Hindi language was used for testing purposes along with prompts in Assamese wherever required. All the users had undergone a course in Hindi language during their training program. Two tasks were given to be completed by the users. These tests were carried out on the final mobile prototype that was developed.

- Task 1: To go through the counselling section on her own. This section comprised a set of 12 messages. Each message asked a question which had to be replied in 'yes' or 'no'. The respondents also had to listen to each question with the voice over and then record their response to the question and move to the subsequent message.
- Task 2: To go to the notification section and read the message from either the health centre or rural people.
- Number of error/confusion spots denotes the number of instances when the user was confused or made an error while navigating through the screens.
- Mobile Phone: Dell XCD 28: Prototype in Hindi Language
- Stop watch was used to check the time taken to complete the task (Figs. 9 and 10).

7.1 Testing Methodology

Coaching method' was used to model the test [14]. Hindi and Assamese languages were used for giving instructions and clearing doubts of the users. Mobile phone was provided to the user to operate and time recorded to perform the task was

Fig. 9 Usability testing on the final mobile prototype (*extreme left*), and on paper prototypes (*middle* and *extreme right*)

Sr. No.	Educationin class passed	Agein Years	Time for T1in minutes	Number of Errors/Confusion	Time for T2 in seconds	Number of Errors/Confusion
1	9th	37	1:40	3	8:24	0
2	8th	45	1:48	2	6:23	0
3	8th	44	1:42	3	7:50	1
4	10th	42	1:50	4	8:24	0
5	9th	36	1:32	2	8:28	0
6	8th	44	1:38	2	7:82	0
7	10th	52	1:42	5	8:24	1
8	10th	46	1:42	3	7.88	1

Fig. 10 Table depicting time taken for the completion of tasks (*T1* Time taken for task 1, *T2* Time taken for task 2, Education-1st to 12th standard in a typical schooling system before entering into university. The table shows the data for the tests carried out on the final mobile prototype.)

noted using a stopwatch. The various screen configurations along with the purpose of the task were first explained, shown and demonstrated to the subjects to make them feel comfortable. The users were asked to use the application for three days. The tasks were then assigned and the test was conducted after this gap of three days. The time taken to perform the assigned tasks was an indicator of how quickly and easily the subjects could learn to operate the new GUI. The test also tested the learnability and the navigability (information architecture) of the information hierarchy of the application. The number of error/confusion spots would indicate the number of times the user were either unsure of what to perform or performed some task wrongly. This would be an indicator of the learnability as well as the cognitive load of the user while navigating through the information architecture.

8 Results

The test data indicates that the average time taken for Task 1, involving listening to the questions in messages under counselling section and then recording their responses, was 1 min and 42 s and the average number of errors faced while performing this task was 3. The error/confusion regions indicated that some regions in the interface were difficult for the health workers to comprehend. Interestingly, these error/confusion spots were uniform for all the health workers. The second task involving going to the notification section and reading a message took 7.8 s on an average and was performed with almost no errors.

9 Conclusion

Using the application ensured that the workers were able to remember and recall effectively, the lessons on general health taught to them during training. They were also able to clear their doubts and engage better with rural people. It saved them time and reduced cognitive load in carrying out their work. Cultural contexts of use need to be incorporated while designing information architecture [15]. The options/number of clicks possible on a screen have to kept as minimum as possible to reduce cognitive load. At every instance, the users must get appropriate feedback on the task they are performing and the number of tasks remaining to be completed. The insights from this project can be used to develop similar applications in agriculture, education, microfinance, insurance, etc. in developing countries.

References

1. Waterhouse Coopers P (2010) Emerging market report: healthcare in India 2007
2. Future of Health PSFK, Available at http://www.psfk.com/publishing/future-of-health. Accessed 2 Nov 2011
3. Srinivasan R (2005) Health care in India-vision 2020, issues and prospects. Planning commission, India
4. Chib A (2009) The acehbesar midwives with mobile phones program: design and evaluation perspectives using the information and communication technologies for healthcare model. In Mobile 2.0: Beyond Voice? ICA Pre conference
5. Pakenham-Walsh N, Priestly C, Smith R (1997) Meeting the information needs of health workers in developing countries. Br Med J 314(7074): 90
6. Kuriyan R, Toyama K, Ray I (2006) Integrating social development and financial sustainability: the challenges of rural computer kiosks in Kerala. In: Proceedings information and communication technologies for development
7. Van Dijack P (2003) Information architecture for designers. Rotavision Publication SA, UK
8. Inclusive Healthcare Management for Sustainable Development, Conference Background Note, Deloitte, Aug 2011
9. Ministry of Health and Family Welfare (MoHFW) (2007) Government of India, New Delhi. National Commission for Macroeconomics and Health Annual Report 2006–2007
10. Ramachandran D, Canny J, Das P, Curtell E (2010) Mobile-izing health workers in rural India. In: Proceeding CHI 2010, ACM Press
11. Mobile Phone to Sub Center ANM. Available at: http://www.nrhmassam.in/anm_mobile_content.php. Accessed 12 Feb 2012
12. ASHA Radio Programme under NRHM, Assam. Available at www.nrhmassam.in/asharadio.php. Accessed 21 Jan 2012
13. Yeates D, Shieldss M, Helmy D (1996) System analysis and design. Macmillan India Limited, India
14. Nielsen J (1993) Usability engineering. Morgan Kaufman Publication/Academic, USA
15. Kolko BE, (2002) International IT implementation projects: policy and cultural considerations. In Annual IEEE IPCC Conference, 352–359

Developing Young Thinkers: An Exploratory Experimental Study Aimed to Investigate Design Thinking and Performance in Children

Anisha Malhotra and Ravi Poovaiah

Abstract It is increasingly popular to teach creative thinking skills in schools. A diverse variety of programmes exist to support practitioners in this task, and some research has been gathered on the effectiveness of individual approaches. However, there is less research on the effect of such programmes in Indian schools and creative thinking. This study aimed to investigate the process of creative problem solving in children observes thinking strategies used by fifteen 11–13-year old children redesigning the traditional board game of Snakes and Ladders. There were three experimental conditions: individual, dyad and triad collaborative. The paper presents results where protocol analysis is used to investigate evolution of design ideas and various thinking strategies to analyze the levels of design thinking. The paper also examines the relationship between creative thinking and collaboration. Results demonstrated differences in levels of design thinking and performance gains for collaborative conditions both dyad and triad.

Keywords Creative problem solving · Design thinking strategies · Divergent thinking · Collaboration in children

1 Introduction

Problem solving has proven to be an effective way through which thinking can be practiced in schools. Conventional school assignments rarely give students the

A. Malhotra (✉) · R. Poovaiah
Industrial Design Centre, IIT Bombay, Powai, Mumbai, India
e-mail: malhotra.anisha@gmail.com

R. Poovaiah
e-mail: ravi@iitb.ac.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_97, © Springer India 2013

opportunity to work on challenging thinking problems which are open-ended. Hence, most students have little experience in skills such as planning, researching, problem solving, idea generation, reasoning and summarizing. Design problem solving encourages such practices where one has to continuously explore and think of multiple solutions for a single problem.

This paper presents findings from an on-going research aimed at supporting collaborative activities in face-to-face environments and developing thinking skills in creative contexts. One objective of the study presented here was to examine the ways in which children that are not trained in any kind of (game) design thinking approach a redesign task and to identify the kinds of strategies they use to accomplish the task. Fifteen children who volunteered for the study became game designers for an hour and worked on redesign of the game of Snakes and Ladders. Three conditions were investigated for the same task where children as individuals, dyads and triads solved the problem in three different sessions. The study presents a comparative difference and similarity in thinking strategies and design process for all three conditions.

The insights from this experiment could help understand a facilitator less situation and help improve design education or creative thinking skills programmes where the focus is on enhancing creative thinking skills in children.

1.1 Problem Solving: Convergent Versus Divergent Thinking

Problems vary in knowledge needed to solve them, the form they appear in, and the processes needed to solve them. The problems themselves also vary considerably, from simple procedural problems in elementary school to thinking of multiple ways to solve a problem with an unknown answer. If a problem is an unknown worth solving, then problem solving is "any goal directed sequence of cognitive operations" [1] directed at finding that unknown.

A critical attribute of problem solving is that the solution is not readily apparent or specified in the problem statement, so the learner must identify not only the nature of the problem, but also an acceptable solution, and a process for arriving at it. The approach to solve a problem may be convergent thinking (a single, known solution) or divergent thinking (one of several acceptable solutions). Well-structured problems with a single solution require the application of a limited and known number of concepts, rules, and principles being studied within a restricted domain. On the other hand, problems which are open ended look forward to solutions those are neither predictable nor convergent.

For a long time, psychologists believed that "in general, the processes used to solve unstructured problems are the same as those used to solve well structured problems" [2]. However, more recent research in creative problem solving in different contexts makes clear distinctions between thinking required to solve problems with convergent solutions and problems with divergent solutions.

1.2 Design and Problem Solving Approaches

Simon [2] points out, a unique feature of design problems is that they do not have a single right solution; there are always alternatives. Previous research on design identified different approaches of handling design problems and used bipolar descriptions, such a "top-down" versus "bottom's up" [3]. The view that has been called top-down tends to see the process of problem solving as one of breaking down a problem into more meaningful sub problems. Here, the designer maps out the context, content, and structure of a design at the beginning. The opposing view, called bottom-up, describes problem solving as a conversation with the situation, in which the design of the game emerges in the process of implementing it. These two views suggest that students may approach the design task from different positions, choose to emphasize different aspects of the design, and think about in different ways depending on their personal preferences.

2 Collaboration and Thinking Skills

The majority of theorists and thinking skills approaches actively encourage learners to work collaboratively (as quoted from [4]). Yet, to date, minimal research exists to endorse the benefits of collaborative learning when fostering thinking skills.

Wegerif [5] argues that collaborative learning improves children's ability to reason, and in general enhances performance on most activities. Wegerif and Mercer [6] coined the term "exploratory talk" to denote the ability to 'reason' through interaction and collaboration with others. Gokhale [7] conducted a study based on Johnson and Johnson's claim [8] that collaborative learning enhances children's critical thinking. There was no advantage of collaborative learning on factual knowledge. The collaborative learning condition experienced greater task enjoyment and were consequently more engaged and motivated. However, more research is needed to determine whether collaborative learning specifically enhances thinking skills.

Because a task division can hinder such a conceptually oriented interaction, we preferred to work with collaborative peer-work groups. In contrast with co-operative learning groups, students in collaborative peer-work groups try to reach a common goal and share both tools and activities [9]. According to Cohen [10], shared goals and tools can strengthen positive student interdependence.

3 Research Questions

We setup an experiment to investigate thinking strategies used by individuals, dyads and triads to solve a game redesign problem. In testing these conditions, the experiment also explores if such a situation can help design education as part of the school curriculum and practice oriented creative thinking which requires a redesign in the mode of instruction, motivation and methodology in a facilitator less environment. The methodology should help open doors to divergent thinking as against learning concepts with defined and absolute solution.

Our study aimed at answering the following questions:

1. In a no input and no facilitator setup, what are the thinking strategies used by children to solve a creative problem like redesigning a traditional game of Snakes and Ladders?
2. Where does the precedence lie for the redesign ideas?
3. What are the different approaches used or developed by individuals, dyads and triads to solve a complex task of redesigning a game?
4. Which group meets the criteria of redesigning the best by thinking of a number of qualitatively different ideas, individuals, dyads or triads?

The paper does not question the quality of the creative output of children in the process of redesigning the game of Snakes and Ladders. The paper concentrates on the nature of design process and various thinking strategies used by children. Later, in future experiments we observe how this ability may be enhanced through providing inputs, built on thinking strategies, to produce new ideas.

4 Method

4.1 Protocol Analysis- Use of Think Alouds for Investigating Thinking Process in Children

The term ‘verbal protocols’ is used to refer to human subjects’ verbalization of their thoughts and successive behaviors while they perform cognitive tasks. The protocols are generally taken concurrently with the task performance but may also be taken in retrospection. Verbal reports, concurrent ‘think-aloud’ protocols, provide a valuable source of data about the sequence of events that occur while human subject is solving a problem or performing some other cognitive task.

As designers, when we frame a situation we create an initial design structure within which we begin to invent and implement solutions. Although this dialectic process is illustrated in think-aloud protocols collected extensively while adults attempted to solve a variety of problems; little is known about problem solving techniques and thinking processes when children solve a design problem.

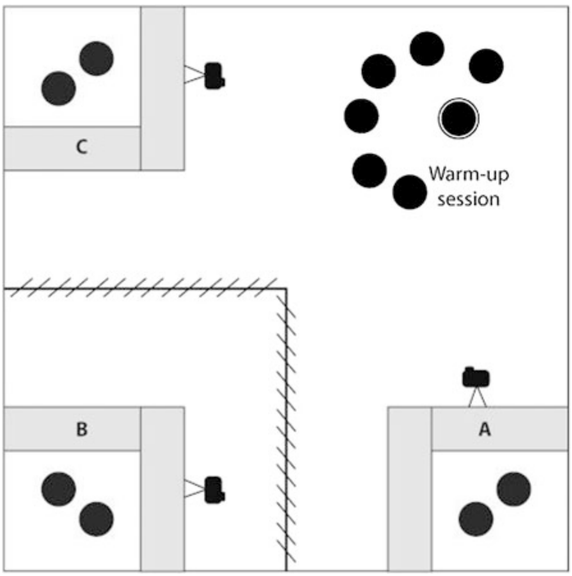
4.2 Experiment Setup

The experiment was conducted with fifteen children of the age 11–13 in a controlled setup. The experiment was performed in a fairly large room which was designed especially for this experiment. The room was divided into four temporary sections (as shown in Fig. 1 below) to conduct parallel sessions. Visual barriers were created in the room so that participants are not able to see each other but are aware of other participant's presence. The barriers were a must so that participants do not get influenced by each other's thinking and concentrate without distractions. The first corner was used for pre-task warm-up session. The rest three corners were used by the participants to perform the task. Also, every session was video recorded separately with one camera per individual in the first session and per team for the next two sessions. A video camera was placed on a tripod at a distance from the participants to record their activities during the task.

The first session was for individual participants, second for 3 dyads and the third for 2 triad groups. Three sessions of fifty minutes each were conducted one after the other. The first twenty minutes included filling a short questionnaire and a short discussion on redesign. The next thirty minutes were given to the participants to work on the task. The experiment was planned in two levels for thirty minutes each- first for idea generation and second for designing and implementing the new game idea.

One researcher was present during all three sessions to conduct the warm-up session, observe and provide assistance whenever required during the task. The assistance did not include any kind of suggestions or guidance to help in thinking of a solution.

Fig. 1 Experiment room design



4.3 Procedure

Stage 1: A warm up session was carried out with children to break the initial inhibitions and get them to think and talk about games. This included filling up a short questionnaire individually and an informal discussion with the researcher on *what is redesign?* During this session we discussed how often do they play games and the kind of games they play?

Stage 2: The design problem was given to all the participants orally together in a group. The participants repeated the design problem before starting the task.

Stage 3: The researcher explained the process of performing the experiment. The participants were told to think aloud during the entire process of redesign. They were told to say 'I am done' when they felt they have no more ideas.

Stage 4: Participants started idea generation on the redesign of the board game.

Stage 5: Execute the 'new game' idea.

4.4 Participants

Fifteen different children participated from same socio-economic background for the experiment. Parents were informed of the study and gave their consent for children to volunteer and participate in the study. The participants were invited for voluntary participation for three separate sessions through posters and informal requests. None of the participants participated in multiple sessions. The mean age of the participants was 11.5. As shown in Fig. 2, three settings were investigated: (a) three children working individually (n = 3; 2 boys, 1 girl); (b) three groups working collaboratively in dyads (n = 6; 6 boys, 0 girls) and (c) two groups working collaboratively in triads (n = 6; 6 boys, 0 girls).

Randomly participants were selected for the sessions on a first come first serve basis and none of the participants participated in more than one session.

Fig. 2 Children solving the problem in each condition: (**a**) individual (**b**) dyad (**c**) triad

4.5 Material Provided

One A3 white sheet to draw, pencils, a ruler and an eraser were provided to each individual. The game of Snakes and ladders was made available only on request of the participants. No colors were provided in any of the sessions. For collaborative sessions, participants shared all resources except pencils.

4.6 Design Problem

The design task given to children was to 'Redesign the game of Snakes and Ladders to make it more interesting.' The focus and the only trigger to thinking that was provided were to focus on thinking of a number of different ideas to change the game and avoid making a 'single' new game.

4.7 Recording the Thinking Process: Logging of the Data

The verbal data, gestures, and the accompanying sketches were recorded on excel sheets by the team. The verbal protocol was divided into chunks of information for analysis in form of 'episodes and events'. The episodes are analyzed and insights are generated which may be useful both for theoretical and practical implications.

5 Results

Qualitative analyzes of transcripts, video recordings, sketches and background questionnaires revealed children used multiple strategies to solve the problem. Also, collaboration positively impacted children's engagement, participation, and enjoyment of the activity. Both content and frequency analysis was performed for the following three processes: Collaboration, Ideation and Execution separately and their combinations. This proved benefits of collaboration over individual problem solving.

5.1 Design Process

The individuals and teams had different processes to solve the problem where some took the approach of idea generation first and then execution and others thought while executing their ideas and the third category used a mix of both approaches. Though the approaches were different but like any other design problem solving activity, giving tentative ideas, keeping alternatives open and keeping some aspects vague were clearly visible in the protocols. A common step toward the redesign solution observed in all the groups except one individual was to draw the baseline grid. Later they used different strategies to think of hurdles and bonus points keeping the same aim of the game that of a race. The process of idea generation was observed to be different in individuals and in collaborative teams. Individual participants hardly questioned their solutions and fewer alternatives were thought of for the same idea. Whereas, in collaborative teams, almost every idea was questioned and improvised which led to a richer thought process and more number of ideas for the final solution.

5.2 Thinking Strategies

Children did not adopt one particular strategy but rather negotiated between skills and multiple thinking strategies. Carryover of elements from the existing game was observed as one of the strongest strategy used by children in the design process; where they replicated the most dominant elements of the existing game. Many visually dominant elements were borrowed either due to the presence of the game board with the participants or because of strong memory of a very often played game. Examples of this strategy can be seen in the Figs. 3, 4, 5 and 6. A square ten by ten grid with numbers 1–100 has been borrowed blindly and as a prerequisite for the redesign. All participants in all three conditions marked ‘Start’ and ‘Home or Finish’ on the grid making this again a ‘race’ where players chase each other to reach the final box. The movement on the new grid follows the existing left to right-up-left-up zigzag path. One long ‘snake’ like element and one long ‘ladder’ like element is also evident of in the new games. The redesigned games follow the rule of repetition of same hurdles and bonus points as in the existing game of Snakes and Ladders.

The common thinking strategies in all three conditions used at different stages of the design process are listed below:

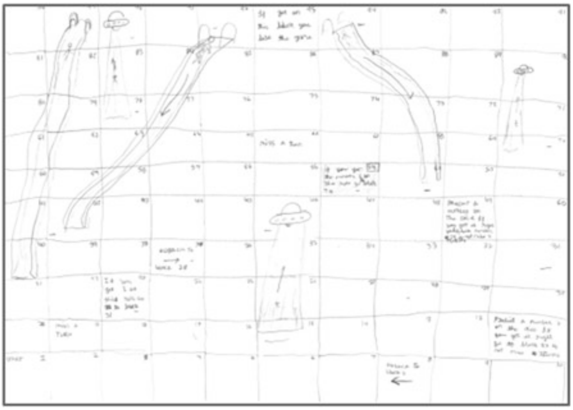


Fig. 3 Individual 1 (Individual B)

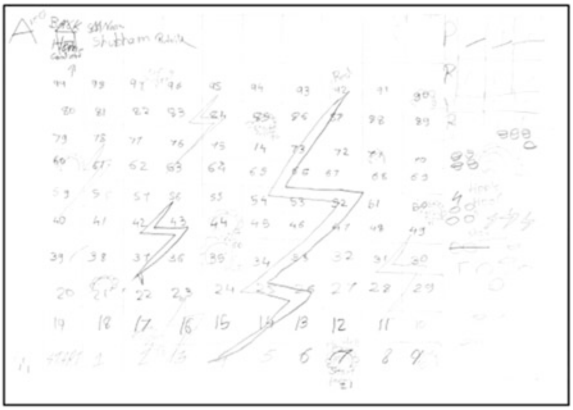


Fig. 4 Dyad 1 (group A)

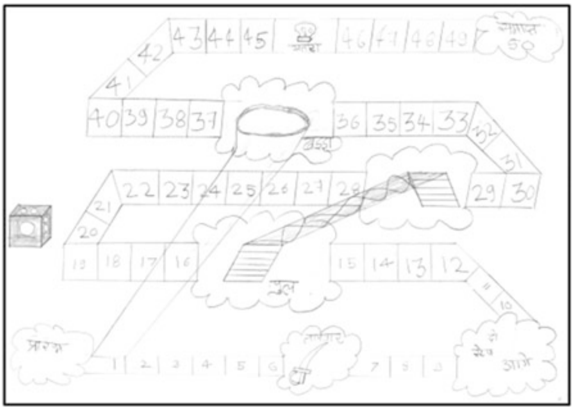


Fig. 5 Dyad 2 (group C)

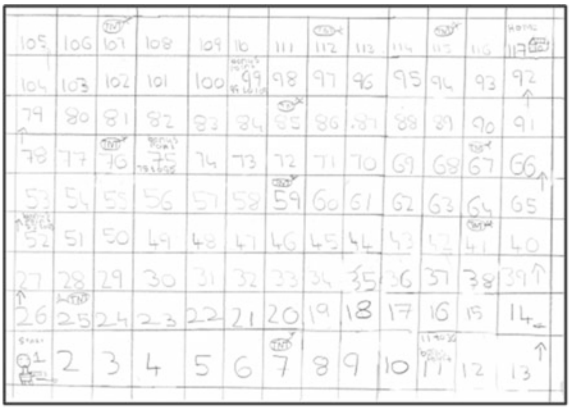


Fig. 6 Triad 1 (group A)

1. Carry over: At least one bonus point should lead you to the top row near the winning point.
2. Baseline for thought process: Drawing the grid, 'Start' and 'Home': Start is
3. Adaptation from other game rules memory: One obstacle in the first row which forces the player to restart the game. More hurdles than bonus points.
4. Analogy from real life situations: Snakes will be replaced by something which affects people in real life. For example: an electric shock, a sword, a pothole, a bomb. Ladders are replaced by objects that help people in real life to move ahead or forward. For example a tunnel, a bridge, a river and a boat, a UFO.
5. Role play: Thinking of real life situations like man going up in the UFO, sliding down, jumping on a boat to move ahead or using a tunnel. The idea of covering the bridge to give it a real look as the participant says the player will fall otherwise.
6. Visual simplification of snakes, ladders and other elements.

Replacement and use of analogy as a strategy was used excessively by the participants. For example:

"2: Where there are snakes we will make ladders and replace ladders by snakes." (Dyad)
"2: We will make a Man in place of Mickey mouse." "2: We will draw the man in the same position as Mickey Mouse." (Triad)
"3: Listen, we can have something in place of Snakes. Like cars or something." (Triad)
"2: Let us draw bombs and ladders now." (Triad)

The participants used either top-down or bottom-up approach to solve the problem. An example of use of top-down approach used by one of the dyad groups is shown below. The group makes a road map of their ideas and actions and later starts executing those ideas where they improvise some on the way.

"2: We will think first and then we will make. As and how we will think we will make."
"2: Here we will make start and there end"
"2: We will make the path like this. From here to here to here to here and end. Ok?"
"2: Later, we will put something like pot holes etc. etc. ok?"
"2: Here let's write FINISH"
"2: This. Start. Finish. Here we will go till 10 then we will have 20, 30 and 40 and finish."
"2: In between we will have some jackpot, then going ahead, then"

Real life situations and role play as a thinking strategy was also used by the participants where they thought of elements (hurdles and bonus) from real life which brings people harm and the ones that help them. Also, while executing a real person was always visualized on the board and design was improvised accordingly. For example:

"1: Draw something here or fill this with color, darken it.
2: Why?
1 (laughs): He will fall otherwise."
"2: Knife? Knife? A sword? When the player will come here he will be killed by a sword and he will come back to 'Start'. What say?"

Adaptation as a strategy was used by a few participants where they picked ideas from memory of the games they have played or play to make new changes to the existing game. Ideas like 'go back to start' or 'miss a turn' were taken and the idea of 'Snakes and Ladders of different genres'—Shooter, Adventure, Espionage and Sport seems to be an adaptation. These genres are most popular in Xbox 360, Wii and other online games.

5.3 Collaboration

Collaboration was an integral part of solving an unknown problem. Children without any training or forced collaboration setup were able to collaborate and work together comfortably towards accomplishing the goal. Many reasons were observed for collaboration among children. Children appeared to participate more actively when common resources were provided for multi–participant interaction. Children made verbal comments and physical gestures to provide input when they were not in control of the drawing sheet. Self initiated distribution of task lead to cooperation to execute the ideas.

For example:

"1: Hey, let us write numbers. You write one line and then I will write the next."
"3: You do the first line. I will do the second and let him do the third line."
"2: You write numbers and I will try drawing the man."

Combined thinking on alternatives and idea generation in a team was frequent. Example:

"2: what should we put here? We want something like..
1: a rat?
2: We don't want a rat. We want something..
1: Lizard?
2: King cobra?"

Implementation and difference in skill lead to interaction between the participants and hence the collaborated better and were found to be more engaged in the task. Example:

"1: Can you draw straight lines?
2: I don't know how to. Is this the way to draw the line? It is not coming straight."
"2: why are you drawing from here? Draw from bottom"
"2: Keep the pencil like this and draw straight."

The participants were constantly asking for each other's opinions and agreement especially in dyads where they worked closely together both on idea generation and execution. Phrases like "Ok?"; "You like it, right?"; "Understood?" were commonly used in their conversations which lead to better collaboration and combined responsibility.

Each transcript hence was coded for any of the three processes: collaboration, ideation or execution. A frequency analysis on occurrence of collaborative ideas in groups was performed on the content where collaboration was distinguished used for ideation or execution. For example, in dyad group 1, total number of collaborative ideation episodes were 16 (collaborative ideation = 9, collaborative execution = 7); for dyad group 2, total number of collaborative ideation episodes were 13 (collaborative ideation = 3, collaborative execution = 6, collaborative ideation for execution = 4); for dyad group 3, total number of collaborative ideation episodes were 17 (collaborative ideation = 6, collaborative execution = 9, collaborative ideation for execution = 2). The results show that there was collaborative ideation but there was more collaborative execution. This may be because of a redesign problem or because of lack of any design instruction given to the children.

5.3.1 Limitations to Designing

Skill proved to be a limitation to design and idea generation. Due to lack of knowledge or skill to draw children were unable to produce and collaborate.

"3: I am not able to make a man, how will we replace Mickey Mouse with a man?"

It was also observed that children were conscious and aware of the fact that their actions are being recorded. This awareness led to a forced collaboration for the camera to show participation. A few examples of that are mentioned:

"1: Let me also draw something"
"1: My photo is also coming let me also work." (Dyad)
"2: You are being watched by the camera. Beware!" (Dyad)
"3: Help please. We will not get anything. Camera is watching." (Triad)

6 Conclusions

This ongoing research study was conducted to investigate the need and benefits of collaboration in a facilitator (input) less setup, when children are involved in a creative problem solving task. Children did not adopt one particular strategy but rather negotiated between skills and multiple thinking strategies. Children used different approaches both top-down and bottom-up in order to solve the task in a successful manner. Design process followed by individuals was found to be linear whereas the groups followed a more iterative process where there was constant evaluation, feedback and improvisation.

The findings indicate that when children are solving an open ended problem with no external input or intervention, the collaborative condition experienced greater task enjoyment and were consequently more engaged and motivated than children solving the problem individually. The lack of skill proved to be a limitation to design and idea generation. Due to lack of knowledge or skill to draw children were unable to produce and collaborate. Otherwise, collaboration occurred at many instances during the problem solving session especially while implementing the redesigned game. It was observed that children probably need more motivation and slight direction to keep the process of thinking moving without disturbing the raw flow of ideas, especially in the case of individuals.

References

1. Anderson JR (1980) Cognitive psychology and its implications. Freeman, San Francisco
2. Simon HA (1996) The sciences of the artificial. MIT Press, Cambridge
3. Kafai YB, Resnick M (1996) Constructionism in practice: designing, thinking, and learning in a digital world. Routledge, London
4. Burke LA, Williams JM (2008) Developing young thinkers: an intervention aimed to enhance children's thinking skills. Think Skills Creativity 3:104–124
5. Wegrif, R. (2002). Literature review in thinking skills, technology and learning. Nest Futurelab Series, Open University
6. Wegrif R, Mercer N (1997) A dialogical framework for researching peer talk. In: Wegrif R, Scrimshaw P (eds) Computers and talk in the primary classroom. Multi-lingual Matters, Clevedon, pp 49–65
7. Gokhale AA (1995) Collaborative learning enhances critical thinking. J Technol Educ 7:1045–1064
8. Johnson RT, Johnson DW (1986) Action research: cooperative learning in the science classroom. Sci Child 24:31–32
9. Webb NM, Palincsar AS (1996) Group processes in the classroom. In: Berliner DC, Calfee RC (eds) Handbook of educational psychology. Simon and Schuster Macmillan, New York, pp 841–873
10. Cohen EG (1986) Designing group work: strategies for the heterogeneous classrooms. Teachers College Press, New York

Part XI
Posters

Learning from Nature for Global Product Development

Axel Thallemer and Martin Danzer

Abstract For both innovation and strategic design management education is shown via a case study how to teach through research in a multidisciplinary manner. Blurring boundaries of professional compartmentalisation and fragmentation of knowledge is leading towards a new era of innovation by not mimicking nature. In contrast to purely aesthetic design with its emphasis on subjective values, the focus of the innovation origination process here is on the rationalised formulation of functional shape in harmony with materials, production and environmental technologies. This is the opposite of prettifying or pure styling. It is also for this reason that there will be no dressing up of a predetermined technical package for the purpose of providing marketing or advertising with better sales or promotion arguments, but instead—and from the start—a concentration on the devising of analytic solution variants.

Keywords Methodology of fostering industrial innovation through observing nature followed by inductive reasoning · Studying live role models leading to purpose-driven design through scientific rationale vs. Subjective approach · New era of innovating by not mimicking nature

---

A. Thallemer (✉)
University of Art and Industrial Design, Chair of Industrial Design/Head of Scionic®
I.D.E.A.L., Hauptplatz 8, A-4010 Linz, Austria
e-mail: axel.thallemer@ufg.ac.at

M. Danzer
University of Art and Industrial Design, Head of Computer Aided Industrial Design/
Scionic® I.D.E.A.L., Hauptplatz 8, A-4010 Linz, Austria
e-mail: martin.danzer@ufg.ac.at

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_98, © Springer India 2013

1 Inspiration and Meta-Level

A humanoid industrial robot arm inspired by nature has been researched, designed, developed, fabricated and demonstrated by bachelor and master students of scionic® I.D.E.A.L. curricula. Both business and educational as well as academic research issues and contexts are being covered. The presentation spans from natural sciences in industrial design management, materials- and production technologies to purpose-driven Gestalt: scionic®

Visualisations clearly depict the design process, the managing of both the conceptual development and the alternative morphologies resulting in the final prototype in comparison to the common industrial solution.

Procedures: Taking inspiration from prototypes found in Nature, inductive reasoning will be used to open up a larger range of strategic solutions than would generally be available in the context of traditional engineering sciences, due to their compartmentalisation of specialised knowledge. With respect to suitable functional shapes, the wider range of deduced scenarios that thus arises, leads into the so-called morphology box. Working from the basis of the respective scientific aims, a combination of appropriate properties will be addressed on a multifunctional and interdisciplinary basis (Fig. 1).

The history of science also plays an ever more central role in the cultural history of humanity. The structuring of human artefacts existed long before the term "design". Coming as it does from the English-speaking world, it has only been since the 1970s that this term has come to be used to refer to the job description of those who were previously known as "Formgestalter" in the German-speaking world. The congeniality that existed in the Renaissance between art and science led to technological innovations. In Roman times, Vitruvius identified the quality characteristics of design as being "firmitas—utilitas—venustas" (stability, usefulness, beauty). In the wake of the increasing shift away from innovation, functionality and scientificality towards superficial prettification experienced in the design sector in the last decades, this natural sciences research and teaching approach is intended to effect a repositioning in the purpose-driven implementation of human artefacts, ranging from materials selection to associated fabrication technologies, taking into account sustainable environmental aspects. The research and development result is a robot arm with anthropofunctional motion patterns for both industrial automation applications and assisting humans directly due to its resilience.

1.1 The Design Process by Scionic® I.D.E.A.L.

Biologically inspired by analyses of lobsters' and grasshoppers' legs and of human pointing gestures, a two-segmented arm with an external skeleton has been developed with motion patterns similar to those of a human. Powered by artificial muscles, "AirArm" is capable of anthropofunctional motion while not looking humanoid (Fig. 2).

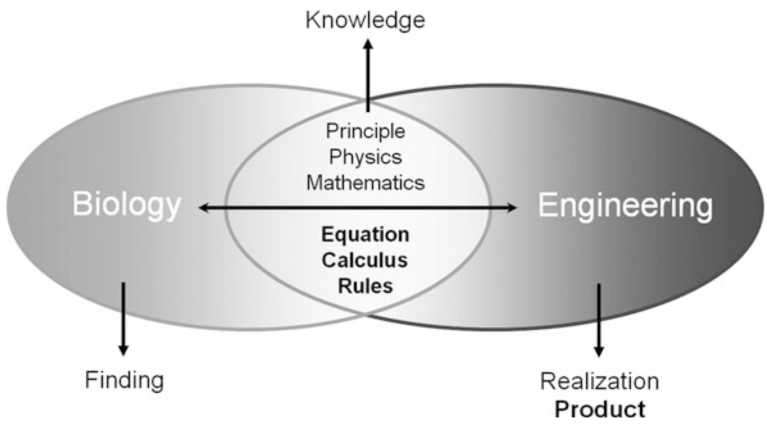


Fig. 1 Biological findings superimposed with engineering lead to extended scientific knowledge for the designer. *Source* Univ.-Prof. Dipl.-Ing. Dr. med. (habil.) Hartmut Witte

Only principles of properties and growth in nature were used in an abstract manner by inductive reasoning to achieve a purpose-driven form for the robotic arm without mimicking the real role models. This can be seen by no direct visual analogy between the life role models chosen and the derived human artefact. A scientific functional analysis of the human arm identified numerous opportunities for technical realisation. The technical purpose of the "arm" is seen as that of reaching as many remote points as possible within a hemispherical operating range from a specified point in space (like under Ref. [4]).

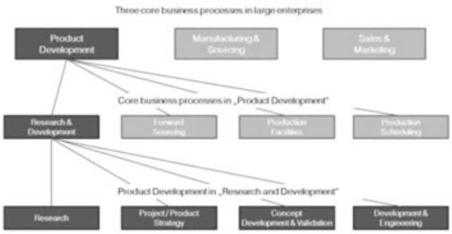
1.2 The Computer Aided Industrial Design Process by Scionic® I.D.E.A.L.

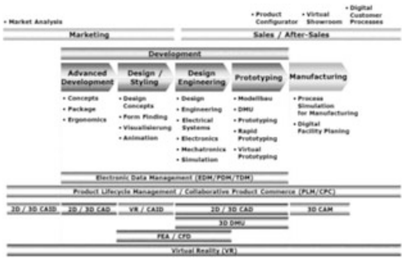
As this prospective robotic arm is representing a research project, which has been carried out for a large industrial enterprise, the challenge for us as an education faculty was to include the teaching by this research in the integrated virtual product development process of that named third-party funded project. Following the rules of the commercial world of professional practice, this study project was to be oriented towards large scale industrial production, enabling it to attain technical or functional superiority in the globally competitive environment.

Numerous IT applications, which together facilitate Concurrent Engineering, enable various departments within an organisation and also external service suppliers to have continuous access to product development data (Figs. 3, 4).

When starting the project, it was our explicit goal to implement a digital/virtual process in the product development—similar of what has been described as methodological principle for product development at large enterprises. To do so, we defined the 3D CAD data as pre-requisite for the complete development of AirArm.

Fig. 2 Because mammal have about the same design from a meta-level, internal skeleton and proportionally scaled bones according to each species, arthropods have been analysed for a broader palette of design solutions as live role models from nature. *Source* scionic® I.D.E.A.L.





Figs. 3, 4 Research & Development as part of the three core business processes in large enterprises and Integrated virtual product development process. *Source* scionic® I.D.E.A.L.

Since the advent of CAID around 20 years ago, design solutions have involved the use of innovative information technologies within an integrated virtual process chain leading to a new product development process. At the end of the 1990s the first IT systems for 3D design and modelling tasks could be developed, again on the basis of newly defined algorithms, which made it possible to trace complex free form geometry by means of NURBS algorithms.

For security reasons and also because of the need for specialization, design and initial surface definition departments of an enterprise have tended to work separately from the development and engineering departments. This division, together with a certain degree of resistance towards computer technology, is the reason why, at the present time, there is no universal data-based communication throughout the field of virtual product development. This means that numerous 'gaps in the system' prevent the existence of an efficient, generally viable process chain such as Concurrent or Simultaneous Engineering. The status of a design and development process is checked and recorded by 'milestones'. As digital technology has advanced, two main scenarios for the (design) evaluation of projects have become established: digital reviews using visualisation based on real-time simulation and virtual reality and/or physical rendering of component parts based on digital input using the rapid prototyping procedure.

2 Purpose Driven Form Finding

As prerequisites for various possible approaches under the heading of "smart design", the following categories were outlined (like under Ref. [5]):

- Lightweight
- Flexibility
- Resilience
- Simplicity
- Robustness
- Adaptive control

2.1 Deriving Shape from Natural Role Models by Inductive Reasoning

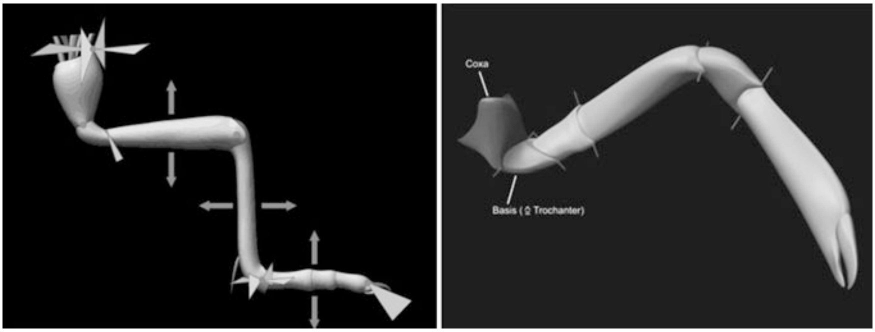
In designing the joints, inspiration was derived from examples found in living nature, but not copied phenomenologically to display visually the live role models chosen. Via the joints of the grasshopper's leg located close to the body (in particular the coxa trochanter joint), the search led to the lobster's leg with its angularly displaced axes of motion. A two-segmented flexing system with muscles operating in contrary motion was chosen as the general principle for technical realisation. By analogy with the natural model, the design was to be kept as simple as possible, and the principles and structures were to be duplicated at various levels; this is known as self similarity. To ensure both lightness and robustness, triangulation of the arm modules was executed by analogy with the exterior skeleton of a grasshopper's leg (Figs. 5, 6). By crossing over the joint axes of the lobster's leg and adapting the segment lengths, a favourable compromise was achieved between simplicity and versatility for the reaching movements within the hemispherical range of operation. The pneumatic muscles as an antagonistic mechanism allow a high degree of yielding ability in combination with minimal expenditure of energy to remain stationary in a specified position (like under Ref. [6]).

Two-dimensional design and contour sketches were initially drawn up for all the functional components required for technical implementation. The three-dimensional realisation was effected using CAID, with verification of the datasets in design programs. The datasets generated by this means served as a basis for production of the functional components by 3D laser processing and CNC milling. In designing AirArm, care had to be taken to ensure that the various functional components could be readily produced from normal metal blanks. In view of AirArm's operation with the medium of water, it was manufactured in stainless steel. As bearings, standard production components were used, thus effecting the best compromise between weight and cost.

The dynamics of the arm system and the patterns of motion within its range of operation were already visualised by means of simulation and computer animation prior to production of the functional components, so that the kinetic characteristics could be analysed and critical system conditions identified at an early stage.

2.2 Transdisciplinary Verification Through Research in Teaching

Inspired by nature, all form finding was done by industrial design students of the author's research institute scionic® I.D.E.A.L., including 3D modelling, FEA analyses and inverse kinematics—the transdisciplinary verification took place both at Friedrich Schiller University of Jena, Germany, Institute of Systematic Zoology



Figs. 5, 6 Degrees of freedom of a grasshopper leg (*left*) versus joint axes of a lobster leg (*right*). *Source* Univ.-Prof. Dr. Martin S. Fischer

and Evolutionary Biology and Phyletic Museum (high-speed HDTV X-Ray, infrared motion capture, Computer Tomography) and at Technical University of Ilmenau, Germany, Faculty of Mechanical Engineering, Department of Biomechatronics and Faculty of Computer Science Technology and Automation, Department of Systems Analysis. They furnished the scientific proof of this industrial designer's purpose-driven way of form giving by getting inspired through functional morphology as well as teaching through research.

The pneumatic muscles used as a drive mechanism have a very favourable ratio between the high mechanical forces attainable and their low weight. The advantages of AirArm thus come to the fore above all where rapid dynamic movement is required. On the other hand, the pneumatic muscles are also highly elastic, and the relations between their contraction, their pneumatic pressure and the forces produced are non-linear. As with its biological model, the technical system must also actively learn to deal with this situation—this is the task of AirArm's control unit!.

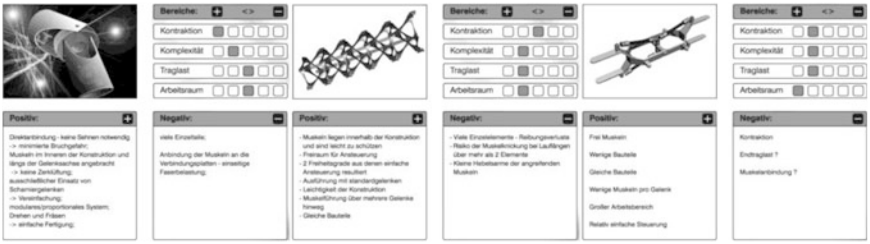
The initial biological inspiration for AirArm was provided by the legs of the grasshopper and the lobster—i.e., legs with internal muscles and an exoskeleton, as are typical of arthropods. However, since AirArm was to combine the structure of an arthropodic leg with the operating radius of the human arm, the axes of rotation and range of motion of the leg joints first had to be determined. It was found that unlike in the case of vertebrates, each successive joint of the arthropodic leg flexed at right angles to the preceding one. The central rotational movement of the arthropodic leg is the sum of the scope of movement of the four joints closest to the body. By contrast, the large scope of operation of the human arm is achieved through a high degree of manoeuvrability in the shoulder joint and muscle assisted flexibility of the shoulder blade (Table 1).

The participating students ideated and sketched about several dozen conceptual design solutions for the prospective arm only after a thorough analysis of most robots via the internet. Global findings were that most of the robots were intended for industrial use. Those could be clustered in six areas: axial, palletiser, scara, portal or gantry, hexapods or deltaic robots. These do all pretty much look the

Table 1 Manoeuvrability of a lobster's leg

Proportion of selected lobster leg segments to total leg length	Selected joint angles of a lobster's leg/Joint axis	Range of motion
Coxa 1	Thorax|coxa to the centre/to the side	Approx. 45°
Trochanter 1	Coxa|trochanter to the front/to the rear	Approx. 85°

Source Univ.-Prof. Dr. Martin S. Fischer

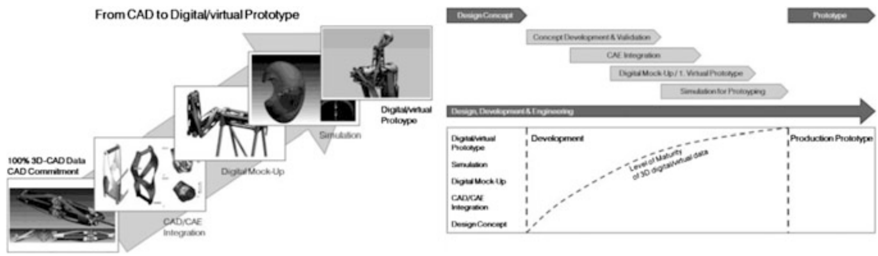


Figs. 7, 8, 9 The final three principles in the evaluated morphological box of about three dozen possible design concepts. The first and third were superimposed for the optimum of the final design concept. *Source* scionic® I.D.E.A.L.

same, no matter which make or company they are stemming from within each category, due to the special functionality those have to perform. Humanoid robots were only found in kinetic art, funfairs, toys, movie industry, laboratory research specimen and/or intended to interact with humans directly in the (far?) future as service robots. A special segment is prostheses. Static devices are recorded for some 3,500 years, mechanically moving ones for some 500 years. Industrial robots are for 50 years existing and operating (Figs. 7, 8, 9).

Digital product development allows photo-realistic designs to be visualized in real time, and subsequently analysed in Design Reviews using VR technology, such as CAVE environment. This offers great advantages compared to complicated and expensive hardware modelling. It is possible to check technical details at an earlier stage, thus anticipating the way the process will progress (front loading) and also improving and enhancing communication with other departments and outside service suppliers.

By means of finite element analysis (FEA) an optimized component shape and load capacity for all functional components was realized as well as sufficient safety tolerance ensured.By collecting the 3D CAD data of all mechanical components including air wiring, a complete assembly has been performed to check any design problems, also guaranteeing data accuracy. PDM systems help to improve design quality via digital mock-up which results in better manufacturing accuracy (Figs. 10, 11).



Figs. 10, 11 Increasing product definition and Level of maturity of 3D digital/virtual data during development lead-time. *Source* scionic® I.D.E.A.L.

3 Feasibility Studies on Anthropofunctional Motion

The movement of AirArm has already been simulated in the early design phase by generating two-dimensional scatterplots of 3–6-segmented arm modules. With the increasing definition of the 3D components and their interaction, the movement of the assembled component was simulated by animation SW using inverse kinematics features. This not only proofs the movements and interactions of the static mechanical components, but also included the air wiring and the respective movements.

The processes of reaching and grasping in mammal were investigated with rats, by means of a high-resolution X-ray camera with up to 1,000 HDTV images per second in two planes. This procedure highlighted the significance of the shoulder blade in executing these movements. Since this method is precluded with human subjects, surface measurements of the arm were used to determine the shoulder blade's role in human reaching movements (infrared motion capture). The results largely corresponded to those determined in the X-ray analysis of rats.

An anthropomorphic, i.e., human-oriented, approach was not adopted in the design of AirArm; rather, the principle of "rotation effected close to the body" was transferred to the use of linear instead of rotary drives (anthropofunctionality). After all, seeking inspiration from nature does not mean directly copying human arm movements (referred to as "biomimicry"), but entails the technical adaptation of human movement patterns, in this case with a lever system based on different lengths, proportions and modes of actuation. Reaching for points within the hemisphere was interpreted as the index finger "reaching" to points on a spherical surface. The movements of the human arm were registered with an infrared-aided motion analysis system. In evaluating the lines of movement, patterns of joint flexing were observed that could be summarised in the form of (apparently) simple rules. The structural solutions produced in the process of human evolution need not be copied; the significant requirement is that the appropriate lengths and forces are made available by technical means. It is not necessary to imitate the human shoulder joint. The evolutionary burden of man once being a primordial fish, going on land, transforming from quadrupedal to bipedal motion, can be seen in the

Figs. 12, 13 Human overshot dart throw with infrared motion capture. *Source* Univ.-Prof. Dipl.-Ing. Dr. med. (habil.) Hartmut Witte

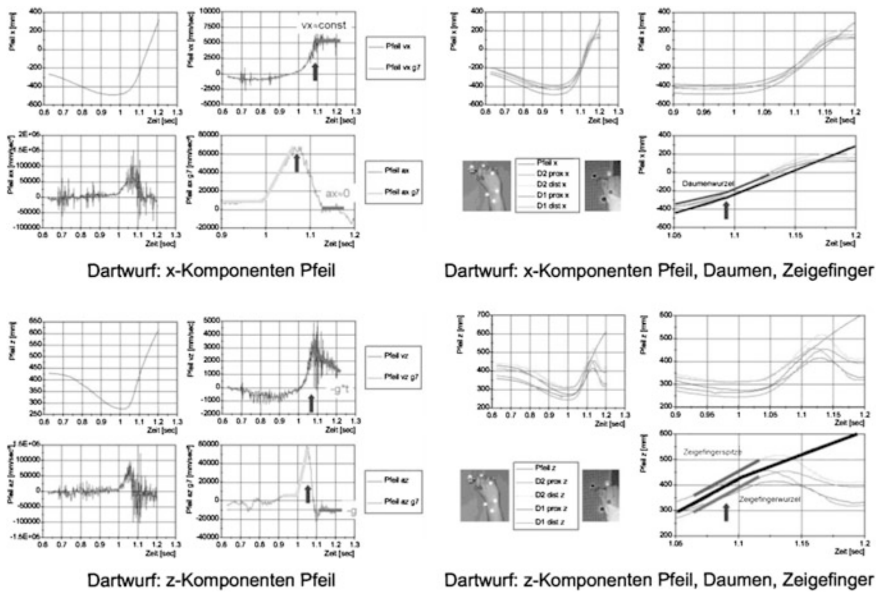
morphology of our arm and hand. Once the breast flipper, the finrays are forming now our five fingers, the shoulder muscles were once pulling water through the gills, later the forelegs became arms.

In analysing the pointing movements, the coordinates of the reference points—marked in the form of reflective spots—and of the targets are registered by means of an infrared camera system generating up to 1,000 images per second. This tracking of coordinates as a function of time provides the basis of motion analysis (Figs. 12, 13).

The entire control system is designed on the basis of a model: the mathematical model of AirArm is first devised on a computer, on which the control system is then drafted and optimised. This system is then transferred via automatic code generation to an industrial PC, which controls AirArm on a real-time basis. AirArm is real-time controlled by means of three nested feedback loops (Figs. 14, 15, 16, 17, 18, 19).

4 Conclusion

The major difference to earlier contributions (like under References [1, 2, 3]) to that topic lies in the transdisciplinary interaction of evolutionary biology, zoologically functional morphology and biomechatronics as well as automation and systems engineering, systems analysis, where industrial design is in the centre of that innovation process described here. By teaching through research on real third-party funded projects and managing a cluster of different universities as well as their faculties and students at various locations, a new way of digital innovation process inspired by natural role models for purpose-driven industrial design could be proven academically. The transdisciplinary crossover between industrial design, engineering and natural sciences is exactly the scope of our bachelor and master curricula yielding to the university degree of (Dipl.-Ing.) “diploma engineer in industrial design”; a unique proposition in industrial design education at university level. The triangle of knowledge in industrial design education comprises purpose-driven form giving inspired from nature, materials-, manufacturing-



Figs. 14, 15, 16, 17 Motion tracking of airarm's overshot dart throw (*left side*) versus human one (*right side*). *Source* Univ.-Prof. Dipl.-Ing. Dr. med. (habil.) Hartmut Witte

Fig. 18 Maximum acceleration 12 g, maximum velocity 11 m/s. *Source* scionic® I.D.E.A.L.

and environmental technologies combined with the digital, virtual development process. It is rarely the case, that industrial design ideation and conceptualisation comes first and engineering is following "simultaneously" through the process;—mostly even in industrial design technical packages are beautified and embellished for the mere sake of advertising and marketing only. The rationale here is the scientification of industrial design by teaching through research versus a subjective "I design" or autographic "designed by me" approach, so commonly known in the world of design. It is rare that design by learning from nature is not mimicking the natural role model visually or phenomenologically, our paper however, shows inspiration by inductive reasoning. The difference is that one cannot see the initial live role model chosen from nature visualized by the (industrial) design (like under Ref. [7]). One is tempted to state, the more similar the looks of the man-made

Fig. 19 Airarm throwing dart. Typical power consumption of 600 W, maximum 2,500 W. *Source* Univ.Prof. Dr.-Ing. (habil.) Christoph Ament

artefact as compared with the natural role model selected, the more likely a mere direct copy has been deduced. But copying nature is futile, because its materials and fabrication methods are completely different to man-made products as well as the reason.

References

1. Aschenbeck KS, Kern NI, Bachmann RJ, Quinn RD (2006) Design of a quadruped robot driven by air muscles. In: Proceedings of biomedical robotics and biomechatronics, 2006
2. Nelson N, Hanak T, Loewke K, Miller DN (2005) Modeling and implementation of McKibben actuators for a hopping robot. In: Proceedings in international conference on advanced robotics, 2005
3. van der Smagt P, Groen F, Schulten K (1996) Analysis and control of a rubbertuator arm. Biol Cybern 75(5):433–440
4. Edelmann TH (2008) An arm, inspired by two legs. Des Rep 4(08):52–53
5. Thallemer A, Danzer M, et al. Airarm—an anthropofunctional robot arm with inherent flexibility. In: 3rd mobiligence conference proceedings, 19–21 Nov, Awaji, Hyogo, Japan
6. Dale-Hampstead A (2001) The fluidic muscle by Axel Thallemer. Modern Classics, London
7. Thallemer A (2010) How bionic innovations redefine design tasks. In: Kronhagel C (ed) Mediatecture. Springer, New York

Design2go. How, Yes, No?

Nikola Vukašinović and Jože Duhovnik

Abstract This paper investigates and discusses the opportunities and possibilities of mobile and ubiquitous technologies in the NPD process. During the 2012 EGPR—internationally based NPD process in virtual environment, we made an analysis on technologies and services that were used for the purposes of the course. Our particular interest was, what platforms the students used for different tasks of the NPD process, and are there any mobile alternatives. Since mobile technologies rely more and more on cloud services this opens many other issues as well: intellectual properties rights, protection of personal information, availability of services and information for different participants, standardization of the protocols which should be well considered before any engineering process such as NPD. Our first observations showed that on one side student participants use more and more of different mobile and cloud technologies available, but on the other side there are situations where they still feel much more comfortable when using "old-fashion" technologies, especially when communicating. One interesting fact is also constantly growing wish of students to use the IT web services which they are familiar with despite all necessary IT infrastructure for their work is provided by the course organizers. This is especially important message for the organizers of such courses, to learn how to balance between accepting the opportunities of new internet tools and threats of privacy and control over the intellectual property.

Keywords Mobile technologies · NPD process · Internet services · Product design · Virtual team

N. Vukašinović (✉) · J. Duhovnik
LECAD Laboratory, Faculty of Mechanical Engineering, University of Ljubljana, Askerceva 6, Ljubljana, SI-1000Slovenia
e-mail: nikola.vukasinovic@lecad.fs.uni-lj.si

J. Duhovnik
e-mail: joze.duhovnik@lecad.fs.uni-lj.si

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_99, © Springer India 2013

1 Introduction

Design has never been so mobile. Smart phones, tablets, net-books, ultra-books, cloud computing, social networks, fast mobile networks, are allowing us to work, create, develop our ideas and share them with the others every second of our lives, no matter where are we or where are the others. But is that really a truth or only an urban myth, triggered by the sellers of mobile devices and media. We will try to answer this question in perspective of the new product design. The NPD process in virtual environment was chosen since it covers a broad range of different activities during different phases of the process, from marketing research to get insight into the project constraints to core engineering tasks which are necessary to finish the project successfully [1].

The question was, whether all product design and development process can really be done on the go with the support of ubiquitous mobile technologies, and there is no further need for an office space, discussion rooms and computer workstations, or maybe we still need them to complete the tasks successfully?

In this paper we will open several point of views for the discussion. What are the phases of product design, which of them could be done mobile and which could not, how we should be concerned about the safety of our intellectual properties and work when working mobile, there are several comfort and ergonomic topics we will touch as well as the meaning of mere human–human interactions.

All this issues have been observed and investigated for several months in real product development process during the last EGPR school process. This is the international school of anew global product design, which gives a participating company five working prototypes and a plenty of fresh ideas every year, and is a never ending source of research material for different design studies every year [2]. In the year 2012 the course connected 38 students from 5 European universities in virtual Multi-X environment, to develop an industrial problem from the idea to the working prototype for participating company from Croatia. Combining the work in virtual multi-X environment, which represents a great learning and realization challenge [3–5] and narrow time constraints which were less than 5 months for the whole NPD process, we got a stimulating conditions for the communication within the virtual teams [6].

The course was divided into four phases of development process which are logical frames of different NPD tasks. In the first—fuzzy front end—phase students gathered information about the company, market, existing products, etc., to set up a design vision which leads into a definition of a design problem to be solved in the following phases. This process consisted of internet data mining, literature overview, interviews and costumer surveys. These activities demanded a lot of work to be done outside the office as well as different ways of electronic communication within team members, industrial partners and external sources of information. The main form of the information during the first phase was digital text and graphics, while the voice communication was used mostly during VC team meetings and some face-to-face interviews.

The second phase is called creative phase, and its final goal is to generate several creative concepts of solutions for the design problem. This phase depends mostly on cooperation within the team members, who were allocated around Europe. Therefore, the main information stream connected different team members and consisted mostly of real time verbal communication (voice and text), text notes and graphical documentation in form of digital pictures and photos.

The third phase represents the detailed design of the selected concept, which consists of CAD modeling, analytical and numerical simulations and analysis and generation of technical documentation. Therefore, this phase demanded daily communication among team members and company representatives to coordinate the activities and exchange the information. Concurrently a comprehensive computer work had to be done for modeling and analyzes. For that reason the amount of digital information exchanged within the team increased respectively.

In the last, fourth phase, all members of virtual teams initiated the process of obtaining and production of components for the prototype realization. At the end of this phase they finally met in person for one week to assemble and present the working prototype. The first part of this phase consisted of communication with the part manufacturers and suppliers while the workshop part of this phase consisted mostly of local tasks, face-to-face communication among team members and local partners, while the exchange of digital information decreased compared to the previous phase.

Due to the virtual nature of the NPD teams most of the work process demanded various means of electronic communication. The methods of communication and the contents of the information to be shared within the teams were in a strong correlation with the phase of the NPD process and each of the tasks requires appropriate information and communication technologies (ICT) infrastructure [7]. However, the results of some researches show that just the availability of the ICTs does not necessary lead to use of them. Therefore, it is essential to establish standards for availability and acknowledgement of communication, which define how dispersed team member will be available for collaboration and how quickly they will respond to the messages [7].

These standards should be specified carefully since other studies showed that the frequency of the communication has a delicate influence on the creativity within the teams. Namely, there exist some optimal frequency of communication within the team, while too low or too high frequency has negative influence on the creativity [8].

However, during the EGPR course these standards were only vaguely specified by course organization—e.g., the use of VC equipment, formal weekly meetings—while the choice of other communication channels depended on team members—e.g., the service for file exchange and instant messaging programs.

Many studies also confirmed that different IT tools have different influence on the market performance, innovativeness and quality of a product, but mostly they foster the results [9]. For example, E-mail communication has been proved to be excellent tool for the engineering project management and information sharing, but it is not that useful as a problem solving tool [10, 11].

The last study [11], not only showed that the IT tools were less suitable for problem solving than for communication purposes, but showed, that web tools in general are more suitable for information sharing, project management and data mining and research than for the creative work. Creative work namely demand more complex services or programs, more computer power as well as the optimal rate of the filtered information flow [8], to establish best condition for creative process and good decision making.

2 Internet Services and Safety of Information

During the course we've been monitoring, what were the services that student used to fulfill different NPD tasks. As it has been mentioned in the introduction, the students had a lot of freedom to establish their own protocols and standards for the (synchronous and asynchronous) communication and document exchange and sharing. Hereby we have to mention that for the purposes for the course, we established the infrastructure for the file depository (FTP server) and teleconferencing equipment for regular VC meetings.

From the Fig. 1, which show the services used for the file exchange, we can see, that despite FTP server, which students used mostly for sending material to the coaches and company, they used Google Documents and e-mail services, which served mostly for their internal communication.

The reason for that is the experience of young generation with these services. They want to use the services which they are familiar with and they know how to use. Therefore, the young generation used third-party online services for the information exchange while many of the students still had to learn how to use the FTP despite the fact that this is an old and most common protocol for the file

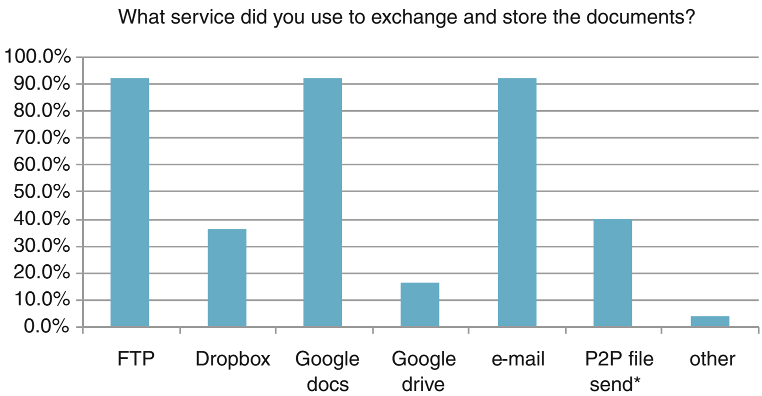


Fig. 1 The services, students used for document transfer. (* peer-to-peer file send using Skype, Google Talk, etc.)

transfer which works behind many cloud services as well. They also found another advantage in Google Docs, which is the possibility to concurrently work on the same document by several team members, while communicating over some synchronous communication channel.

The other advantage of online cloud service (e.g. Google docs, Dropbox, etc.) is also in accessibility to the documents through any web browser or special applications, which makes the documents and service independent on operating system and hardware platform and specifications. This fact together with the availability of highly portable IT devices enhances the possibilities to move the NPD out of the office if necessary.

When we check the services, which were used to communicate within the team (Fig. 2), we notice similar pattern as before. Namely, besides VC equipment, provided for formal meeting of the teams and coaches, all teams established their own communication channels. Here again, most of the students used e-mail as a tool of asynchronous communication, and Skype as a mean of synchronous communication. Surprisingly, the use of Skype conferencing was almost 100 % which is more than VC equipment, and there were no real alternative, despite of the availability. Google Talk was following with 63 %, while social networking communication channels like Facebook chat were almost unattended.

Here we need to mention also the use of the telephone as a communication tool. With the development of smartphones, a telephone is no longer a tool for the classical voice communication but can serve also as a platform for chat and VoIP talks. 55 % of the students said, that they used the internet access on their phones, which only confirms our statement. However, classical phone service was still used, mostly for the local research work and communication with local team members.

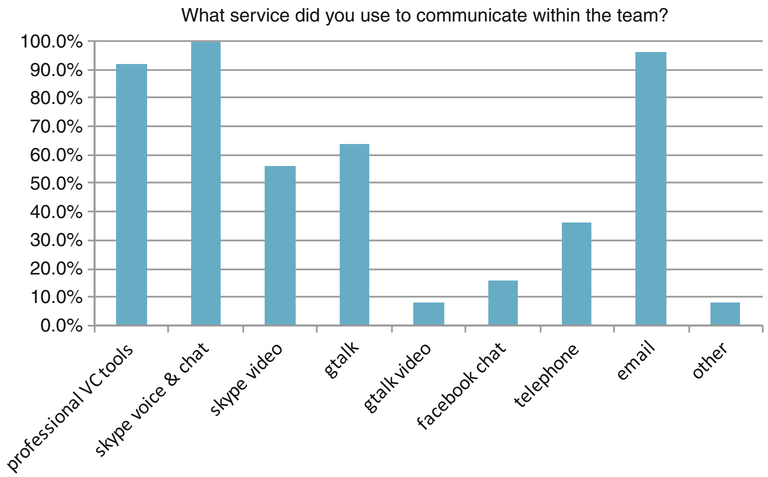


Fig. 2 Communication services used for the purposes of the EGPR 2012 course

If we return to the e-mail, we also observed the origin of e-mail accounts. Almost 90 % of the participants (students and even coaches) used their private e-mail addresses, created at some of the web e-mail providers, among which Google took again the biggest share of approximately 80 % (Fig. 3). Even in the previous years we observed the similar phenomena, when the students applied to the course with their faculty e-mails but in a few weeks they usually switched to their Google mail account, due to the services which Google provide and condition with the use of their e-mail: e.g., Google groups or Google documents.

Since, every third-party IT service always comes with its License agreement and Terms of use, we asked participants of EGPR course, if they normally read those conditions of use. More than 70 % of them answered negative (Fig. 4). That means that most of the course participants don't even know to whom they share their information and how this information will be treated by potential third-party persons.

As the course involves the cooperation of an industrial partner, the participants work also with some company's delicate information. In the year 2011 the company representatives therefore demanded not to use Google services for the course tasks, while the signing the NDA agreement prior the course start is already a standard procedure at the beginning of this course.

Therefore it will be necessary to establish an educational cloud service for the exchange of the information for the purposes of this course, and the service should allow concurrent work on the same document by several participants, as an alternative to free web-based services.

The results of this research show that it would be better if the course organizers prepare the IT protocols and standards which can be used by the students for this course, instead of teams doing this by themselves. This might demand of the

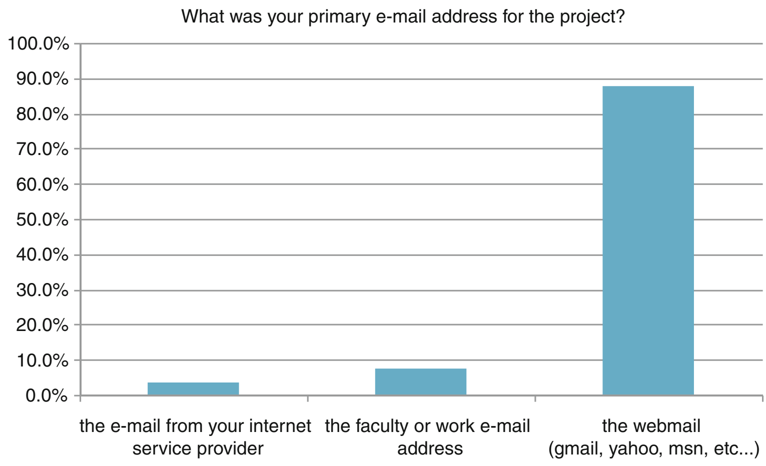


Fig. 3 E-mail provider for the primary e-mail addresses used during the course

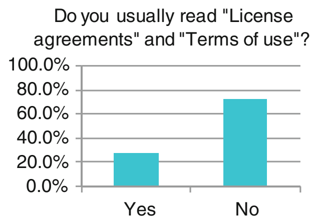


Fig. 4 Most of the participants don't read License agreements and terms of use, when using internet services

students some additional learning, but also more effort for the organizers to establish an IT system which would not limit the communication of the students, regardless to their location and electronic device they use.

3 Electronic Tools for Different NPD Activities

The other subject of our interest was what devices participants used for certain tasks of the NPD process. The tasks were divided into three major groups: *communication*, which included all flow of the information among team members: file and data exchange, synchronous and asynchronous communication regarding the project as well as informal communication which is essential for the team building and the level of trust among team members [3]; *Creative work*, which included all task connected directly to the development of the product: idea generation, concept selection, detailed design and prototype realization; *Research work*, which included all fuzzy-front-end process, SWOT analysis, and gathering the information, necessary for the creative phase. It included online surveys, internet research, on-site research and interviews with the companies and customers. The results are graphically represented in Figs. 5, 6 and 7. From our survey we noticed that participants used mostly their laptops, PCs and mobile phones, while they mostly didn't possess and use smaller laptops and tablet PC yet.

Figure 5 shows that participants frequently used for their communication tasks mostly their laptops (75 %), PCs (40 %) and also their mobile phones (together up to 45 %).

Figure 6 shows the frequency of use of different devices for the creative tasks. There was no need for the mobile phones, which seem to be inappropriate devices for serious creative work in the creative phases of the NPD. Even the use of laptops and PCs is slightly smaller as for the communication, which suggests that the creative process is not a process which could be much fostered by the use of electronic tools, since it is mostly the function of personal cognition and skills. The creative tasks depend on the results of communication and research work. And consist of three interfering and iterative operations: information filtering, contemplation and creation. Especially contemplation step is many times underestimated, but it is essential part of every creativity process, and it demands reduced information inflow to be successful. This is probably also one of the reasons for

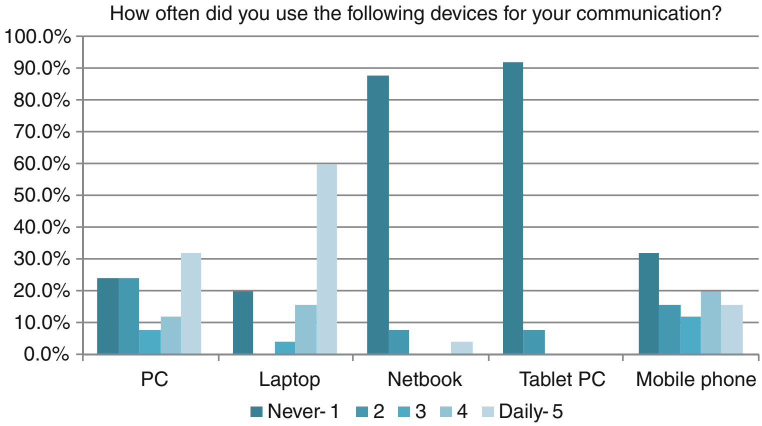


Fig. 5 Frequency of use of different electronic devices for communication purposes

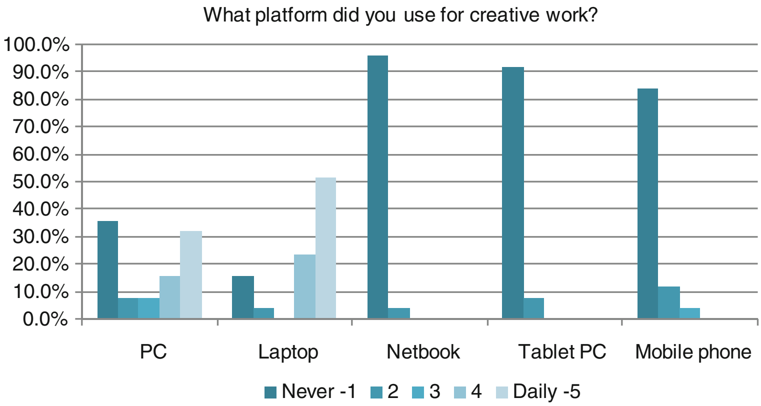


Fig. 6 Frequency of use of different electronic devices for creative activities

reduced use of all tools in the creative phase, but this would be good research topic for the future.

Again, slightly different results we got when we investigated the use of different devices during the research work as show on Fig. 7. The use of all electronic devices was even higher than compared to communication tasks, only there was slightly smaller use of mobile phones, which were mostly used for the interviews with the industrial partners and customers.

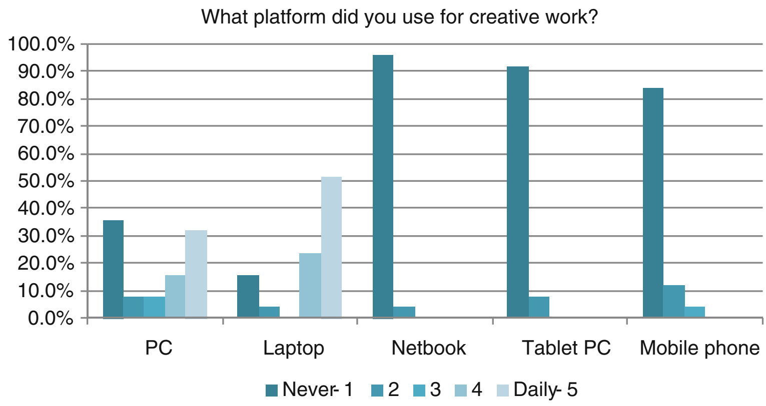


Fig. 7 Frequency of use of different electronic devices for research activities

4 Discussion

Hence, we can conclude that different devices do not have the same potential for different NPD tasks. Unfortunately, we didn't have good insight into the possibilities of the use of smaller versions of laptops and tablet PCs.

We believe that netbooks are not commonly used, since most of the participants already own the laptops, while netbooks and tablet PCs are usually bought as a second personal device. Since most of the participants have engineering background, and this was not their first NPD process, they chose their devices on previous working experience and needs.

Tablet PCs are a new market hit and still establishing their place in the engineering fields. Their use in the engineering future is supposed to increase but in the first phase mostly for the management, research and communication tasks. The use of tablets for the creative engineering work is not expected to rise in the near future for the same amount as for the other tasks for two reasons: The first reason is that the computer power and capacity of tablet PCs is still far behind performance of professional laptops and desktop workstations, while the second reason is the limited ergonomic performance of human-device communication interface: the screen size is limited by portability, while the input is done mainly through the touch display, which is unsuitable for an intensive long-time work.

From the research we can conclude, that most of the NPD work during all phases was still done within the office. However, some tasks, especially information digging and managing tasks are already moving out of the office for information to be available to other team members in the shortest possible time. Hereby, it is important, especially for the real industrial environments, to have established a proper network of communication and data storage and sharing protocols, which would prevent any leakage of delicate information to unauthorized parties, and allow users safe work regardless on device or platform they use. This will be priority also for the future of the EGPR course, since industrial partners play a crucial part of the process. The first step will include testing and implementation of different educational PDM systems. The selection of the best system will depend partly on the results of this research and the results of researches mentioned in this paper.

References

1. Fain N, Kline M, Duhovnik J (2011) Integrating R&D and marketing in new product development. J Mech Eng Stroj Vestnik 57(7/8):599–609
2. Žavbi R, Duhovnik J (2007) Experience based on six years of the E-GPR course, international conference on engineering design (ICED07)
3. Vukašinović N et al (2009) Education of NPD in virtual multi-x environments, international conference on research into design, ICoRD'09
4. Žavbi R, Tavčar J (2005) Preparing undergraduate students for work in virtual product development teams. Comput Educ 44:357–376
5. Fain N, Moes N, Duhovnik J (2010) The role of the user and the society in new product development. Vestnik 56(7/8):521–530
6. Darrel SFC et al (2012) Bringing employees closer: the effect of proximity on communication when teams function under time pressure. J Prod Innov Manag 29(2): 205–215
7. Montoya MM et al (2009) Can you hear me now? communication in virtual product development teams. J Prod Innov Manag 26:139–155
8. Leenders RTAJ, van Engelen JML, Kratzer J (2003) Virtuality communication, and new product team creativity: a social network perspective. J Eng Technol Manage 20:69–92
9. Durmusoglu SS, Barczak G (2011) The use of information technology tools in new product development phases: Analysis of effects on new product innovativeness, quality, and market performance. Ind Mark Manag 40:321–330
10. Wasiak J et al (2011) Managing by e-mail: what e-mail can do for engineering project management. IEEE Trans Eng Manag 58(3):445–456
11. Farris GF et al (2003) Web-enabled innovation in new product development. Res Technol Manag 46(6):24–35

Integrating the Kansei Engineering into the Design Golden Loop Development Process

Vanja Čok, Metoda Dodič Fikfak and Jože Duhovnik

Abstract One of the main tools for translating customer's psychological feelings and needs into product's design domain is Kansei engineering (KE). It is important that analogy of Kansei engineering enters into the product development process on time and fulfills the role of complementary methodology which gives an emotional value to the product. This paper describes how Kansei engineering works, what are its subgenres and options of integration in following design processes. We will describe standard procedure of Kansei engineering type 1, design process VDI 2221 and Global product or services development process called "Design Golden loop" (DGL). The detail description—research on possibilities of integration of Kansei engineering type 1 framework into the design Golden loop process will be described.

Keywords Kansei engineering · VDI 2221 · Design process · Customer · Global product or service development process

V. Čok (✉) · J. Duhovnik
Lecad Laboratory, Faculty of Mechanical Engineering, University of Ljubljana, Slovenia Askerceva 6 SI-1000 Ljubljana, Slovenia
e-mail: vanja.cok@lecad.fs.uni-lj.si

J. Duhovnik
e-mail: joze.duhovnik@lecad.fs.uni-lj.si

M. D. Fikfak
Clinical Institute of Occupational, Traffic and Sports Medicine, University Medical Center Ljubljana, Slovenia, Poljanski nasip 58 SI-1000 Ljubljana, Slovenia
e-mail: metoda.dodic-fikfak@guest.arnes.si

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_100, © Springer India 2013

1 Introduction

Today, product design for the global as well as for the local market is often very complex. The reason for that are contemporary industrial products which have to fulfill more and more user requirements. When a product reaches desired functionalities the decision of purchase is based on a customer impression, perception and his emotions about the product. This becomes very important when the customer has to choose from different products which fulfill the same functions. According to nowadays complexity of producing a competitive and user friendly product many research methods of integrated product development processes have been revealed. As mentioned before one of frequent used tool for customer's emotional impression detection and translation into the product features is Kansei engineering. While Kansei engineering covers an emotional aspect of the product other product development processes as VDI 2221 [1] and Design Golden Loop [2] focuses on holistic product design procedure.

1.1 Description of Kansei Engineering (Literature Review)

Kansei engineering was founded by Nagamachi at Hiroshima University about 40 years ago. It is defined as a tool for translating the customer's Kansei into the product design domain. The term Kansei used in Kansei engineering refers to an organized state of mind in which emotions and images are held in the mind toward physical objects such as products or the environment [3].

Kansei is an individual's subjective impression from a certain artifact, environment or situation using all the senses of sight, hearing, feeling, smell, taste and the sense of balance as well as recognition [3, 4]. The consumer Kansei is difficult to grasp and complex to measure. Nagasawa states that "autonomic nerve reflections are not the Kansei itself, but only correspond to the Kansei". This makes physiological measuring methods to an indirect measuring method [3]. The customer's Kansei has a diversity of expressions, from psychological to psychophysiological so both we can measure with different techniques and tools [5]. Lokman divided existing Methods of User's evaluation as Self-Reporting Techniques which are gathering data about feelings for product by asking people to report their feeling in adjectival words [5]. She also listed the following self-reporting techniques: Semantic Differential Methods, text completion, free following speech, Conjoint Analysis; Physiological and sub-conscious Method: video-recording, eye tracking cameras, Electro-Myo-Graphy (EMG), Electro-Encephalo-Gram (EEG), Electro-Cardio-Gram (ECG), Semantic Description of Environments (SMB), Quality Function Deployment(QFD), PrEmo, Kesoft [3], Kansei engineering (KE) [4], etc. There are few methods known in Kansei engineering for capturing consumer's internal sensation. It can be measured physiological or behavioral responses using electromyography (EMG), heart rate, electroencephalography (EEG), event-related potential (ERP), Functional magnetic resonance imaging (fMRI) or expressive by observing body or facial expression [5, 6]. Furthermore, psychological responses can be measured by semantic differential scales method, different personality tests or other questionnaires techniques [5]. There are six proved and tested types of Kansei engineering: Kansei engineering type I as category classification, type II as Kansei Engineering Computer System, Type III as Kansei Engineering Modeling, Type IV as Hybrid Kansei Engineering, type V as Virtual Kansei engineering and type VI as Collaborative Kansei engineering [5, 6].

1.1.1 Kansei Engineering Type 1 (Category Classification)

Our interest lays in Kansei engineering type I (KE1) which is described as "fundamental" technique using the process-ruled means [6]. This technique is also known by category classification or definition of targeted concept for new developing product to the design characteristic. We will pay attention on its basic procedure. The KE1 has his own process which is covered in ten steps. A following procedure is shown in Fig. 1.

At a beginning of the process engineer should pay an attention to R&D manager instructions and client company's CEO requirements. He must be informed with the company new product development strategy and understand each step. At this point it is important to gather and select a priority requirements and solving

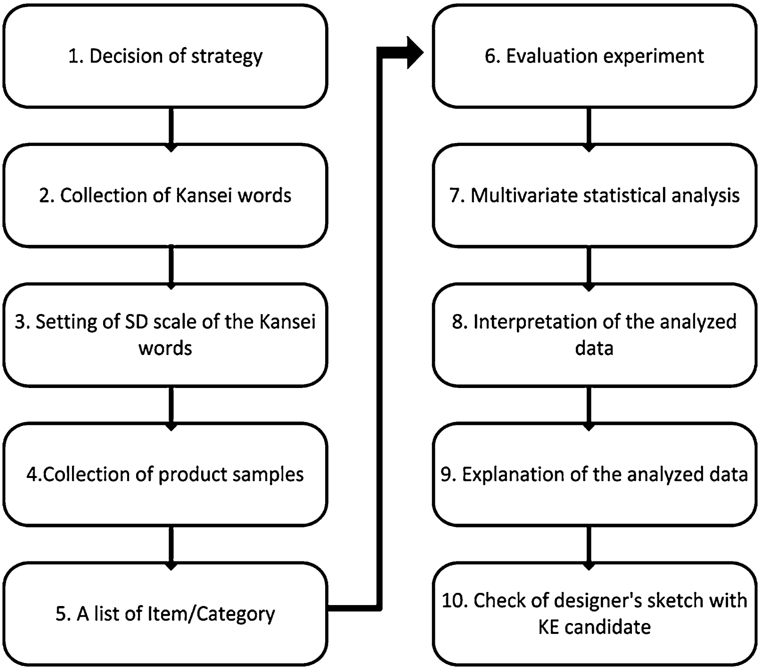


Fig. 1 The process of Kansei engineering Type I [13]

principles together. After clarifying those tasks an engineer collects Kansei words related to the product domain. Kansei words are adjectives, nouns, verb or even sentences. They are often collected from books, magazines, newspapers or other sources. First Kansei words must be collected and later to follow a selection of relevant and important ones. Later on a development of a psychological measurement scale devised by C.E. Osgood called a "Semantic differential scale" is followed. This method is used to make clear the psychological language structure [6]. Positive and negative words are arranged on both sides of a horizontal line. This kind of arrangement allows the respondent to value Kansei word that "feels" like a physical property of a product. There can be used different scales from 5, 7, 9 to 11-scale rates. Collection a number of 20–25 samples it's sufficient. There should be gathered samples of similar product as we plan to create. Later on the preparation of a list of items and categories related to the final design specifications is followed. For example, the evaluation experiment means, that a 7-point semantic differential scale is used for evaluation of each sample. From received data a multivariate statistical analysis can be done. Within it is used a Principal Component Analysis (PCA), Factor analysis and Quantification theory Type I (QTI). The next is the interpretation of the data and integration them into the product design properties. As the most important issue, Nagamachi exposed the interpretation of the data to designer. Designer must understand the final data interpretation correctly. His task is to create an emotional design based on those data. At the end of the process the engineer should do another check, to make sure that the product designer's interpretation was correctly interpreted and new design fits the customer's emotion. Otherwise a product designer should repeat the procedure and create a new proposal for product design [6]. KE1 is a standard procedure which aims to develop or improve products and services by translating customer's psychological feelings and needs into product's design domain [4]. However, there is a lack of information where occurs the integration of KE1 into the traditional product development process. Based on researches, many of them implement a general understanding, thinking processes, ontology, etc. [5, 7, 8]. However, research requirements regarding the general Kansei engineering procedure should be taken into consideration. Limited knowledge about combining different KE1 and DGL process conceals the new solutions and possibilities.

1.2 VDI 2221(Verein Deutscher Ingenieure)

VDI 2221 as a Product Development Process belongs to the history of design research in Germany carried out in this area. The name comes from Association of German Engineers. It is worth mentioning that all these research efforts resulted in VDI 2221 are a synthesis of various researches carried on the integrated product development. Guideline VDI 2221 is most often used by European schools in Central and Northern part of Europe, among others in German speaking countries. However, it is an approved standard product development process [9]. Its process structure is designed in a way that solves complex design tasks which are often complicated and unclear. This was solved as a systematic arrangement of the process which does split off on several development phases. This makes clearer review and evaluation of individual phases. We can easily return to the previous phases if a predicted model turns to be unsuccessful.

Methodological steps of construction work on the guidelines in construction process are:

- task definition
- defining the product conception through to a solution constituted,
- develop and result in the form of design solutions and
- detailed construction and solution of technical documentation.

Description of VDI 2221 Procedure

At the beginning of the design process search for solutions must be the task which is chosen to be solved a well-based. It is necessary to identify and meet the requirements that affect the solution. These tasks are categorized by their importance in the written document in which the task is broken down and described to the details. However, considering that the task meets the objectives of business and manufacturing opportunities, we approve the conceptual phase. Concept (draft) indicates a new, task-concept solution of the problem, which arises from the product, which is based on a new working principle. Even the conceptual phase is divided into several smaller working steps. Usually, we get a number of different solutions for each step, among which the best one is selected. Individual solutions are evaluated according to criteria contained on the list of design requests. If selected concept solution meets the criteria specified on the list of design requests, work can continue in the next work step, that is the design phase. However, if the solution does not correspond to the concept, a few preliminary steps are repeated to get better starting point for finding appropriate final solutions. The concept solution is only an approximate solution without design details which have to be solved during the design phase. Design phase represents therefore more or less a completion of a device or machine parts with the selected materials. Before that a plan procedure for production must be made. Design phase is divided into coarse and fine or refined design that can be economically evaluated. Based upon evaluation we select the best variant, and approve the functional decomposition phase. In the breakdown phase we make the product documentation for all components, after which the workshop produce a device or machine that gets to this final form.

Figure 2 shows the different phases of the overall workflow in the search for solutions till the choice of tasks to product documentation. In this respect, each stage of design decisions emphasis a choice of best solution. The advantage of finding new solutions by the methodical steps is that the solution is produced gradually, and anything of significance is not dropped. An experienced designer used in the construction of a new product numerous working steps unconsciously, often by combining some or even skipping. Described working steps are particularly suited to finding new solutions to new technical problems. Then we have the conceptual stage to find a new working principle is based on a new natural law.

VDI 2221 design process is based on the evaluation of each work step at a specific stage. If acquired solution does not meet the necessary criteria we should repeat the step, as shown in Fig. 2. Upgrade process is done in “Design Golden Loop—DGL” process [2], which is an iterative process or decision making procedure, where the decision for final product is made. An integrated process for developing a product or service is shown Fig. 3.

Description of “Design Golden loop” Process

DGL can be used in the Design Process (DP) by the Development and Design Process (D&DP). General paradigm of the DGL is based on the iterative steps in the design process [2]. A comprehensive D&DP model with the addition of DGL was first developed in 2001. There are three key parts of the whole D&DP. At first a goal definition is done, which covers a holistic process from abstraction to the goal definition. Second phase reveals key elements of process planning where an individual activities and team definitions are planned. Mentioned phases are parts of D&D process. Third phase represents construction process. Goal definition depends on activities analysis. Regarding on defining activities the design process

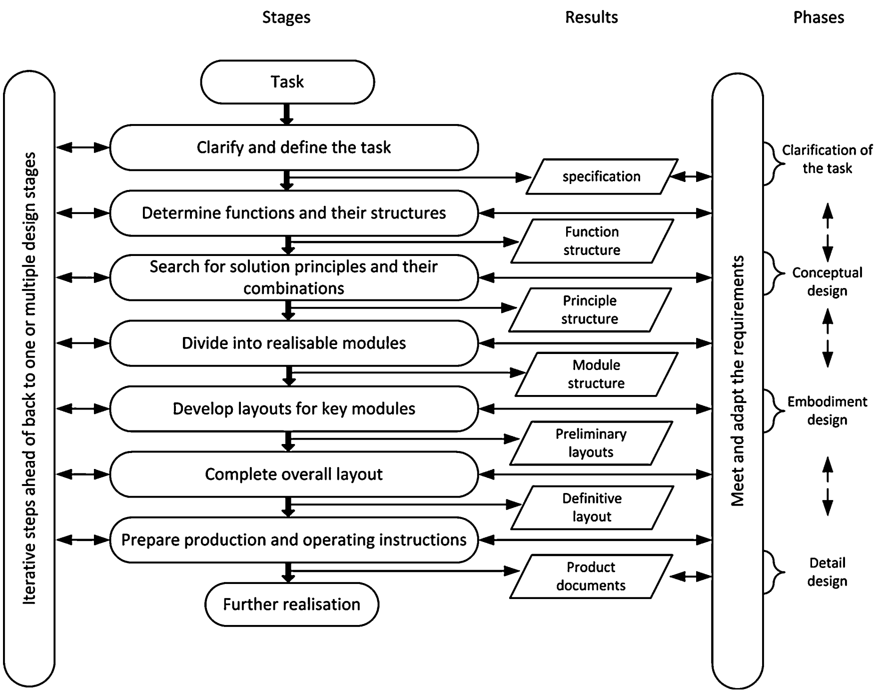


Fig. 2 Design process as guideline VDI 2221 (verein deutscher ingenieure)

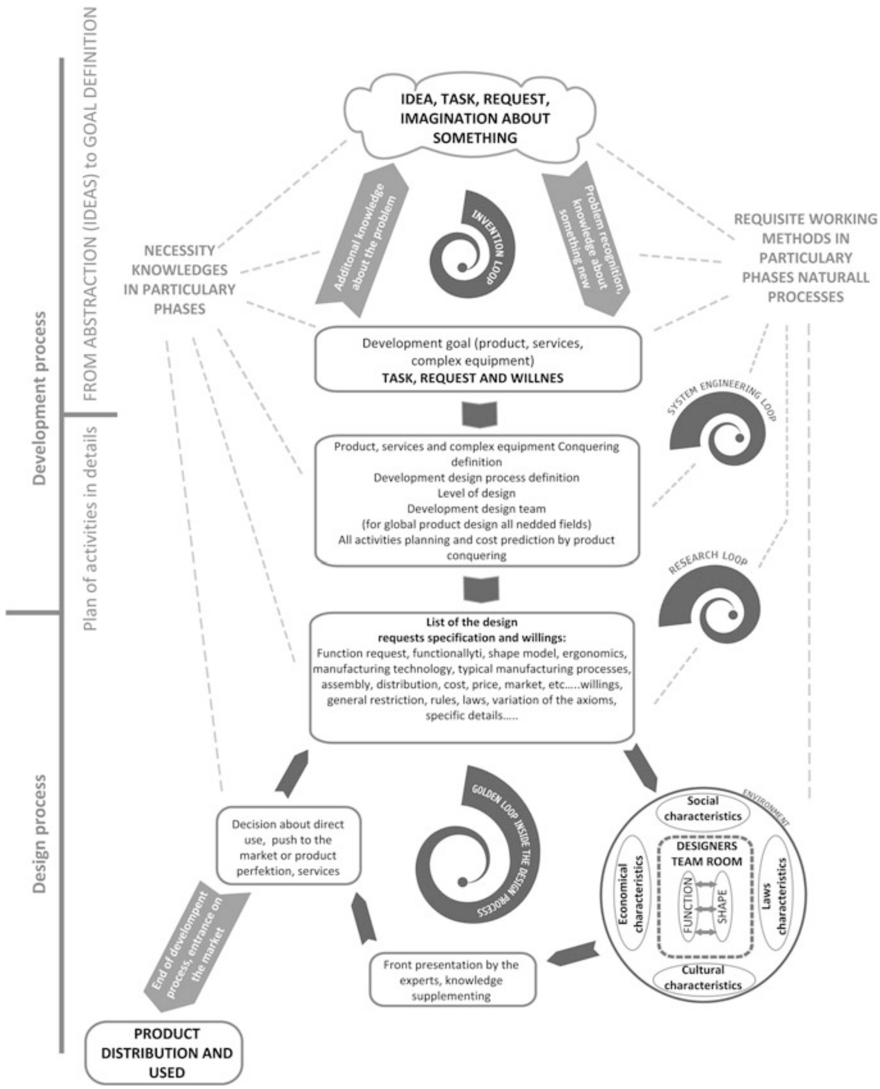


Fig. 3 Global product or services conquering process or "GDL" [2]

is more purified and gives us more clearly idea for development. The product development phase is divided into two tasks: the first one is goal definition and the second one is request, desires and tasks of the D&D process. Since the two jobs are closely connected, they are not performed sequentially or separately [2]. They take part of the iterative process of first development loop. Initial iterative steps are used when goals and tasks are defined. This is the second phase of the D&DP starts when the goal is very clear and the process must be defined more clearly and detailed. Cost analysis is also included in this part. However, it is of vital importance for a comprehensive monitoring of the economical side of a project. DGL was named since the shape of the product, resembling the end product, appears for the first time in front of the designer. Designers team room play an important role in defining the relationship between function and form, since both links. This way the difference between the aforementioned three loops in the development process and essential loop that brings a product into real life [2, 10–12].

2 Framework of Kansei Engineering Integration into Design Golden Loop Process

The starting point of a procedure shown at Fig. 4 is a methodological analogy of VDI 2221 design process. A previous description has given us more details on operations from task determination till final phase. Systematic structure of design process is based on evaluation or estimation of each work step, so to avoid mistakes the best solution at some stage should be chosen. In addition to VDI 2221 design process or guidelines aims to describe multiple design stages there are also mentioned the requirements which are meet and adapt during the procedure. This reference mostly refers to the product functionality requirements. There is a definition of requirements in VDI 2221 design process but they don't give us clear information on how customer needs and requirements should be met and adapted in product design. As already mentioned, improving products requires knowledge about how product properties affect customers. Anyway if the product fits to the customer's emotional needs there is more likely that he will decide to buy it. Product's appearance and added value through the customer esthetics preference within his emotional needs should be considered parallel with the development of features and product functionality. Therefore, it is necessary to integrate Kansei engineering methodology which aims to design and develop product/services that match customers' emotional, psychological feeling and needs [7] in traditional product development process as it is VDI 2221 or modified DGL procedure.

A model of Kansei engineering type 1 (KE1) integration into traditional product development process was made after a study of those three product development methodologies later on observation and comparison. Model of integration is shown on a Fig. 4. It represents steps where integration should be implemented. Nevertheless VDI 2221 design process is based on a strategic arrangement which guide us through iterative steps or multiple design stages till further realization in comparison with DGL process its final phase is more justified and upgraded. Therefore the integration should be done in DGL design process taking into account VDI 2221 procedure principles. According to the KE1 methodology which describe a basic procedure of KE1 the implementation in DGL design process should be done for a beginning in a first design stage where we define the task and product specification. Later on customer emotional needs and requirement

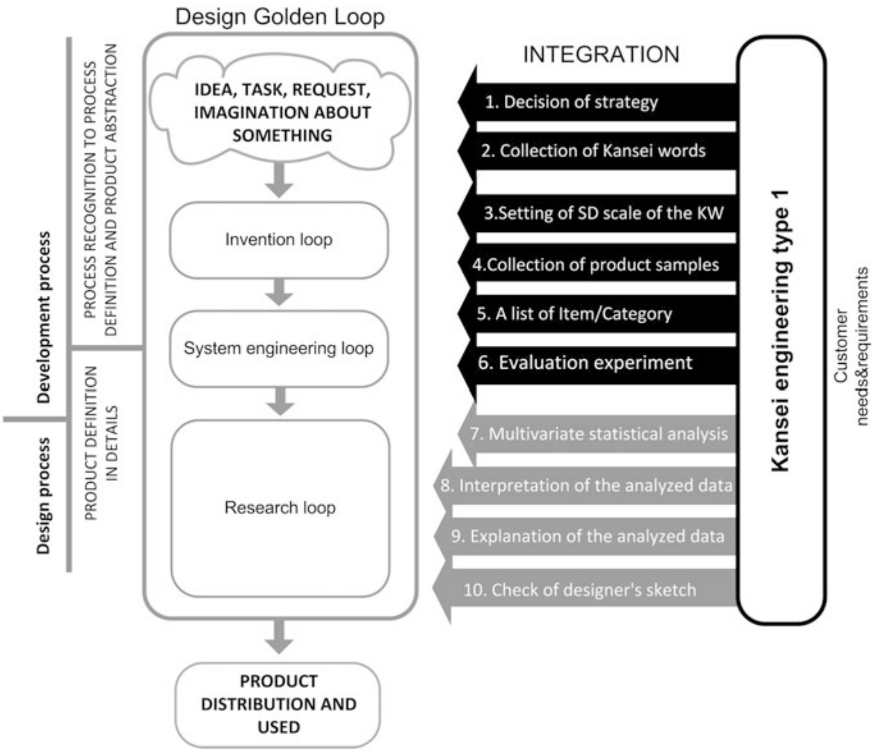


Fig. 4 A Framework of Kansei engineering integration into traditional design process. VDI 2221 design process was modified and supplemented by Duhovnik [2]. Description of Kansei engineering type 1 integration is revealed in a structural model

will be met already in the early phase of product development so the product design procedure will be adjusted according to this aspect. KE1 could be used as a tool which enables purifying the idea by means of requirements for clearer goal definition (in aspect of product visual appearance). As already mentioned KE1 procedure should be integrated from the first step of DGL design process where idea, task, request, imagination about something appears. Simultaneously when a decision for a product which will be developed is made a development strategy is followed. KE1 procedure should be considered when problem recognition appears and a new knowledge about something is needed. As soon as we have a clear goal of developing product or service, when task request and willings and development strategy are known we start collecting Kansei words. In this segment definition of product or service properties is made. The aim is to determine potential properties or design elements of the future product or service, which include the collection of existing product (20–25 samples), creation of new concepts, identification of potential customer and company images and priorities as well as the definition of properties, elements (i.e., attributes or characteristic) and design categories [13].

Therefore, a list of item/category must be made. The list is related to the final design specifications. Item (for example: color, shape, size, roundness) implies the design item of the sample product, and category (for example: yellow, green, red, blue) means the detail of the design item. After a selection of Kansei words is made we develop a semantic differential scale for evaluation experiment. The subjects receive an instruction and evaluate each sample with the 5, 7, 9 or 11-point SD scale of Kansei words. By this approach design assess patterns and design features we are looking for a product that will suit the user. The evaluated data are analyzed using a multivariate statistical analysis. Then we interpret the data using different statistical tools and integrate them into the product design properties. Afterward we explain interpretation data to a designer which is a member of a development design team in the nearly end research loop of DGL process. All the activities that are happening through the main three development phases in DGL process are intertwined with KE1 procedure. The development of function and functionality cannot be considered divided from form and visual characteristics which emotional value should be given inside the product development process like in our case DGL process.

3 Conclusion

This study showed a structured model of Kansei engineering integration into traditional design process as an proposal worth of future work. Therefore, the authors will continue investigating also other options of customer requirements and emotional needs integration in product development processes such as VDI 2221 and DGL process. As seen in previous descriptions KE1 procedure could not be an independent tool for new product development but is equivalent with DGL and other design processes. Integration of KE1 procedure is done simultaneously as other processes at different iterative stages because its focus is in customer's psychological feelings and needs and it's translation into product's design domain. It is hard to determine a clear border where KE1 should take a part in DGL process especially after a first design stage is carried out. Further research is required to develop a deeper understanding of a specific activities occurring in the different design stages and how integrated methodology influence a holistic traditional product development process.

References

1. VDI (1993) VDI 2221: systematic approach to the development and design of technical systems and products. Beuth Verlag
2. Duhovnik J, Balić S (2004) Detail functionality analysis using design golden loop. In: 4th International seminar and workshop, EDIProD

3. Schütte S (2005) Engineering emotional values in product design Kansei engineering in development. Dissertation 951, Linköping studies in science and technology
4. Nagamachi M (2002), Kansei engineering as a powerful consumer-oriented technology for product development. Applied Ergonomics, Elsevier, London, pp 33289–33294
5. Lokman AM (2009) Emotional user experience in web design: the Kansei engineering approach, Doctoral Thesis
6. Nagamachi M, Lokman AM (2010) Innovations of Kansei engineering. Taylor&Francis, UK
7. Dahlgaard JJ, Schütte S, Ayas E (2004) Kansei/affective engineering design: a methodology for profound affection and attractive quality creation. TQM J 20(4):
8. Levy P, Nakamori S, Yamanaka T (2008) Explaining Kansei design studies, conference of design and emotion. Kansei, Hong Kong
9. Tomiyama T, Gu P, Jin Y, Lutters D, Kind C, Kimura F (2009) Design methodologies: industrial and educational applications. CIRP Ann Manufacturing Technol 58:543–565
10. Zadnik Ž, Čok V, Karakašić M, Kljajin M, Duhovnik J (2011) Modularity solutions within a matrix of function and functionality (MFF). Tehnički Vjesn Tech Gazzete 18(4):471–478
11. Zadnik Ž, Karakašić M, Kljajin M, Duhovnik J (2009) Function and functionality in the conceptual design process. Strojniški Vestn J Mech Eng 55(7/8):455–471
12. Tavčar J, Benedičič J, Duhovnik J, Žavbi R (2004) Creativity and efficiency in virtual product development teams TMCE. In: Proceedings of the 5th international symposium on tools and methods of competitive engineering, pp 425–434 Millpress, Lausanne, Apr 13–17
13. Nagamachi M (2010) Kansei/affective engineering. Taylor&Francis, UK

Design and Development: The Made in BRIC Challenge

Luciana Pereira

Abstract The study examines the level of design and development in three multinational subsidiaries working on fluid power industry in Brazil. Some authors say that decentralization of R&D activities by MNCs is an important source of innovation for BRICS countries. Using a case study method this paper has found that the type of design and development activities performed by these companies are more related with redesign than original and innovative activities, which would demand more complex system approach. The answer for increasing innovation levels might be in domestic firms and not in multinational ones.

Keywords Design · Innovation · Fluid power · BRIC

1 Introduction

Recent literature on global research and development (R&D) location decisions by multinational firms (MNCs) has emphasized the importance of emerging economies like India, China, and Brazil as R&D center. The so called BRIC is an acronym for Brazil, Russia, India, China, plus South Africa, the leading emerging economies. Together, the five countries represent almost 3 billion people, with a combined nominal GDP of US$13.7 trillion [1].

Despite of all their cultural differences, Brazil, China, and India have followed a similar pattern of industrialization, which was based on foreign direct investment

L. Pereira (✉)
Center for Engineering, Modeling, and Social Applied Sciences, Federal University of ABC, Rua Santa Adélia, 166 A646-1, Santo André, SP, Brazil
e-mail: luciana.pereira@ufabc.edu.br

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_101,

attraction combined either with Import-Substitution Industrialization Model (India and Brazil) or Export-Oriented Industrialization Model (China) [2]. However, nowadays, instead of the traditional role of adapting products and services to local market conditions and supporting MNCs manufacturing operations, some claims that investments have being increasingly motivated by tapping into worldwide centers of knowledge as part of firms' strategies to source innovation globally [3].

In spite of this, relatively little attention has been given in this literature to the role of product design and product development in these emerging markets. There are a number of partial exceptions that have suggested that the new product development is becoming the fastest growing segment in India, Brazil, and China [4, 5]. Meanwhile, Manning et al. [6] suggest that this growth in innovation off shoring is driven by increased globalization of markets for technology and knowledge workers.

This paper is part of a large project that seeks to understand the quantity and quality of product design and development activities in some multinationals' subsidiaries. All over BRIC countries, governments have proposed policies to foster innovative activities inside their industrial park. This can be fully checked at Brazil Maior Plan, India National Innovation Council (NInC), and the Chinese 12th Five Years Plan.

The purpose of this paper is to gain a better understanding of MNCs regarding more complex activities. Are MNCs companies really relocating their R&D facilities to these countries? If this is the case, we may expect that design should be strategic because it has a key role both in product development and technological innovation. In order to reach this goal and learn what is going on inside the industry, we have conducted an exploratory case study in three MNCs located in Brazil working with fluid power systems technologies.

The importance of fluid power systems lies in the fact it provides key applications for industrial, mobile, and aerospace, all important sectors for the mentioned countries. For our data collection, we have used technical visits, and interviews. As a parameter we studied a Swedish group that work close with fluid power industry, so we can compare the type of activities they have performed with the Brazilian experience.

The case study has shown that more complex activities related with design or product development is far from happening. Different from what is found in the literature, there is no evidence that MNCs are moving R&D Centers because of knowledge pool. The reason seems to be related more with old strategies such as cutting costs and take advantage of local resources, including skilled and cheap workforce.

The contributions of this paper are twofold. First, it offers the opportunity to shift the innovation debate from the policy level to the position of those who actually are in charge of making innovation happen. In this case, designers and product developers solving problems at the firm level. Second, it brings together an interdisciplinary perspective in a multicultural context.

The paper is organized as follows: Section 2 presents a brief review of the literature concerning the *relationship* between design and innovation. Section 3 presents methodological tools and the triangulation data analysis as the research design. Section 4 discusses some important initial observations identified with the case. Section 5 delves into conclusion including directions for future research.

2 Design: The Materialization of Innovation

In this section we reflect upon the major themes we are interested in gaining more insight into design and development capabilities and the relationship between R&D decentralization. If it is true that MNCs have relocated its R&D centers in some emerging countries, we expect to see different design skills been demanded by them.

Design is defined as the core of innovation, the moment when a new object is imagined, devised, and shaped in prototype form. Design clearly plays an important role in the realization of the radical invention as an innovation [7]. In particular, systemic innovations need a great deal of design co-ordination in development and commercialization because systematic adjustments to other parts of the system have to be made [8].

But design is also important in the period of 'swarming secondary innovation' via competing designs, in product differentiation and reliability, and in price competition via the efficient use of materials and design for ease of manufacture. Thus design is important throughout the industry life cycle and at different stages of economic upturn and downturn, but plays a different role at each stage.

Over the years, BRIC countries have excelled in their manufacturing capabilities and today they are responsible for one fifth of the global manufacturing value added (MVA), or the relative share of value added to gross domestic product by manufacturing [9]. Although MVA indicates a country's level of industrialization, it does not account for the technological structure of production neither its level of innovation. On the other hand, according to the same source, the design and production of high-technology manufacturing goods still been dominated by advanced countries.

In short, although manufacturing is a very important skill, its value depends on technological content of the products manufactured. In this paper we claim that innovation is close related to design skills. Therefore, existence of a competitive manufacturing sector alone does not, however, automatically lead to industrial upgrading [10]. We claim in this paper that innovation is close related to design. And even design has its own nuances according to the activity they carry out [11]:

1. Original design

   In this case the designer designs something that did not exist previously. Thus, it is also called new design or innovative design. For making original designs, a lot of research work, knowledge and creativity are essential. This type of design can take place when there is a new technology available or when there is enough market push.

2. Variant design

   This type of design demands design ability, in order to modify the existing designs into a new idea, by adopting a new material or a different method of manufacture.

3. Adaptative design

   In most design situations the designer's job is to make a slight modification of the existing design. This type of design needs no special knowledge or skill. Typically, products with higher technological content still have been designed, and, depending on the sector, even manufactured, in the headquarters. Therefore, if we want to check the quality of the innovation, we would expect to see more of the type (1) and (2) activities been performed in BRIC.

3 Fluid Power Case Study

This paper presents a study on the challenges for BRIC in product design and development activities given the aspiration of these countries to start playing a more direct role in fostering innovation. By product design and development we mean a multi-disciplinary problem-solving process which involves a series of complex skills that lead to innovative solutions.

In fluid power, the demand for new types of more efficient systems concepts has called for new design parameters, which has, consequently, affected the dynamic behavior of the whole system. Understanding the design rules is essential so that the problem can be controlled. Moreover, it is important to highlight that the design process should be performed at the system level rather than at the components level. In short, innovation in fluid power has been much more part of incremental, but constantly improvements in design, aiming systems performance optimization rather than technological advancements, or breakthrough innovation.

The work is based on an exploratory case study, which is a qualitative research method, in the fluid power technology. Fluid power is a designed system to transmit and control energy by means of a pressurized fluid, either liquid or gas. According to the US Fluid Power Association, fluid power technology has multiple applications in a wide variety of markets such as mobile, industrial, and aerospace. Table 1 gives an overview of the fluid power technology, divided by market, type of application, products, and end users.

The design of fluid power systems has generally focused on power and productivity giving little thought to the efficiency of the system. In recent years, however, new and stricter emissions regulations and increasing energy costs have caused the industry to look for more efficient system designs [12].

Therefore, the greatest challenge facing designers and product developer's teams working on fluid power systems are:

Table 1 Fluid power applications

Market	Fluid power used for	Product	End users
Mobile	Transporting	Backhoes	Construction
		Graders	Agriculture
	Excavating	Tractors	Marine
		Truck brakes	Defense
	Lifting	Suspensions	
	Controlling	Spreaders	
	Powering	Highway maintenance vehicles	
Industrial	Power transmission	Metalworking equipment	Machine tools
	Motion control	Controllers	Industrial automation
		Automated manipulators	
		Material handling	
		Assembly equipment	
Aerospace	Operating	Landing gear	Commercial aircraft
	Propelling	Brakes	Military aircraft
	Propulsion	Flight controls	Spacecraft
		Motor controls	Related support equipment
		Cargo loading equipment	

Source Elaborated by the author with data from US Fluid Power Association (NFPA)

1. Minimizing energy consumption
2. Decreasing power requirements
3. Achieving international emission requirements
4. Improving standard machine design
5. Identifying the technological barriers to achieving these goals

From a socio-economic point of view, all the sectors where fluid power can be applied play a key role in the process of economic development, employment creation, and income generation and redistribution in BRIC. At the same time, the emergence of new demand for innovative solutions creates opportunities for companies located in those countries.

In order to gather information on trends and changes in organization of design of the fluid power systems we have proposed a field research in sites such as universities and industries located in countries like Brazil, India, China, and Sweden. This paper is part of a larger project that has started in May 2011 called Collaborative Engineering for Sustainable Mobile Systems, COSMOS, aimed at promoting collaboration in research between Brazilian and Swedish universities and companies in fluid power engineering and system design.

3.1 Data Collection

A set of data collection techniques, such as key informant interviews, correspondence with experts, organization of workshops, and field observation has been used for conducting the research. However, as a starting point some literature

Table 2 Information on studied companies

Company	Headquarters	Products
A	United States	Tractors
B	United States	Components
C	Germany	Components

Source Elaborated by the author

review and research on Fluid Power Associations provided us with critical background information.

The next step was arranging meetings with academic experts in the field of our inquiry. In this sense, they are crucial tool to obtaining information from the state of the art of and the historic development of the field. These people are in a position to know the community as a whole and also in particular portion we are interested in.

It is important to remember that usually academic experts in fluid power have a close relationship with industry, which has fostered an environment of cooperation and mutual assistance. To sum up, the contact with academics help us selecting informants with different backgrounds and affiliation. Giving the geographic distribution of the project, another method to collect information and keep track of what was going on was correspondence with experts.

The first workshop on Innovative Engineering for Fluid Power and Vehicular Systems brought together Brazilian, Swedish and international industry and academia to promote collaboration in development of technologies, education, innovation management, and methods and tools for system development and design [13]. Organizing and attending the workshop was an opportunity for taking notes at lectures given by experts and to meet and talk with speakers and fellow attendees as well as to learn and practice the language of the field.

Following the workshop, technical visits to three multinational companies located in Brazil allowed us to observe the field. Table 2 provides the main characteristics of companies visited.

The visits have provided us with a wide variety of learning experiences. This time was possible to talk with product engineers on site, at the same time we saw how companies behave, and how they provide their products and services. Since this visit was made in group, later on a conversation allowed us to share our impressions differentiating between fact and opinion.

3.2 Data Analysis

In order to strengthen the case study findings and conclusions we propose the triangulation of the collected data as the analysis technique. Triangulation is broadly defined as synthesis and integration of data from multiple sources through collection, examination, comparison and interpretation. By first gathering and then

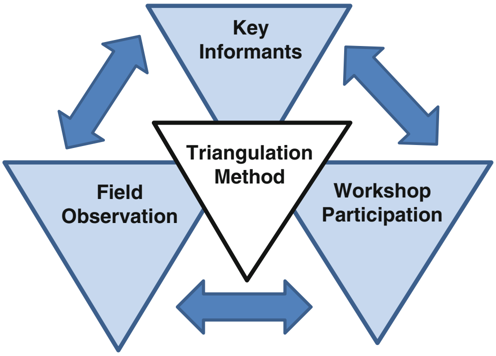


Fig. 1 Triangulation for fluid power case study. *Source* Elaborated by the author

comparing multiple datasets to each other, triangulation helps to counteract threats to validity in each approach [14]. Figure 1 illustrates the different methodological dimensions that were considered in this paper.

4 Initial Findings

Having the assumption that if MNC are relocating R&D activities, we would expect to find more design and product development activities taking place in their subsidiaries. Therefore, this section examines what type of design and development activities have been observed in selected Brazilian subsidiaries of MNCs working on fluid power technologies.

The question we asked was: How is R&D in these companies geographically distributed? First of all we found that all three sampled companies have R&D facilities in their headquarters. The German has R&D facilities in the US while the Americans have development centers in Europe. The American company working with tractors has recently opened a development center in Germany and Finland, but there is no mention about any emerging countries. The other American company working with hydraulics components has opened up new state-of-art manufacturing plants both in China and India, but there is no comments about expanding R&D centers to these countries.

This is also the company with the closest ties with Sweden. In the past thirty years this company has acquired some Swedish companies, which explain the collaboration with Linköping University. Although the ownership have changed, they were able to keep long term relationship with the local knowledge base supplying new employees and working to solve problems together.

The German company is the only one who is establishing a R&D center in China. However, as stated by them:

> The company hopes to take better advantage of the high-growth regions of Asia and South America with the continual expansion of its international development and production network. For example, products and solutions will be adapted to the specific requirements of each region based on platforms developed in Germany.

Looking at the Brazilian experience, none of the companies has even mentioned invest in R&D. They do have a Product Engineering Department, where design and product development are important functions. However, taking the stages of design framework into account, we would see that the activities performed by the Brazilian companies can be classified as a mix of adaptive and variant design.

In this case, the subsidiary works in the redesign of some components under the headquarters supervision. The goal is to adapt the original design to suit local conditions at various levels of the supply chain, both internal and external, such as technical and budget standardization, supplier development, and regulations. These design activities are closely related to achieve cost competitiveness while making the transition to manufacturing.

Not surprisingly, when the Brazilian experience is compared with the Swedish, we noticed that in Sweden, the company work close with the university to reach original design. In Linköping University's experience, companies interested in turning their fluid power systems more innovative have been partnering for decades with the division of Fluid and Mechatronic Systems (FLUMES). Together they have collaborated to maximizing performance in existing technologies results and investigating the dynamics of fluid power systems.

How much of the fact that subsidiaries engage in redesign can be put down to location and how much simply to the field in which they operate? Despite of the demand for new solutions, the problem solving is focused in some parts of the world. Not different from what was stated by the German company, there is the international development and the production network. Therefore, both redesign and location choices are close related with market size. It happens that MNCs do not have in their portfolio products that meet the real needs of these markets.

4.1 The BRIC Dilemma

Although some say research and development (R&D) location decisions by multinational firms are driven by increased globalization of markets for technology and knowledge workers, the truth is that the decentralization of R&D has been primarily motivated by the necessity of establishing a global presence with products that fits the local income and taste.

Given MNCs face even tougher competition; they have adopted strategies to meet consumer demands in markets previously considered irrelevant. The fact that there are high-skilled workers and public policies to attract these activities have been just a bonus, not the main motivator for companies to decentralize their development efforts. There are undeniable evidences of this phenomenon in BRIC automotive, consumer electronics, telecommunications equipment and, pharmaceuticals sectors.

However, in spite of a dramatic increase in the quantity of what MNC have called R&D centers located in BRIC countries—especially in China and India- the core of original design and development activities, which demands both structures and strategies for more complex problem solving are still been doing at the headquarters. The paragraph below shows how MNCs see the question:

> The design probably would not be acceptable in the U.S. or Europe where the business dynamics and customer needs are very different, and it eliminates the problem of giving them our premium technology to copy and sell at a much lower price.

The innovation performed by these companies is related with manufacturing, moving from Fordism mass production processes to the Toyotism lean mode. In this moment, there are some opportunities to redesign a component or two, always under the leadership of a more experienced project manager located overseas. When we look carefully at Sweden′s experience, we noticed that a strong, long-term interaction between researchers and companies take place in the process of bring a new solution for a problem, most of them closely related with new design parameters.

Therefore R&D localization is mainly determined by the existence of economic incentives such as minimum project cost, which is possible due to a wage gap for local high-skilled workers. At the same time, the demand for skilled labor has raised manpower costs, putting pressures on companies to stay cost-competitive with other outsourcing destinations. In addition, governments' subsidies to attract foreign investments have been an incentive to relocate. In this sense, how much the name R&D is not just propaganda still remain to be proved with more detailed studies about the complexity of the activities performed.

On the other hand, BRIC's economic opportunity, leadership, and business development—and the ensuing distribution of new wealth—have led them to enter an era of new opportunities and challenges. Interesting enough is that the most innovative companies in these countries are the domestic ones such as the automaker Tata Motor's in India; the Brazilian aircraft maker Embraer; the telecom Huawei, in China, and the Russian jet engine maker NPO Saturn [15]. What do they have in common? They all have mastered the art of design and product development lifecycle, including complex technological systems that meet the particular needs of consumers and businesses.

5 Conclusion and Discussion

This study examined design and development associated with Brazilian efforts to upgrade the overall industrial structure with higher value added activities and skill—intensive labor. In order to get a better understand, we have done: (1) an assessment of product design and development process for three multinational subsidiaries in the field of fluid power technology; (2) an investigation of the academic and industrial collaboration in Linköping University.

The first part of this study indicates that MNCs have not totally decentralized their design and development activities, only allowing subsidiaries to work on less complex activities. Even in redesign, the subsidiary teams are always under the supervision of a headquarters project leader. Although these projects demand more skilled professionals, they have been done mainly to achieve cost and quality performance.

The second portion of this paper suggests that more innovative and complex design, many based on disruptive technologies, which have not seen before, are centralized in the headquarters with collaboration of traditional university partners. There appears to be no competition between them and BRIC countries. Even among BRIC there is some kind of natural selection when MNCs have to choose where to invest in a new project with Brazil lagging far behind the other BRIC mates in costs and availability of skilled workers. Despite of it, in order to increase innovation made in Brazil, government has proposed a policy that force some sectors to spend 1% of their revenue in R&D.

Domestic companies are a key part of turn BRIC countries more innovative. The challenge in design and development involves achieving a more proactive approach in complex problem solving. It has become increasingly clear that the dependence on MNCs R&D decentralization may be not enough to achieve the level of innovation BRIC expect to change their industrial structure. Hence, natural directions for future research include studying fluid power systems in other BRIC countries.

Acknowledgments This research was partially supported by São Paulo State Foundation Agency (FAPESP) grants #2010/12119-4 and #.2011/1475-2 Thanks to the academia, and industry interview participants, for sharing their experiences. My thanks to Petter Krus from Linköping University division of Fluid and Mechatronic Systems (FLUMES), and also, to Victor Juliano de Negri from the Laboratory of Hydraulic and Pneumatic Systems (LASHIP), Federal University of Santa Catarina for insightful discussions about fluid power. The usual disclaimer applies.

References

1. IMF 2012 April 2012 data. Retrieved 2012-04-21
2. Amsden A (2001) The rise of the rest: challenges to the West from late-industrializing economies. Oxford University Press, NY, p 405
3. Bruche G (2009) The emergence of China and India as new competitors in MNCs. Competition Change 13(3):267–288 22
4. Mundim A, SharmaM, Arora P (2012) McManus. Innovation in emerging markets: the new competitive reality. Accenture. http://www.accenture.com/us-en/Pages/insight-product-development-innovation-emerging-markets.aspx
5. Edwards D, Waite G (2011) Designing for emerging markets. Quarterly of the industrial designers society of America, Summer, pp 31–34
6. Manning S, Massini S, Lewin AY (2008) A dynamic perspective on next-generation off shoring: the global sourcing of science and engineering talent. Acad Manage 22(3):35–54
7. Walsh V, Roy R, Bruce M, Potter S (1992) Winning by design: technology, product design and international competitiveness. Blackwell, Oxford
8. Walsh V (1996) Design, innovation and the boundaries of the firm. Res Policy 25(4):509–529
9. UNIDO Report (2011) The international yearbook of industrial statistics 2011

10. Azadegan A, Wagner SM (2011) Industrial upgrading, exploitative innovations and explorative innovations. Int J Prod Econ 130:54–65
11. Pahl G, Beitz W, Schulz H-J, Jarecki U (2007) Engineering design. A systematic approach, 3rd edn. In: Wallace K, Blessing LTM (eds) Springer, Berlin
12. Center for compact and efficient fluid power. http://www.ccefp.org/index.php
13. First workshop on Innovative Engineering for Fluid Power and Vehicular Systems http://cisb.org.br/workshop-inovacao
14. Denzin NK (2006) Sociological methods: a sourcebook: Aldine transaction, p 590
15. The top 10 most innovative industry by countries in 2011 http://www.fastcompany.com/most-innovative-companies/2011

Stylistic Analysis of Space in Indian Folk Painting

Shatarupa Thakurta Roy and Amarendra Kumar Das

Abstract The paper aims at identifying the design principles of Indian folk painting by analyzing some paintings of master painters from Srikalahasti, Madhubani, and Raghurajpur. The authors further discuss the different initiatives to reinterpret the effectiveness of storytelling through graphic visuals among mass. The age-old *chitrakatha* tradition of narrative paintings with oration, as an intrinsic part of Hindu folk religion has played a significant role in the proliferation of the doctrines of Hindu epics and moral stories. The space division aims at an optimum clarity for impelling communication. The dimensions are often mandatory rather than arbitrary. Yet, often esthetic overpowers the theme. The authors as evaluators adopt the method of three folded analytical study of semiotic, iconic and thematic aspects. The tradition of narrative folk paintings although has emerged and grew in remote and isolated locations but is not confined to the temples and rituals anymore because of cross cultural exchanges. They are rich as artistic expression and potent enough to amalgamate and evolve with time. The paper, therefore briefly opines on the significance of folk art practice in the changing society.

Keywords Critical analysis · Design principles · Visual communication · Contextualization · Innovation

S. T. Roy (✉)
Department of Humanities and Social Sciences, Indian Institute of Technology Kanpur, Kanpur, India
e-mail: stroy@iitk.ac.in

A. K. Das
Department of Design, Indian Institute of Technology Guwahati, Guwahati, India
e-mail: dasak@iitg.ernet.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_102, © Springer India 2013

1 Introduction

The definition of folk art can be free flowing and ever changing as per the dynamism of its phenomena. The authors here make an attempt to indoctrinate the design principle of folk art in the Indian context. Folk art practice in India in spite of being vernacular and varicolored, shares a lot of commonality in them. The age-old traditions of narrative scroll paintings of regional India as well as the art practices intrinsically connected with the temple rituals have always played a vital role in the proliferation of Hindu epics and moral stories. Vatsyayan in her book titled "The Squire and the Circle of the Indian Arts" [1] writes, 'All ritual first establishes a point, a metaphorical center, around which lines are drawn to make triangles, squires and circles of great symbolic value. Notions of space and time are comprehended through it' (p. 163). The principle of folk art in spite of being rudimentary and down to earth also follows a somewhat similar concept of space organization.

2 Style and Narrative

The study involves a scrutiny of five such examples from the traditional folk paintings of India. They belong to five different states of India, namely Rajasthan, Bihar, Bengal, Odisha and Andhra Pradesh. It is to realize how the artworks hold similarity in their subject matters, expressions and purposes in a heterogeneous cultural and lingual periphery.

To encipher the orderly construct of space in traditional folk paintings the authors chose a wall art from Madhubani (Fig. 1), Bihar that is locally known as *Kohber*. They are drawn on the wall of the bridal chambers as popular ritualistic practice of the region. The conception of the space division is centralized and symmetrical to ensure harmony to the composition. The image is liner and radially balanced with a distinct point at the center, around which images that are symbolically related to fertility are drawn in plenty to adequately fill up the space in a geometric formation. The apparently intricate and semi-recognizable motifs are the derivatives of natural elements such as flowers, weeds, seeds, aquatic animals, amphibians and reptiles. The compositional formation is confined with the boundary of squires and circles with decorative and repetitive patterns to ensure an organized readability to the otherwise crowded visual.

The authors chose the next example from the traditional *Pichhvai* Paintings of Rajasthan to confirm this centralized formation of space that is based on several circles and squires. The word *pichhvai* means backdrop and the tradition is related to the worship of Shrinathji, at Nathadwara temple, Rajasthan. The philosophy behind the image of Shrinathji, a form of Lord Sri Krishna is vastly metaphorical. Lazaro, in his book Material, Methods and Symbolism in the Pichhvai Painting Tradition of Rajasthan [3], writes, "on-dualism or 'not-two' is that which

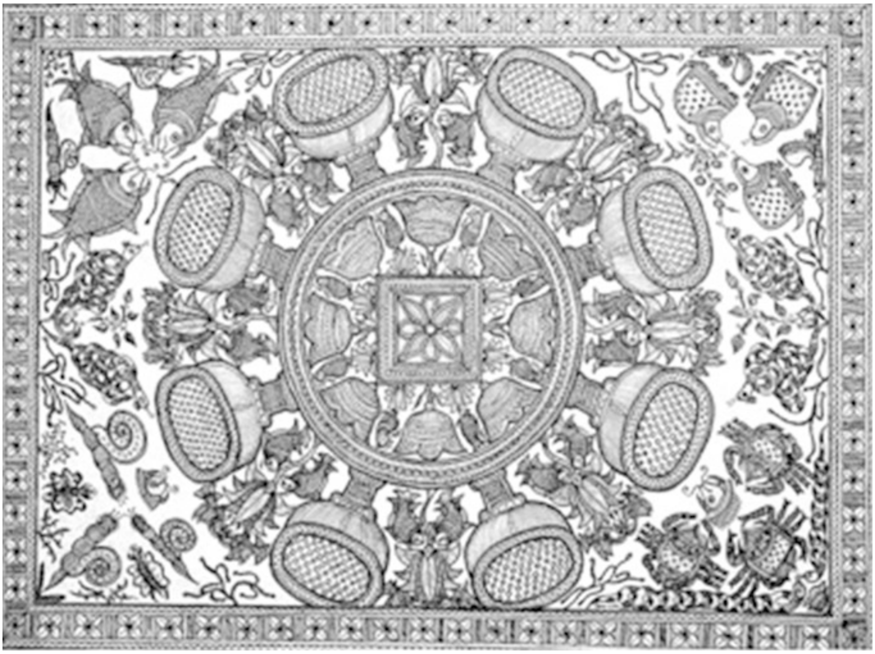


Fig. 1 Kohber, Madhubani

Pre-manifestation is. It is the complete, whole un-differentiated point, *bindu* (dot), into which all will ultimately withdraw". The image of Shrinathji in the paintings done in traditional Indian miniature technique may be decoded with the following diagram (Fig. 2). The length of the idol from the crown to the base of the feet can be primarily divided into four equal circles. A larger circle surrounds the entire body that touches the crown and feet. The geometric construction even if not so visible provides the composition with a desired balance and harmony.

Folk art is a countenance of traditional culture. The intrinsic association of art forms with ritualistic and religious purposes laid the foundation of folk art practice of India. It perpetually insured a continuity of the tradition but it is also the simplicity of mind that has always drawn the viewer toward it. Such traditions have also been generating highly individuated self-conscious artists. The above-discussed folk painting traditions of India are intrinsically associated to the customary rites. To trace their principle origin, one needs to understand its religious compulsion that operates the flow of the practice and is primarily responsible to shape up its stylistic identity. They are often budded in the vicinity of the Hindu temples, as sacred wall hangings, that harmonize the walls around the chambers and passageways of the temple. Roving minstrels (kathakas, story tellers) painted mythological figures and carried them to places, with the oration of the words of God. The painters over ages have been performing a role of a reformer by promoting the flare of rectitude in the minds of the common populaces not as a

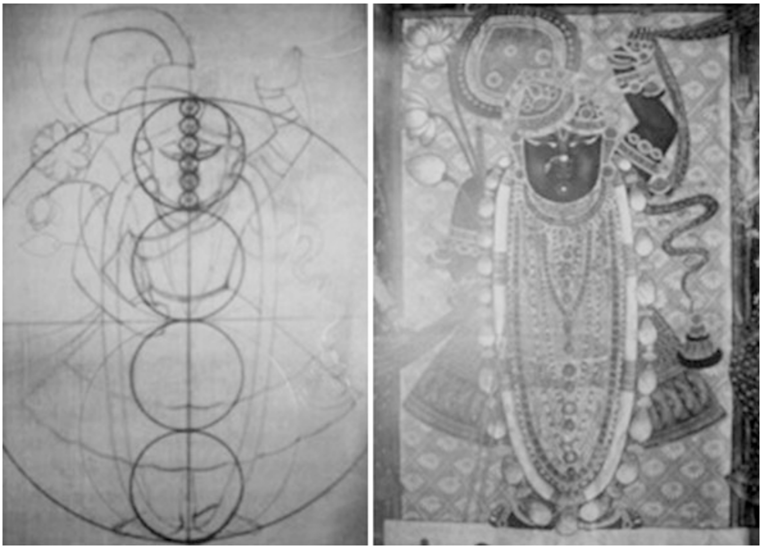


Fig. 2 Construct of Shrinathji at Nathadwara temple, Rajasthan

preacher but entertainer with their artistic ability of painting and singings. In the process of viewing and analyzing the art works to access the strength and weakness the research aims at achieving the right vision to determine the life of the cultural dynamism in the changing social milieu. “The meaning of art is similarly a mystic experience for which one needs *divya chakshu*, the inner perception. For understanding Indian traditional art, or for that matter, any art form, one needs Divine vision to understand the message of the artist. Beyond the outer image is the inner meaning, which can be perceived and shared both by the artist and the viewer. It is this vision, the shared experience that reveals the Soul of Art”, Ramani [2].

The present study is an effort to indicate the notions of viewing and appreciating the artworks to conduct a comprehensive art critique. The art works although made by artists who are not educated in academic style in urban art schools, but inherit the skill and carry it through generations, may seem to contain elements in them that are ageless and primitive, and even be crude or amateurish. They are far beyond the representational norms of realism and naturalism and can be totally idealistic in nature. Folk art being a community practice the skill is often common in almost every inhabitant of a cluster. Not everyone qualifies to be a master, but only a handful of them. The rest of the people perform as followers to contribute to the process as skilled craftsmen. To understand and critically appreciate the artworks one must adopt the age-old three level method of critique. Thematic, iconic and semiotic levels of a thorough reading prove to do justice to the rich esthetic that the artworks contain. In the thematic level, an overview to the socio-cultural background is considered. Understanding the context is the most important part of it.

Can folk art be set apart from its historical context? The art, that takes birth and get nurtured to the serenity of the rural landscape and to the temples where the God is believed to dwell and thus being worshiped, when taken out and placed for the market display, juxtaposing numerous other items, may not always be successful in holding the similar identity. This contextualization and re-contextualization have had phenomenally influenced the viewers.

In the cultural center named Bharat Bhavan, Bhopal, J. Swaminathan initiated a unique coexistence of modern art and folk art in an exhibition in the early 1980s. Jayakar, as the director of Handicraft Board, Government of India, caused a paradigm shift for the female painters of Madhubani when she asked them to draw on paper instead of the mud walls. In 1966, during the drought and famine in that region Bhaskar Kulkarni represented Jayakar to offer them papers to work on so that they may generate some fund for them during the crisis. These incidents hold a lot of importance in the history of those traditions and cannot be kept unmentioned in the thematic critique. Realistic, representational and recognizable images are to be appreciated and criticized at the iconic level. In order to understand Indian Folk Painting, it is mandatory to be familiar with the iconic characters in the paintings that play the central role. In this level of critique the viewer mentally alter and reposition the figures within the frame according to their change in preference. The religious connection of folk painting seldom allows its practitioner to disturb the cosmological order and there by limit the scope of experiment in the execution. The use of color in most cases are mandatory over arbitrary. Vast use of hieratic scale contributes to the story telling process.

The following image (Fig. 3) of Ramayana inscribed on the body of Hanuman painted by Shilpaguru Ananta Maharana, Raghurajpur, Odisha, one can observe, as it has been pointed out to the authors by the artist's son Bibhu Maharana, that, all happy episodes are put on the face of Hanumana, while episodes related to Ravana, the antihero in the epic are drawn around the lower body. In the iconic level it is

Fig. 3 Complete Ramayana on the body of Hanumana (detail), Raghurajpur

not only needed to recognize a figure but also to identify it with the prior knowledge of history and mythology that refers to the thematic level.

The layer of semiotic comprehension applies to a critical analysis free from any foreknown information. Non-representational and abstract images are best read applying this very level of critique. In the semiotic level the artwork can be viewed and analytically appreciated regardless of any prior knowledge of its history, background, method, medium or material. In this level each and every dot and pixels can be analyzed and thus be visually communicated. In the semiotic level the critic directly approaches to the elementary part of an artwork. It is read in terms of quality of line, form, shape, volume, color, texture etc. The elements here enable to establish a language for improved expression. The perception of the artist in this level makes an entry to the language of art. The vocabulary of visual art adds to the possibility of communication and connects it with the desired message irrespective of its existing cultural fabric. Indian painting tradition that spans over two millennia, in spite of having remarkable variety does not include folk art in the family of its major distinctive styles. Folk art practice has emerged and grew independently in regional locations there by holding the core essence and spirit of the soil. In the present study the authors primarily focus on the mandatory regulations that the practice prevail in them in order to assess how stringently they adhere to the rules. This is to scrutinize the tradition and change that keep up with the free spirit that the practice is desired to hold in them. The semiotic analysis of the space in the artworks hence will be conducted with a few relevant visual examples.

Ramayana is among the most popular religious texts of India. The central characters of this epic namely Rama, Lakshmana, Sita and Hanumana are worshiped as incarnations of God and God themselves in Hindus all over in the country. Episodes from Ramayana in single frame (ekachitra) as well as complete Ramayana both as narrative scrolls and single frames are to be found in almost all the regional folk clusters. The narrative that is orated with these pictures tells the stories in regional languages. In the past those narrations must have been the only source for the common people to learn the incidents and the paintings worked as illustration to add life to it. The paintings also have functioned as wall hangings in the temples. The story of Ramayana as all other epics have been told and retold for ages and never to lose its significance. But, regardless of the text the paintings hold a high quality esthetic value in them that can be viewed and appreciated independently as visuals irrespective of any clue to the story. The space is two-dimensional in general with no intension to create any illusion of depth. The use of perspective is aerial rather than linear. The compositions are dominant with linear qualities and all the characters and objects are confined in well-defined contour lines.

In Madhubani painting [4] of Bihar complete Ramayana is not so common. Episodes of Rama's wedding, Hanumana's faithfulness, Ravana's abduction strategies for Sita and finally Ravana's defeat to Rama are most popular as subjects. They use a technique known as *bharni* that literally means to fill. The painting styles defer in the major casts but the process in general is to draw the contours and fill them up with colors or decorative patterns. Empty spaces without any filling are rarely observed here, that enhances the decorative quality in these paintings. Angularities of all sorts including the limb joins are totally avoided in these works to ensure the harmonious lyricism. Visual abstraction achieves a representational dimension rich with naive esthetic excellence as the figures appear in their most descriptive features with faces in profile with a frontal eye and torso, with hands and legs in their sidewise views. The lines do not show any rendering of light and shade in them. They follow an idealistic style with no sign of line variation in the style that may indicate and naturalistic quality anywhere in them.

Narrative scrolls (Fig. 4) depicting the story of Ramayana from Midnapur, Murshidabad and Birbhum, Bengal is not different as far as the principle of image making is concerned. The delineation with repetitive forms and decorative lines gives the images the required movement in the otherwise static space. In Bengal the narrative scrolls are known as *dighalpata* and *jaranopata*, which has related meanings. *Dighal* means long, *jorano* means rolled up and *pata* means canvas space. The dispersion of images is based on continuity. Continuity in composition is caused by repetitive forms and well-calculated proximity within the images. Even when the episodes are essentially separated and confined with a borderline the similarity in form causes the entire scroll to look united and harmonious with no visual break.

Complete Ramayana painting (Fig. 5) made by the master painter of Raghurajpur, Orissa still follow a regimented norm in the distribution of space in their composition. The skeleton structure if studied properly takes care of the marvelous balance with a preconceived and conniving repetition of circles, squires and rectangles.

Complete Ramayana in Kalamkari technique on cloth painted (Fig. 6) in Srikalahasti , Andhra Pradesh, incorporates typography in the horizontal borderlines to divide the space. The roundish regional scriptures blends as exactly and effectively with the drawing style that the scripts even if unreadable do not cause any hindrances to its smooth viewing. Painter M. Nagaraja Setty in his conversation with

Fig. 4 Narrative scroll paintings of Ramayana from Bengal

Fig. 5 Complete Ramayana, Raghurajpur

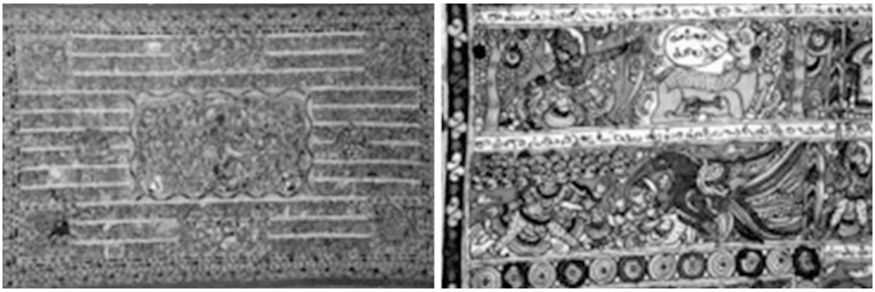


Fig. 6 Complete Ramayana, Srikalahasti

the authors put stress on that. It is indeed interesting to see how the Telugu script acted as a decorative pattern for the people who cannot read the language.

3 Conclusion

The expression of folk art is simplistic, but not as rudimentary as tribal art forms. In tribal art we see images that are related to votive cults that are untouched by the complexity of civil livelihood. Folk art belongs to the people who are exposed to many a cross cultural and cross media influences. They are literate and educated socialites who have complex religious foundations. Moreover they belong to the time that is dynamic and prone to change.

The ethnographic study of folk culture enables the researcher to understand the evolution of creative minds. Subramanyan writes, ‘In present-day society like ours art does not have a decided role or patronage, and no decided thematic supports; hence the artist has either to devise his own supports, however small, or make more radical choices’ [8].

The various government and non-government initiatives have caused a lot of innovation possibilities to the happening. The practice has lost its relevance in the society from time to time with the introduction of new ways of living. Comic books and television serials have replaced the practice of oration and painted illumination, with their big budget and glossy productions. The new modes of communication have left little to the folk painters to play any role that is vital and indispensable for a society. Nevertheless the condition like this, has offered newer openings to the folk art practitioners to create with no bindings and obligations. The folk art market of today is based on pure esthetics. The master artists who have always been extremely innovative and talented are now getting a platform to experiment and explore depending on various stipends and awards. The numerous trained artists from the community and form outside the community who are not involved into the innovation related to the image making are engaging themselves with the industries that deal with lifestyle products and earning their livelihood by trying their painting skill on designer saris, wall hangings, lampshades etc. The abrupt patronage that has helped the practice to sustain and come this long a way deserves a parallel study. The contribution of Kamaladevi Chattopadhyay and Guru Saday Dutta along needs an essential mentioning here. The folk painters are taking interest to explore the possibilities of new media. They are contributing and collaborating in animation filmmaking and book illustrations that are not away form their own principle purpose of image making. A few successful initiatives from recent time where the eminent folk painters of contemporary India took part that needs to be mentioned here are Moyna Chitrakar’s Sita’s Ramayana, Dulari Devi’s Following My Paint Brush, Swarana Chitrakar’s The Patua Pinocchio and Monkey Photo, T. Balaji’s Mangoes and Bananas, Radhashyam Raut’s The Circle of Faith Rambharas Jha’s Waterlife, and many more published by Tara Books. Having been written in English language they have crossed the limitation of vernacular communication. However, it is the semiotic comprehension that proves to be the best way of communication outreach that has an appeal that is beyond all limitations and universal. The understanding is based on the fundamentals of human gesture that is rooted in the cosmos.

Tradition, religion, time, change and words like those if considered as the keywords for this article may sound as oxymoron in the present context, where the validity and significance of all these factors are primarily based on the uplifting of folk art as the thriving cultural industry for our country. The variety yet integrity in the folk styles hold the potential to establish a distinct cultural identity as well as can mirror the living visual culture of India. The process of semiotic viewing gives emphasis to its expressional prospective that is universally recognized and appreciated with due round of applause.

References

1. Vatsyayan K (1997) The squire and the circle of the Indian arts. Abhinav Publications, New Delhi
2. Ramani S (2007) Kalamkari and traditional design heritage of India. Wisdom Tree, New Delhi. ISBN ISBN 81-8328-082-X
3. Lazaro DP (2005) Materials methods and symbolism in the Pichhvai painting tradition of Rajasthan. Mapin Publishing Pvt Ltd, Ahmadabad
4. Anand MR (1984) Ministry of information and broadcasting: government of India. Madhubani Painting Publication Division, New Delhi
5. Archer M, William G (1974) The hill of flutes life, love and poetry in tribal India: a portrait of the santals. S. Chand Publications, New Delhi
6. Jayakar P (1975) Paintings of rural India. The Times of India Annual, Bombay, pp 53–62
7. Jayakar P (1980) The earthen drum: an introduction to the ritual arts of rural India. National Museum, New Delhi
8. Subramanyan KG (1987) The living tradition: perspectives on modern Indian art. Seagull Books, Calcutta. ISBN ISBN 81 7046 022 0

Classifying Shop Signs: Open Card Sorting of Bengaluru Shop Signs (India)

Nanki Nath and Ravi Poovaiah

Abstract Any Classification into categories aids in retrieving information. It develops a system for an object or phenomena. Hence, a classification of shop signs would provide an informed view about the system of elements that form the identity of a shop sign. The Philosophy of Classification as explained by Ereshefsky [1] brings to light three kinds of paradigms: Essentialism Sorts, Cluster Analysis and Historical classification. This study investigates the relevance of creating categories through cluster analysis. The analysis helps collate the pragmatic approach applied by the viewers of the shop signs. How people classify shop signboards mentally? What clues they use to attach qualities or concepts with a shop sign? Applying the method of Open Card Sorting [2] increased the analytical scope about the new values attached with the identities represented on these shop signs through text, images and materials. There is a paucity of published research in favour of the above statement. Therefore, this paper is a sincere attempt to substantiate the benefits of arriving at new categories via Open Card Sorting. This method provided the participants to design their own labels and classification structure for the given shop signs. A group of 30 participants (15 designers and rest 15 from other professions) underwent Open Card Sorting exercise. With formal instructions about card sort method, every participant was asked to 'think aloud' in order to resolve the 90 cards puzzle. Additionally, two standard questions regarding good and bad signs in the picture cards were asked. Around 20 new categories could be accumulated in the SPSS software. The viewers did not categorise total 10 cards of the 90 into any label(s). Cluster Analysis of this data gave rise to new classes/genres of these shop signs. It also clustered those cards that

N. Nath (✉) · R. Poovaiah
Industrial Design Centre (IDC), Indian Institute of Technology Bombay (IIT-B), Powai, Mumbai 400 076, India
e-mail: nanki.nath@iitb.ac.in; nankinath@gmail.com

R. Poovaiah
e-mail: ravi@iitb.ac.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_103, © Springer India 2013

were considered good and bad shop signs. It is a unique study to know how people view, read and form opinions about shop signs. Results of this study can be used to inform the designers about the new features/qualities of the content and form observed by viewers along with their opinions on good and bad signs. Therefore, these insights would be the essential parameters in terms of elements of design and related qualities that sign designers should apply in the design of shop signs.

Keywords Open Card Sorting · Generative Research Methodology · Classification · Structures · Taxonomy · Shop Signs · Identification · Signs · India

1 Introduction

There are different types of visual display that create the visible appearance of the shop signs in India. The perception and meaning of the elements and designs (say, posters in the streets, a magazine ad or a sign in a train station), must attract the attention of viewers [3]. The vast number of elements would make specific classification of every shop sign quite difficult. However, it is important to have an understanding of the basic elements to help us narrow down the research and selection of the most crucial elements of the shop signs. Designers and non-designers have a different way of viewing/reading/interpreting shop signs. Hence, for the experiment of Open Card Sorting here, aims to understand the overall rationale that people used to classify shop signs of Bengaluru:

1. To accumulate new nomenclature/terminology applied by people to name various sign classes, qualities/attributes assigned to these various classes to understand significant parts of the shop sign's language.
2. To identify the significant parameters that could be best used to arrive at a preliminary.
3. To accumulate all the parameters those were given preference against the left ones.

1.1 Basics of Classification

Classification is as an effective method to generate an order; that aims to formulate a system of understanding for objects, ideas, phenomena etc. Therefore, it is required that the approach to classification should be well articulated and should also project a logical correctness [4]. The following basics of classification explain the above requirements with simple visual examples:

1.1.1 Mutually Exclusive Classification

When an object is classified on the basis of many aspects, then each of these aspects have their own set of groups. For instance, shop signs can be classified on

Fig. 1 Genres: Indian commercial cinema. *Source* http://www.bollywoodwallpapersfree.com/

the basis of graphics, text, information and material display etc. Some people may notice further sub-aspects within these primary groups. For instance, ‘hand-painted’ and ‘hand-crafted/3D fabrication’ can be the sub-aspects of ‘material display’ for these shop signs. ‘Material Display’ is an exclusive aspect in itself, mutually aligned to others, but not a sub-class of others (others here being graphics, text and information).

To illustrate mutual exclusiveness approach, Indian Commercial Cinema has mutual and exclusive genres (see Fig. 1). In addition to mutual exclusiveness of respective categories, the respective categories display a *logical correctness* to them. For instance, ‘Devotional’ and ‘Patriotic’ movies express different themes. Both, in a way, are belief systems of the people of India, but their social meanings are different. ‘Patriotic’ genre is a special feeling for one’s country (that is very different from devotional subject of ‘Devotional films’).

1.1.2 Collectively Exhaustive Classification

When an object can be easily classified under more than one category, the classification structure becomes collectively exhaustive. For instance, *faceted classifications* are generally collectively exhaustive. In such classifications, a facet includes “clearly defined, mutually exclusive, and collectively exhaustive aspects, properties or characteristics of a class or specific subject” [5]. For example, in case of shop signs, ‘form’ as the facet, ‘shapes’ (geometric, natural, oriental etc.), ‘volume’ (mass, contours etc.), ‘proportion’ (upright, uniform/non-uniform) etc. are the sub-categories within the facet.

In 1954, French typographer Maximilien Vox developed the Vox ATypI classification has nine classes (see Fig. 2). It elaborates on the evolutions of tools and techniques in respective time periods of specific typeface genres [6].

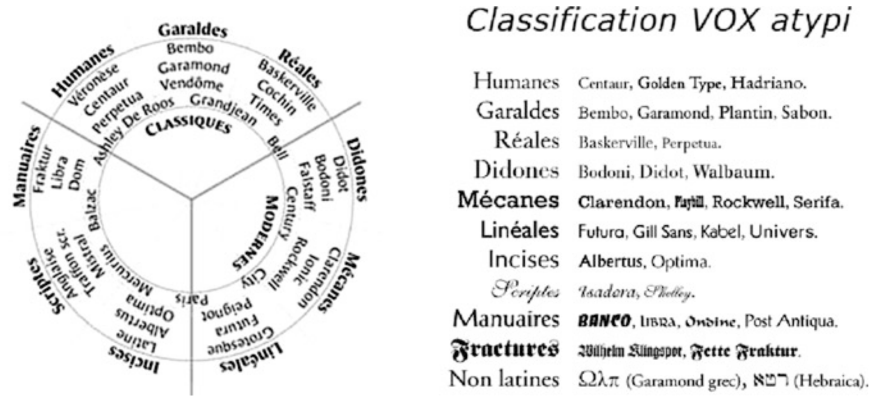


Fig. 2 Vox ATypI classification map, from la Chose imprimée, chapter on type classification by the author, 1999. Classification Vox ATypI—additions of *Blackletter* and Non-Latin genres. *Sources* http://typofonderie.com/gazette/post/on-type-classifications/, http://illusive-pixel.com/art-general/typographie-histoire-et-pratiques/

1.1.3 Internally Homogenous Classification

When all the objects are grouped together under one category regardless of the common connection/likeability amidst them as a group, then this approach of classification is *Internally Homogenous.* For instance, in case of modern (commercial) shop signs, 80–90 % of the signs can be grouped under Digital Art group (see Fig. 3).

Fig. 3 Digital art, India. *Source* http://beclee.wordpress.com/gallery/signsweb/

Though, in the grouping, we would see various nuances of digital art in the text/graphics/material use and treatment/background visual effects or signboard in totality. But, these different nuances are of least concern being internally homogenous. There is advantage to this approach for commercial signs displayed here—the designer/maker of shop signs can find all the materials on a given topic in one area of shop signs.

2 Methodology

2.1 Experiment Design and Process

2.1.1 Experiment Setting and Instructions

A big space of four tables of regular height was selected for the open card sorting experiment. This space is part of a large working studio (Shenoy Innovation Studio, IDC, IIT Bombay). The lighting conditions were kept ambient. The experiment was conducted within the duration from 9 a.m. to 6 p.m.

2.1.2 Preparation of Stimulus

Each of the 90 shop sign picture cards, each of 6 by 3 inches, includes shop sign picture (in correct upright perspective). The sizes of the shop signs vary in sizes. The card sheet of 120 gsm (matte finish) was used for the prints. These 90 cards are from the city of Bengaluru, India. They have been collected from three different marketplaces of the city, namely Shivajinagar (oldest marketplace), Narasimha Raja Road (older one) and Avenue Road (new one). (Similarly, 30 signs have been collected from five more cities; in addition to Bengaluru. The basis has been devised to formulate a mathematical logic to quantify essential attributes to get changes (transitions) and co-relations; that would help discover new aspects of shop sign designs and the co-related factors that are instrumental in the process). This was not shared with the respondents. Rather, the whole bundle of 90 shop signs was handed over to every participant. But, at the back of each card, a linear code was written (for later information retrieval) in following way:

- [City—Marketplace—Time Period—Shop Kind—Serial number].
- [BA—MP1—30–44—A—01].
- [Bengaluru—Marketplace 1—Time period—Shop Kind—Serial number].

2.1.3 About Respondents and Instruction Session

Total 30 respondents participated in the experiment (15 designers and other 15 non-designers; range of age groups: 20–65 years.). In the designer gamut, design faculty, technical staff, one master student and research scholars from IDC, IIT Bombay participated. In the non-designer gamut, two B.Tech. students, M.Tech. students and Research Scholars from other departments of IIT Bombay participated. The following paragraph presents the instruction imparted to all the participants per card sort exercise:

The aim of this experiment is to know how you classify a group of 90 shop signs as picture cards here. Look at the group of cards and sort them into separate groups. All the groups that you make together would be a classification structure of 90 signs that you sort. Think Aloud and name or label all the groups you construct. You can put one particular card into as many groups as you like and include as many cards as part of a group. When you have finished sorting cards and labelling the groups, we would like you to tell us the approach that you followed to sort these cards.

2.1.4 Finalising Categories from 30 Card Sort Exercises

Every classification structure was observed for each respondent. When we started manually filtering the most common ideas/concepts/names as group labels; various aspects appeared to mix together that made labels very unclear. For instance, a group named 'Bilingual signs, with local language prominent and hand-painted signs'. With this multi-dimensional labelling, it was becoming difficult to lump all the selected shop signs by the participants under the label. Though, this being a major limitation of the labels we accumulated, we have tried to visually map all classification structures (by designers and non-designers) from most general to specific category (Table 1).

Table 1 List of main categories

Shop functions (SF)	Letterforms in signs (LF)
Information signs (IS)	Language in signs (LA)
Confused signs (CS)	Naming kinds in signs (NA)
Perfect signs (PS)	Price signs (PR)
Bad signs (BS)	Qualities in signs (QA)
Artistic signs (AR)	Representation in signs (RP)
Graphic signs (GR)	Layered signs (LA)
Graphic + typo-text signs (TTGR)	Typical signboards (BS)
Typo-text signs (TT)	Miscellaneous (MS)
Fonts in signs (FS)	Uncategorised signs (UnS)

2.2 Hierarchical Cluster Analysis

The method generates a system of clusters, collecting small clusters of very similar items to large clusters having only dissimilar items. This method helps create a sequential and logical order of segmentation by accumulating co-related clusters. It tells you the distance between two and more clusters, which clusters are important ones to consider. It presents the similarity and dissimilarity between clusters. The largest cluster in the resulting dendrogram from this study combines case/variable 3 (No. of Structures) with 32 (Photos)—see Fig. 4.

2.3 Data Feeding and Output

Putting the data in SPSS and then doing cluster analysis has given us following outcomes. Following is the analysis for each result:

2.3.1 Proximity Matrix (P)

Presents the co-relations that exist between cases/variables. How closely associated are some cases? With $n = 99$ (all variables), we are measuring here n-by-n matrix of similarities and dissimilarities (see Table 2 and footnote. Similarly, we have observed five more cases).

2.3.2 Agglomeration Schedule

An Agglomeration schedule (AS) table aids us to find relevant clusters to study as the final solution of cluster analysis. Also, significant cluster formations are those where we see sudden jumps in the coefficient values. This jump from one neighbour formation to the other indicates close cluster formations. Statistically it means, that for 0.031 coefficient value increase for clusters 12th and 28th at stage

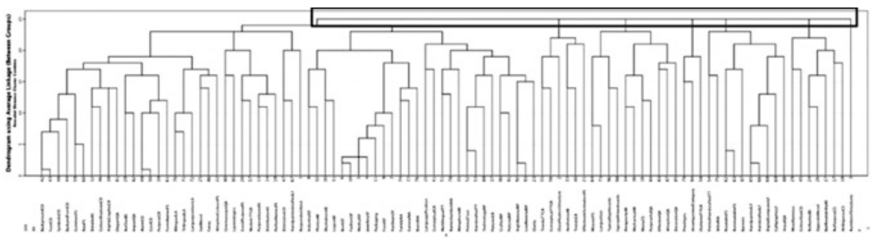


Fig. 4 The *black box* encloses the biggest cluster having most dissimilar cases together, with Case 3 and 32 being the most dissimilar, forming the extreme branches of the group

Table 2 Co-relation values of two adjacent cases/variables

FASF (Fashion shops)	PSF (Packaging shops)
−0.242	−0.365
−0.087	0.002
0	0
0.89	0.794
0.894**	0.769
0.946	0.893**

Source IBM 19.0 SPSS; output sheet of proximity matrix (*P*)
**Correlation is significant at the level of 0.01

68th, these clusters are more closer to the significance value in comparison to 23rd and 37th clusters with less significant coefficient value at stage 69th of the table (See Table 3).

2.3.3 Vertical Icicle (VI)

The presented parts of Vertical Icicle plots here represent how individual cases (variables) are combined into clusters per iteration of the analysis at the scale of 0–100 clusters formed. In the following two enlarged views of parts of the big Icicle that we got for 99 variables, we can see Fig. 5: Part a, we can see that all 'Letterform' (LF) cases are 60 at 60 clusters, 80 at 80 clusters and 100 at 100 clusters.

2.3.4 Dendrogram

Measure of average distances between two leaf notes (forming a close cluster). A cluster may have several leaf notes, but the average distance between the leaf notes may be more. This makes the group statistically not a cluster i.e., the group of variables are not that co-related as compared to others with lesser distance between the variable.

1. *Distribution into Groups:* The plot below shows that the cases are clustered into two main groups. Group 1 and 2 have further sub-clusters, demarcated by Gp.

Table 3 Highlighted part of the agglomeration table

Stage	Cluster 1	Cluster 2	Coefficients
38	65	69	0.486
39	55	56	0.470
68	12	28	**0.300**
69	23	37	**0.269**

Source IBM 19.0 SPSS; output sheet of agglomeration table

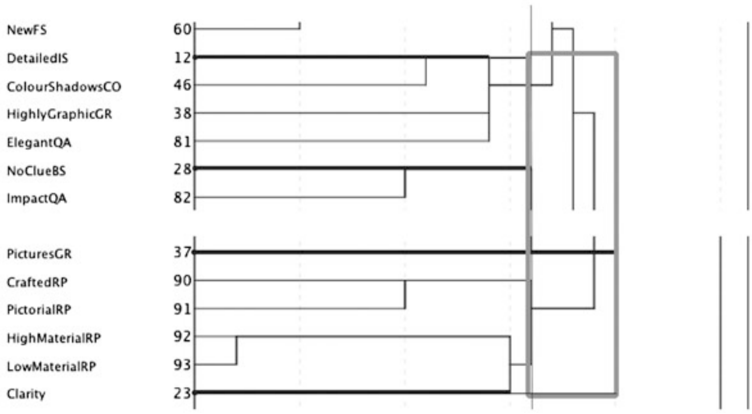


Fig. 5 *Vertical* icicle plot related to above discussion

1a (clustering ‘Colour’, ‘Font’, ‘Graphics’, ‘Qualities’, ‘Information Signs’ cases/variables in sequence) and Gp. 1b (clustering ‘Bad Signs’, ‘Qualities’, ‘Colour’ and ‘Graphics’ cases in sequence) and Gp. 2a (all ‘Language’ cases together) and Gp. 2b (‘Quality’ and ‘Perfect Signs’ in sequence) respectively (see Fig. 6).

2. *Analysis*

Total no. of *Variables* (categories under study): 99.

Total no. of Leaf notes (cases—indicated by dots in the Dendrogram (D)—see Fig. 7).

In the dendrogram, we could get 13 concrete and visible clusters. They are emerging from the branches anchored to the nodes of larger clusters. There are three large gamut’ that encompass these three clusters. Of all the 13 clusters, cluster no. 1 has the maximum number of 16 leaf notes (see Fig. 8).

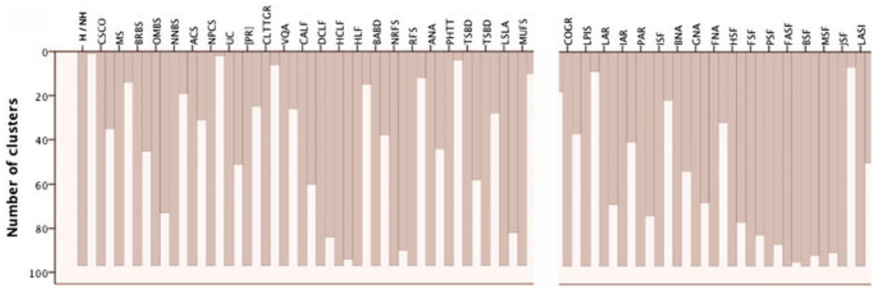


Fig. 6 Average distance between groups of clusters—an example

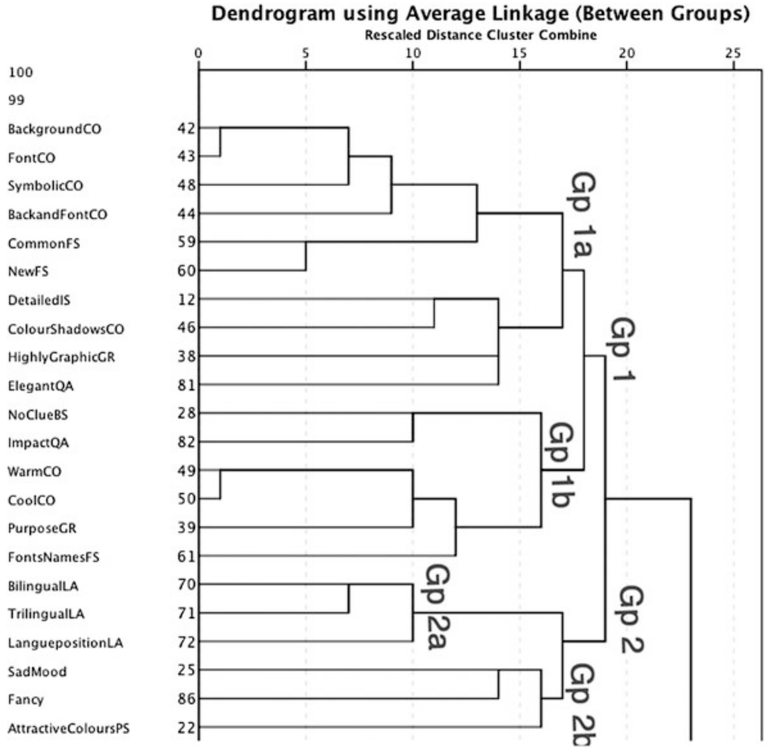


Fig. 7 The *grey box* highlights the jump from 0.269–0.300 for clusters 23–37 and 12–28 respectively. *Courtesy* Dendrogram representation of Hierarchical Cluster Analysis

2.4 Standard Questions: Qualitative Inquiry

Respondents were asked to give answers for following questions, keeping in mind a hypothetical scenario of imagining the 90 shop signboards erected on buildings and shop facades inside a street bazaar.

Q.1 a. Which signs are good/effective signs from the point of view of visual? communication?
b. Which signs are bad/ineffective signs from the point of view of visual communication?

Q.2 a. Which signs are good/effective signs from the point of view of typography/lettering styles used on these signs?
b. Which signs are bad/ineffective signs from the point of view of typography/lettering styles used on these signs?

Designer versus Non-Designer comments with respect to good and bad signs:

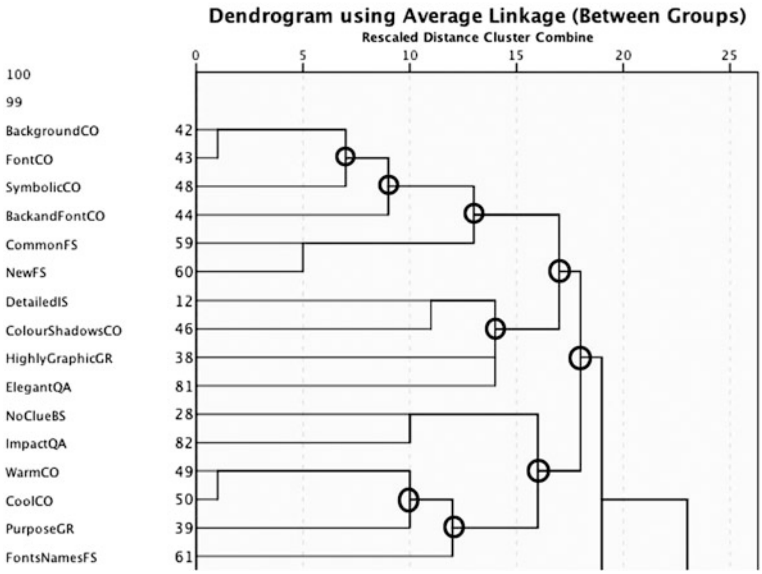


Fig. 8 Cluster 1—having maximum number of clusters. 9 nodes = 9 cluster formations

Designers made comments pertaining to design context, like likeability of font/ lettering, visual representation, information flow. Non-designers looked into purpose, wordings, visual mood. Following views are summarised versions of six kinds of opinions given by designers as well as non-designers (Tables 4, 5):

Table 4 Designer versus Non-designer views about effective/good signs

Comments: good signs	Number of designer responses	Number of non-designer responses
Likeable (text + pictures/colours used)	10	14
Names/wording for names	8	12
Visual representations/styles/symbols	6	6
Likeable fonts	6	5
Clear/straightforward signs	5	4
Innovative/novel look/novel treatment to fonts	3	2

Table 5 Designer versus non-designer views about ineffective/bad signs

Comments: bad signs	Designer	Non-designer
Unlikeable fonts	15	8
Bad use of type and space	15	8
Cluttered/loud/messy/overflow/chaotic	12	20
Bad expressions/disconnect with meaning/message	8	15
Bad readability (size/effect/colour)	8	10
Over-persuasiveness like advertisements	5	4

Table 6 Working framework for Bengaluru shop signs

Elements (primary attributes)	Parameters (functional basis)	Values (selected units)	Context
CO	Colour contrast, colour perception	Foreground-background; warm-cool	Design
RP	Material culture	High-low quality	Design
TT	–	Painted-handcrafted	Design and content
FS	Font kind; readability	Regular-stylised; readable-non-readable	Design
LA	Multilingual identity	Bilingual-multilingual	Content
SF	Business strategy	General-specific products	Content

3 Conclusion

3.1 Working Framework

1. According to the dendrogram and related coefficient values in the agglomeration table, the closest primary variables in decreasing significance are: Colour (CO), Material Representation (RP), Text and Type (TT), Language format (LA), Fonts (FS) and lastly Shop Functions (SF). These are related to the principles that theoretically regulate the elements. In case of Text and Type group, it is a mixture of equal importance of the words used in shop names and other information, along with the visual identity of letters, their style and form (Table 6).
2. Maximum number of comments regarding the effective signs (why they function as 'good' signs) by the respondents good colours—their distribution in the layout and their visual mood and relative contrast, picture-text relation and visual styles. The colour dynamics and material pragmatics of shop sign are crucial principles that should be applied in the design of a shop's sign. The comments are almost equal for both CO and RP from both designers as well as non-designers. This is further supported by their close similarity cluster values in the dendrogram.

3.2 Advantages of Classifying Shop Signs

1. *Grouping*: With classification, we group things together. With grouping, we get a sense of features/characteristics that play a crucial role in defining these shop signs.
2. *Organisation*: This is required to make sense of the vast variety of elements of shop signs. This has been achieved with two different kinds of classification structures made by designers and non-designers in this study.

3. *Overlaps* (*Shared characteristics*): The Greek philosopher Aristotle first began classifying plants according to their shared characteristics. Groups of plant varieties helped biologists/scholars in the field to the details as well as the heritage associated with specific varieties. Similarly, application of the science of classification in the case would aid us in accumulating the details and the subjective basis of the shop signs.
4. *Hierarchy*: The relative importance of one group over the other would help us in understanding the thought process/approach of segmenting visual components/elements by designers versus non-designers.

Acknowledgments I express my utmost gratitude to my guide, Prof. Ravi Poovaiah for motivating discussions regarding the research aims and the methods used for the current study. My deepest gratitude goes to Prof. Uday A. Athavankar to share his insights as one of the participants and further aid in bringing more respondents for the study. This experimental study wouldn't have been possible without the support of Prof. B. K. Chakravarthy. He provided us with good space of IDC studio to conduct the experiment.

A Big Thank You to all the respondents from IDC and other departments of IIT Bombay for their keen interest to sort cards and solve the puzzle.

References

1. Ereshefsky M (2000) The poverty of the Linnaean hierarchy: A philosophical study of biological taxonomy. Cambridge University Press, Cambridge
2. Nielsen J (2004) Card sorting: how many users/to test. Alertbox: current issues in web usability. Available at:www.useit.com/alertbox/20040719.html
3. Nath N, Poovaiah R (2011) Understanding richness: a new typology of visual cues and meaning in Signs. Design, development and research conference, CPUT, Cape Town
4. Lazarsfeld PH, Barton AH, Bartholomew DJ (eds.) (2006) Qualitative measurement in social sciences: classification, typologies, and indices. Measurement 1:149–150 (SAGE Publications)
5. Maple A (1995) Faceted access: a review of literature. Music library association annual meeting
6. Dalvi Vinod G (2010) Conceptual Model for Devanāgarī Typefaces. Ph.D. Thesis, industrial design centre (IDC), Indian Institute of Technology—Bombay (IIT-B) 2010

PREMΛP: A Platform for the Realization of Engineered Materials and Products

B. P. Gautham, Amarendra K. Singh, Smita S. Ghaisas, Sreedhar S. Reddy and Farrokh Mistree

Abstract Integrated computational materials engineering (ICME), an integrated systems engineering approach is expected to (a) reduce the time and cost of discovery and development of materials and their manufacture, and (b) enable faster development of products assisted with richer material information. Development of a comprehensive IT platform that facilitates this through the integration of models, knowledge, and data for *designing both the material and the product* is a need of the day. In this paper, we introduce PREMΛP—Platform for Realization of Engineered Materials and Products conceptualized for this purpose. We also introduce two foundational problems that include (a) the development and production of steel mill products meeting stringent requirements of quality and cost and (b) the integrated design of gears and their manufacture, and how these are envisaged to be executed on PREMΛP. We envisage PREMΛP to be a platform for discovering new materials and concurrently designing materials, manufacturing processes and engineered components. The three associated papers in this series deal with application of the compromise Decision Support Problem construct for a manufacturing process

B. P. Gautham (✉) · A. K. Singh · S. S. Ghaisas · S. S. Reddy
Tata Consultancy Services, Pune 411 013, India
e-mail: bp.gautham@tcs.com

A. K. Singh
e-mail: amarendra.singh@tcs.com

S. S. Ghaisas
e-mail: smita.ghaisas@tcs.com

S. S. Reddy
e-mail: sreedhar.reddy@tcs.com

F. Mistree
School of Aerospace and Mechanical Engineering, University of Oklahoma, Norman OK 73019, USA
e-mail: farrokh.mistree@ou.edu

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_104,

design and component design problems, and perspectives on knowledge engineering application in the platform being proposed.

Keywords ICME · Integrated simulation · Materials design · Knowledge engineering · Robust design

1 Introduction

Traditionally, a component designer selects a material from a list of choices he/she has, to meet the design and performance requirements. For example, Ashby's charts [1] are widely used for preliminary material selection during the design of mechanical components. However, a designer uses these merely as look up database for short-listing of material options for further exploration. However, the actual performance of the material in the product often depends on parameters not addressed at this stage; for example the cleanliness of the steel or flow lines from a shaping operation. Having a closed-loop over the mechanical design of product, and the material and manufacturing process parameter selection will lead to better utilization of the material and better products. Such an integrated approach helps speed up the introduction of new materials and can support new material development in a target-oriented fashion.

Integrated Computational Materials Engineering (ICME) is conceived as a way future materials development will be done in close association with end product design [2, 3]. An integrated systems engineering approach envisaged in ICME is expected to reduce the time and cost of development of new materials and their manufacturing processes besides allowing for faster deployment of new materials in products and products designed with detailed material state information. Besides this, such an approach is expected to enable systematic development of materials as compared to the current dependence on heuristics or serendipity. The use of modeling and simulation tools to facilitate the exploration of the materials and product design space simultaneously is envisaged as the primary driver to reduce time consuming and expensive experimentation [3]. Modeling and simulation tools are expected to map the composition, processing, structure and properties of materials and ultimately link them to evaluate product performance. However, the current state of the art of materials science maps these only partially with significant gaps [2, 4]. Besides this, such models can, at best, only be used to answer questions on the impact of changes in composition and processing on material related performance through structure–property relationships. In view of the nature of these relationships, special methods are required to address inverse questions such as designing appropriate composition and processing parameters for desired end performance. To address the gaps in materials science, in addition to the use of physics-based models and established empirical models, one needs to look at other opportunities such as mining the vast amount of materials related data available for discovery of new phenomena or relations and the use of tacit or experiential knowledge [5]. All of these require multiple tools spanning a wide range of functionalities and complexity. Such a broad based study of material-manufacturing-component-performance problems must be facilitated by knowledge engineering systems to support human decision through the use of tacit knowledge and studies of past designs and systematically guided new experiments to reduce experimental efforts. Finally, such a platform will have many stakeholders such as scientists, manufacturing process engineers, product designers and managers, and may require considerable collaborative decision-making. Enabling all these possibilities can be achieved only through the use of appropriate IT systems [2].

There have been various attempts at building ICME systems for specific purposes. The AixViPMaP platform developed at RWTH Aachen University deals with linking models for a chain of manufacturing process related to steel processing [6]. A European consortium developed through-process-modeling tools for aluminum, the Vir* set of tools [7] which link processes from casting to sheet forming. Use of commercial tools such as iSightor ModeFrontierto integrate simulation tools [8] have also been reported. These integration tools facilitate communication between simulation tools, build surrogate models and carry out optimization. The PLM/PDM tools, can also help link simulation tools, however they need considerable customization for each application. None of these tools are domain specific and generally it is not easy to use them to set up knowledge support systems to assist guided design. A comprehensive materials engineering specific IT platform that addresses these problems with tools for modeling and simulation, materials informatics, knowledge engineering, decision support systems, collaboration, etc., is not available to the best of authors' knowledge.

In this set of four papers, we describe our work towards the development of a platform for ICME at Tata Consultancy Services.

- PREMΛP—A Platform for the Realization of Engineered Materials and Products.
- PREMΛP—Exploring the Design Space for Continuous Casting of Steel, [9]
- PREMΛP—Exploring the Design and Materials Space for Gears, [10]
- PREMΛP—Knowledge Driven Design of Materials and Engineering Processes, [11].

In this, the first paper, we describe our vision for an IT platform, PREMΛP, enriched with various tools for modeling and simulation and supported by informatics, knowledge engineering, collaboration, robust design and decision support tools along with appropriate databases and knowledge bases that will facilitate the simultaneous exploration of the material and product design spaces. We also elaborate on the way the platform is envisaged to be used by illustrating of two key problems concerning steel mill products and mechanical components made of steel. We illustrate the exploration of the material and the component design spaces using the compromise Decision Support Problem (cDSP) [12, 13] in two companion papers [9, 10]. In Ref. [9] we illustrate the exploration of materials space using the cDSP for a continuous casting operation, where operational parameters are to be evolved to meet target properties at maximum productivity. In

Ref. [10] we illustrate the exploration of the design space involving geometric parameters and material properties for a transmission gear where the total cost of the gear must be reduced while meeting performance requirements. In Ref. [11] the authors introduce the ontologies, knowledge engineering systems and the platform architecture of PREMΛP.

2 Purpose of the PREMΛP

2.1 Motivation

The advances in modeling and simulation tools for materials and manufacturing processes have significantly enhanced the capability of predicting evolution of properties of materials and also the performance of the material under service conditions. This facilitates addressing a number of material related decisions in industry to reduce the dependence on heuristics and individual knowledge. Some of the commonly encountered problems are listed below:

- New product design—material and manufacturing process selection that meets material performance requirements, low overall cost, etc.;
- Material and/or process substitution—to reduce cost, enhance performance, reduce weight, geographic constraints on cost and supply chain;
- New material development—to develop new material with enhanced performance properties or customize material composition and processing for given needs;
- Materials for special needs—to impart very specific properties through material and manufacturing process design;
- Develop and/or enhance specifications—to accommodate new needs or if components, which were designed and manufactured to specifications fail in service for no previously known or obvious causes.

All the above have to be carried out with a significant reduction in lead-time, minimum disruption to existing production and wider exploration of opportunity space for better material utilization in the future. PREMΛP is envisaged to be a platform to help address such problems in an industrial environment. In addition to its application in industry, the platform also will be useful for the research community.

2.2 Usage Scenarios

PREMΛP is a platform for concurrently designing materials, manufacturing processes and engineered components with increasingly exacting requirements through intelligent recommendations and decision support systems that engineers can use to make appropriate decisions in an industrial setting. With PREMΛP in place, in the long term, we envision using it to discover and improve materials, manufacturing processes, and product combinations. It is envisaged that the platform will be used by a variety of users, including experts involved in new materials or process development, process experts that can make standard templates for usage by non-experts in their day to day work, non-expert users who use the predefined templates and researchers testing their new models/tools for simulation. The potential utility of PREMΛP for various stakeholders is summarized below.

For expert users:

- Build simulation process steps for a chain of events that occur during material processing, testing and product design where simulation tools are available for a given need; knowledge assistance will be made available to facilitate this.
- Set the process chain in a decision support framework to make informed decisions about the design of the material, process parameters and product;
- Add models/simulation tools with appropriate connectors to the platform along with knowledge elements;
- Enable robust design in the presence of noise and uncertainty;
- Enable an engineer to explore material and component design spaces concurrently and to design the material and the component concurrently.
- Build simulation/design templates to make them available for non-expert users;

For non-expert end user:

- Use an existing template designed to solve specific problems (e.g., templates with a series of manufacturing operations to determine the process set points)
- Knowledge enablement for use with the process templates through guidance on inputs to be given or models to be selected (e.g., recommend an initial guess for temperature and time for a heat treatment process.)

For researcher:

- Ability to add/substitute models and verify them for improved performance
- Design and develop new materials and manufacturing processes
- Enrich the knowledge base through machine learning from past cases as well as systematic inputs from experts
- Statistical model development and knowledge enhancement through materials informatics/data mining
- Build low fidelity models from high-fidelity models for faster computation with desired accuracy.

In the next section we describe the key components of PREMΛP.

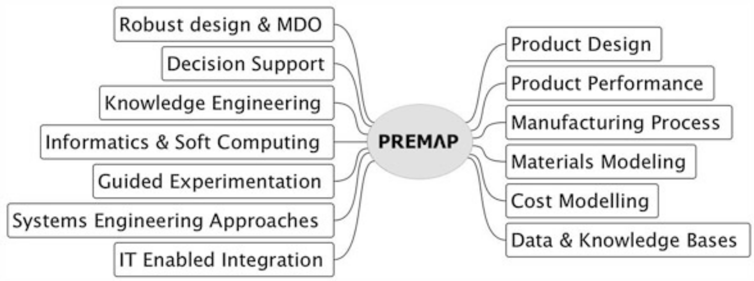


Fig. 1 Domain independent (*left*) and domain dependent (*right*) components of the platform

3 Components of PREMΛP

In view of the vast numbers of diverse material systems and component/product application categories that such a platform has to deal with, we envisage both a set of domain dependent and a set of domain-independent components as shown in Fig. 1. On the right side of the figure are the components that are domain dependent and those on the left are domain independent. This categorization is done in order to build an extendable platform, which can be used for multiple domains. A domain may refer to a material category with associated manufacturing processes and/or a product category. Appropriate ontologies are being developed and applied to develop data and knowledge models of various components to make integration of various components and adaptation and extension to different domains easier, in addition to enabling drawing inferences based on ontologies.

PREMΛP enables setting up design problems with a systems engineering approach. It offers support tools to capture requirements, constraints, goals etc., for a specified design problem. The key tool bases that are being developed include, (a) tools for robust design to facilitate the exploration of design spaces and determine ranged sets of specifications, and multidisciplinary optimization techniques (MDO), (b) decision support tools (e.g., the compromise decision support problem construct) driven by both formal mathematical techniques as well as heuristic techniques, (c) knowledge engineering tools based on case-based or rule-based reasoning, machine learning and data mining tools for capturing knowledge from the past cases and (d) materials informatics for the discovery of knowledge from data bases and (e) design of experiments and combinatorial experimentation tools to drive both simulation and experimental studies. Select tools for achieving the above are being added to the platform with facilities for adding more in the future. The platform also needs appropriate IT architecture that enables configurability of different tools and their communication in an easily adaptable and scalable way. Data and knowledge bases regarding materials, processes, products, use of simulation tools etc., are being captured in an ontological framework and a detailed description is given in the fourth paper of this series [11].

4 Illustration of PREMΛP Usage

As an illustration, we look at an end-to-end problem involving a steel component starting from chemistry selection (secondary steel making). The life cycle of design and manufacture of a steel component, generally, involves two major stages; (a) production of an intermediate mill product form such as a rolled sheet/rod or an ingot carried out at the steel mill and (b) design and manufacture of the component carried out by the original equipment manufacturers (OEMs). The material related performance of the component is influenced by the design of the product as well as the processes involved both during the mill product production and manufacture to the final form from the mill product stock. Hence, the component design and material and manufacturing process selection needs a higher degree of coordination than that is in conventional practice today in order to achieve products with more stringent requirements (e.g., weight). The component considered for illustration is one of the critical components in an automotive industry, a gear. For gear design, information from the manufacturing process on the distributed properties of the materials such as strength, fatigue life and residual stresses from the initial bar stock from which it is manufactured can lead to a better design with reduction in total cost. Other aspects such as forming defects or final fatigue properties may depend on segregation and inclusions that come from mill product production processes, besides the material chemistry [14]. An integrated analysis allows for the interaction between the steel mill and component design and manufacturing in a more informed way.

We plan to design the steel and the gear in a closed loop involving design of the product, material and its manufacture, using physics based models, empirical models and knowledge engineering systems. The materials design problem and a discussion of the integration of the two problems are described next.

4.1 Development of Steel Mill Product

A steel mill produces a variety of intermediate mill products such as slabs, billets, and blooms and finished flat and long products such as sheets, bars, etc. These intermediate and finished products are used for component manufacturing with or without further processing. We consider two such applications from automotive domain.

The first one is for the production of steel sheet, which is used as a raw material for the manufacture of car body and other sheet metal components. The production of a steel sheet in a typical flat product production line is illustrated in Fig. 2. Starting from the chemistry and cleanliness of the molten steel, casting, rolling, heat treatment, forming and other processes influence the properties and performance of the steel sheet produced in the mill. The performance of a formed sheet

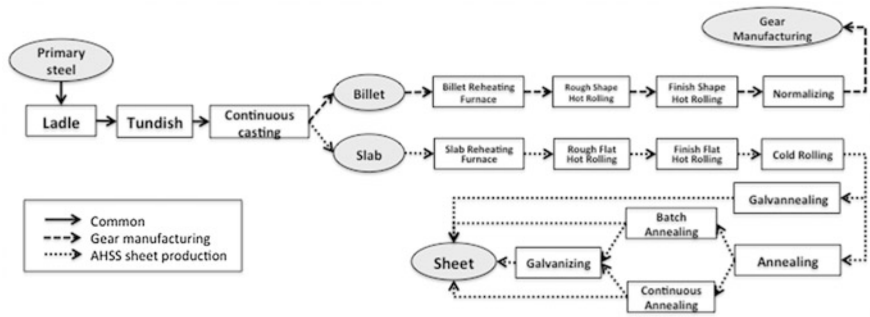


Fig. 2 Flow diagram for steel mill products

component in an automobile is influenced by the entire life cycle the material has gone through in its production including the mill processes.

The second mill product, a steel bar, is produced in a long product line as shown in Fig. 2, and is used as raw material for the production of a transmission gear. Again the evolving properties of the bar are dictated by the chemistry and cleanliness of molten steel, the micro and macro structure of the cast products and the subsequent deformation and thermal processes.

Tracking the evolution of the properties as well as determining the influence of evolving structure on various properties is a challenging task. Apart from developing models to track the evolution of properties, an enabling platform is required to integrate these interconnected models across multiple-scale as well as multiple unit operations with knowledge and data to obtain the optimized design set points of various unit operations of the entire production path. This will assist develop materials and processes to meet the ever-increasing demands of lighter sheet materials or bar with better properties. PREMΛP, the enabling technology described in this work, is aimed at addressing such complex problems.

Here PREMΛP links various physics based models (e.g., fluid flow, heat and mass transport, diffusion and deformation) along with empirical correlations (e.g., for property prediction) as appropriate, for various processes illustrated in the picture. The models, after successful validation, will be subsequently put in a decision support framework to assist design of the chemistry and process conditions to achieve desired end properties.

Among the processes given in Fig. 2, continuous casting operation is a crucial step involved in production of a variety of steel products such as slabs and billets from liquid steel owing to the complex nature of physics involved (multi-phase flow, phase transformations from liquid to multiple solid phases, chemical segregation, etc.) and its effect on further downstream operations. Productivity and yield are two key parameters indicative of caster performance and both are required to be on the higher side while meeting quality requirements from an industrial perspective.

In a companion paper [9], we explore the design space consisting of process and equipment parameters for this important intermediate operation of slab casting, which is used for sheet manufacturing. The same methodology is valid for exploring the design space for casting a billet, which is used for gear manufacturing. An integrated design framework comprised of a cDSP using metamodels for continuous casting has been developed to explore its design space. Our focus is on demonstrating the potential of integrating mathematical modeling and multi-objective robust design formulations in an integrated design framework specifically for the materials and design communities.

4.2 Integrated Design of Steel Gears

One of the largest consumers of steel gears is the automotive industry. Automotive transmission gears are generally helical or bevel gears and are made of case carburized steels. While fatigue life and reliability are the most important driving parameters, reducing transmission weight and noise are key drivers for successful gear design. Some of the challenges articulated in the Gear Vision document [16] that are affected by materials include the need to (a) enhance power density, (b) achieve 100 % reliability for 20 years for large gears, (c) increase overall achievable accuracy during manufacture at the same perceived cost, and (d) reduce time to market for gear components by 25 % in 5 years and 50 % in 10 years. The document further states that achieving these require innovative gear design and development with predictive tools (virtual testing). It also anticipates the use of steels that heat treat to RC70+ and higher with cleaner steel to enable greater power density; new steels to reduce/eliminate intergranular oxidation; shot peening and other innovative manufacturing processes for improved performance; and high quality and stable production processes.

This vision can be achieved by concurrent design of products and materials and manufacturing process with greater information exchange between the design and manufacturing teams to address the interconnected problems. In Fig. 3, the "manufacturing" block illustrates the choices of manufacturing processes to generate the shape and tailor the material properties to the desired product performance. The upper block illustrates the design requirements. Currently, a product designer uses this information along with the limited amount of information about material properties available from material and manufacturing departments. ICME paradigm enables tightly coupled materials and manufacturing processes development and product design.

If simulation assisted detailed material state information is available, the designer can take advantage of the actual variation of properties of the material (e.g., hardness distribution in place of two parameters—case and core hardness; impact of residual stresses), on the gear fatigue life to make a better design. Often the impact of processes such as shot peening are not fed back into the design

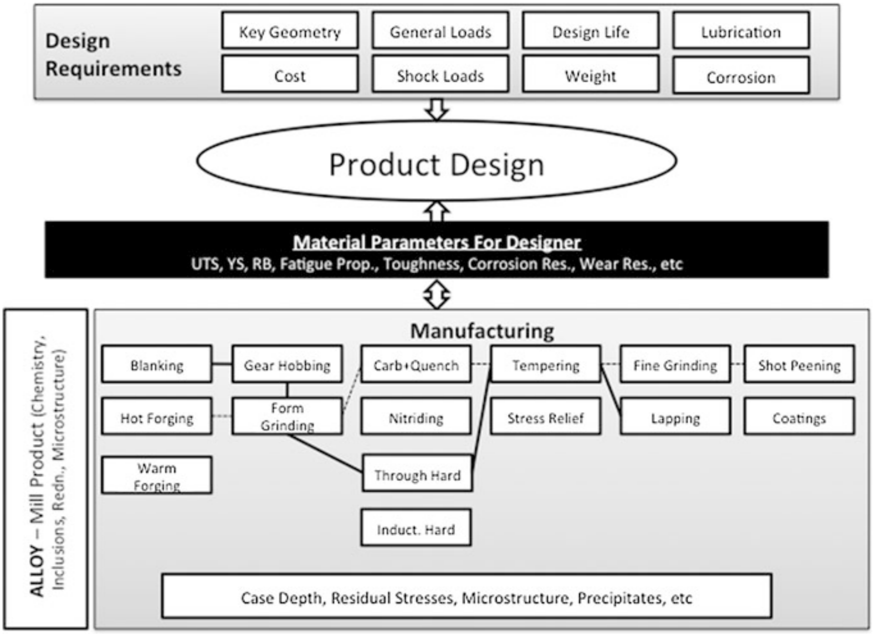


Fig. 3 Interaction between design and manufacturing for gears

process due to lack of appropriate tools. An ICME platform such as PREMΛP is expected to facilitate this.

As illustrated in Fig. 4, a number of alternative paths are possible to achieve the final desired properties and a systematic evaluation of some of these can lead to a more cost effective design. Besides this advantage, such an enablement can reduce the dependence on empirical correction factors of AGMA (American Gear Manufacturers Association) to lead to better designs, effectively bringing in a paradigm shift in gear design. When the simulation chain also incorporates "virtual testing" (e.g., simulation of operating conditions incorporating fracture phenomena), it may lead to discovery of new failure modes, not addressed in standard design procedures, when designs are significantly modified from the range of standards (e.g. slender teeth to reduce noise may lead to a new failure mode called tooth interior fatigue failure [13]).

Tools for addressing a subset of the above problems to establish and demonstrate such an approach for gear design and manufacture are being developed on PREMΛP. Here we concentrate on one major manufacturing path with two key manufacturing processes, carburizing and tempering. These are linked to AGMA based material design and fatigue analysis for design and virtual testing segments, as illustrated in Fig. 4. The purpose of this exercise is to carry out geometric design, material selection and manufacturing process parameters in a closed loop for overall cost reduction. This will be put in a formal decision support framework through use of compromise decision support problem (cDSP) framework for

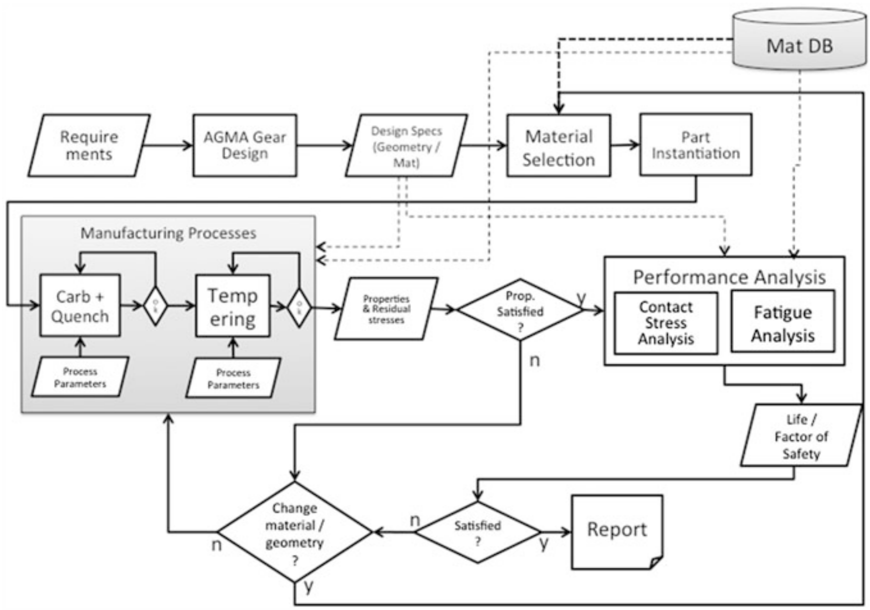


Fig. 4 Flow chart for the integrated gear design

obtaining good engineering solutions to meet the required targets. A companion paper, third in this series [10] illustrates the application of cDSP for a subset problem consisting of geometric design and material selection.

In Fig. 4, the key functional and performance requirements, constraints and other information are captured in the requirements block. The AGMA gear design block allows a geometric design and specification of material requirements. Subsequently, material selection will be carried out from the database. With the information on geometry and material, a gear part will be instantiated in appropriate CAD format and FEA mesh in PREMΛP for further analysis. We simulate the carburization-quenching and tempering operations using thermo-mechanical-metallurgical models to predict the residual stresses, hardness and other material properties with point to point mapping. The output of these simulations will subsequently be used in stress and fatigue analysis. Here we use standard empirical relations to link the hardness to fatigue strength and also incorporate the effect of residual stresses. This linkage allows the designer to check the feasibility of various combinations of manufacturing process parameters and make informed decisions and further use in virtual testing to verify design in an iterative mode.

At various stages, knowledge engineering tools guide selection of appropriate parameters. For illustration, the user would get guidance on appropriate temperature and time for carburization through simple formulae, which are input for detailed simulation so that even if the user is not very familiar with the process, he/she will start with a reasonable combination. Armed with this information, a designer can either modify geometry or material along with process parameters to improve the design (weight, cost, etc.). In future we will add more upstream processes such as gear blanking, machining etc., and the impact of the mill product state from the previous study will be incorporated.

5 Closing Remarks

In this paper we introduced PREMΛP a platform, being developed by Tata Consultancy Services, for concurrently discovering and designing new materials, manufacturing processes and engineered components. With the advent of modeling and simulation tools and other enabling technologies from the information technology field such as knowledge engineering, the future of materials, manufacturing processes and product design is set to make a paradigm change. PREMΛP is being developed to fulfill this vision. Various aspects of PREMΛP such as usage scenarios, its segments and its architecture are briefly discussed. In the next two papers in this sequence we introduce two problems of relevance to industry that are being developed as test examples for PREMΛP and outlined how we propose to use a combination of modeling and simulation tools along with knowledge engineering and decision support tools in these cases. This paper also sets the context for three related papers on using cDSP and knowledge engineering framework in PREMΛP.

Acknowledgments The authors acknowledge the management of TCS for encouraging this research. The authors acknowledge various colleagues who have contributed to this endeavor through discussions and suggestions. Farrokh Mistree acknowledges financial support from the L.A. Comp Chair at the University of Oklahoma.

References

1. Ashby MF (2005) Materials selection in mechanical design. Butterworth-Heinmann. ISBN: 9780750661683
2. Pollock TM, Allison J (2008) Integrated computational materials engineering: a transformational discipline for improved competitiveness and national security. The National Academies Press, National Research Council, Washington, D.C
3. McDowell D, Panchal J, Choi H-J, Seepersad C, Allen J, Mistree F (2010) Integrated design of multi-scale, multifunctional materials and products. Elsevier Inc, New York. ISBN 9781856176620
4. Fullwood DT, Niezgoda SR, Adams BL, Kalidindi SR (2010) Microstructure sensitive design for performance optimization. Prog Mater Sci 55:477–562
5. Rodgers JR, Cebon D (2006) Materials informatics. MRS Bull 31:975–980
6. Schmitz GJ, Prahl U (2009) Toward a virtual platform for materials processing. J Metals 61(5):19–23
7. Hirsch J (ed) (2005) Virtual fabrication of aluminium alloys. Wiley-VCH, Weinheim

8. Backman DG, Wei DY, Whitis DD, Buczek MB, Finnigan PM, Gao D (2006) ICME at GE: accelerating the insertion of new materials and processes. J Metals 58(11):36–41
9. Kumar P, Goyal S, Singh AK, Allen JK, Panchal JH, Mistree F (2013) PREMΛP—exploring the design space for continuous casting of steel. In: Proceedings of the 4th international conference on research into design, IIT Madras, Chennai, India, Paper no. 65
10. Kulkarni N, Zagade PR, Gautham BP, Panchal JH, Allen JK, Mistree F (2013) PREMΛP—exploring the design and materials space for gears. In: Proceedings of the 4th international conference on research into design, IIT Madras, Chennai, India. Paper no. 64
11. Bhat M, Das P, Kumar P, Kulkarni N, Ghaisas SS, Reddy SS (2013) PREMΛP—knowledge driven design of materials and engineering processes. In: Proceedings of the 4th international conference on research into design, IIT Madras, Chennai, India, Paper no. 66
12. Mistree F, Hughes OF, Bras BA (1993) The compromise decision support problem and the adaptive linear programming algorithm. In: Kamat MP (ed) Structural optimization: status and promise, Washington, D.C, pp 247–286 (AIAA)
13. Chen W, Allen JK, Mavris D, Mistree F (1996) A concept exploration method for determining robust top-level specifications. Eng Optimiz 6:137–158
14. Şimşir C, Hunkel M, Lütjens J, Rentsch R (2012) Process-chain simulation for prediction of the distortion of case-hardened gear blanks. Materialwiss Werkstofftech 43:163–170
15. Mackadlner M (2001) Tooth interior fatigue fracture & robustness of gears. PhD Thesis, KTH Sweden
16. "Gear Industry Vision: A vision for the gear industry in 2025." (http://agma.server294.com/images/uploads/gearvision.pdf). Accesed on 27 May 2012

PREMΛP: Knowledge Driven Design of Materials and Engineering Process

Manoj Bhat, Sapan Shah, Prasenjit Das, Prabash Kumar, Nagesh Kulkarni, Smita S. Ghaisas and Sreedhar S. Reddy

Abstract In this paper, we present the knowledge engineering aspects of an IT infrastructure for a Platform for Realization of Engineered Materials and Products (PREMΛP). PREMΛP enables harnessing available knowledge, learning emerging knowledge and continually creating new knowledge. It consists of an ontology-based, knowledge-assisted method and platform to capture, structure, configure and reuse knowledge for designing materials and engineering systems. The PREMΛP ontology provides extensible representation of data and knowledge. The semantic mappings of concepts in the ontology are used to draw inferences and provide pro-active guidance while designing manufacturing processes and selecting parameters to meet the product specification that addresses a given engineering problem. We show how the ontological models can help in (a) automating process design starting from a requirements statement to selecting a suitable design process and (b) creating a parameterized instance of the selected

M. Bhat · S. Shah · P. Das · P. Kumar · N. Kulkarni · S. S. Ghaisas · S. S. Reddy (✉)
Tata Consultancy Services, Pune 411013, India
e-mail: sreedhar.reddy@tcs.com

M. Bhat
e-mail: manoj.bhat@tcs.com

S. Shah
e-mail: sapan.hs@tcs.com

P. Das
e-mail: prasenjit.d@tcs.com

P. Kumar
e-mail: kumar.prabhash@tcs.com

N. Kulkarni
e-mail: nagesh.kulkarni@tcs.com

S. S. Ghaisas
e-mail: smita.ghaisas@tcs.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_105, © Springer India 2013

process. In the context of two engineering examples, namely, the simultaneous design of a gear and the steel from which it is to be made, we illustrate the salient features of knowledge driven design.

Keywords Material design · Manufacturing processes · Ontology and knowledge engineering

1 Introduction

Knowledge of structure–property relationships is at the heart of material science. Properties such as strength, hardness, toughness are the consequence of the material microstructure. Materials engineers experiment with compositions and processes in order to arrive at the right microstructure and thus the desired properties. But the structure–property relationships are not well understood;—especially across multiple length scales. While physics-based models do exist for some materials and phenomena, for many others there are no such models and one has to rely on experiential knowledge, past cases and rules of thumb. A lot of research has gone into this area over the years, a lot of results have been published and experimental data has been generated. A wealth of useful knowledge can be gleaned from these results, and insights can be drawn if this data is systematically collected and mined. PREMΛP is an attempt to accomplish this [1].

Knowledge guided process design is one of the core activities within PREMΛP. Different processes may be used for different purposes. Also, models of different levels of accuracy may be used within a given process—an approximate model for quick answers, and a detailed simulation model for more precise answers. The ability to set up such process chains, and carry out simulations is an integral part of the platform.

The vision for PREMΛP is to build a comprehensive knowledge base of materials, components and manufacturing processes, and use this knowledge to (1) significantly accelerate the design and development of materials and manufacturing processes, (2) significantly improve component design practice by integrating material information into the design process. Knowledge of different kinds needs to be captured: material composition, microstructure and properties; manufacturing processes and their effects on material structure and properties; component models, their design requirements and so on. This knowledge exists in a variety of forms: factual data, design guidelines, rules of thumb, process templates, simulation models, empirical models, case histories, and so on. This knowledge has to be captured and structured so that it can be effectively utilized, bringing the correct knowledge to bear on the right problems. It should effectively guide different stakeholders in their respective activities, such as capturing product specifications, setting up the manufacturing process chain, selecting input materials, executing and optimizing the process chain, and so on. A high quality ontology is a critical foundation to this kind of a platform.

So also is a high quality infrastructure for data extraction and integration. Data comes from a variety of sources such as online databases, manufacturer's catalogs and publications, in a variety of forms such as tables, graphs, diagrams and so on. It has to be extracted from all these sources and integrated. Also, data is produced in a variety of contexts, such as an experimental context and application context, etc. It is critical to identify these contexts, because data from one context may not be applicable in another context. We expect the PREMΛP platform itself will produce a lot of data as a part of process design simulation and lab experiments. This data also has to be captured and integrated with rest of the data.

In order to support all these things, the platform should have a highly flexible and open architecture. It should be possible to add new processes, models, rules, procedures, and so on without modifying the code of the platform. It should also be possible to add new simulation tools without affecting the rest of the infrastructure. Similarly it should be possible to add new data sources without changing the data architecture. Ideally, all these elements should be first class artifacts in the knowledge base, so that one can simply pick them up and use them as required, without having to hardwire them into the platform.

The rest of the paper is organized as follows. In Sect. 2 we present two materials engineering problems, namely, development of steel mill products and gear design, and discuss their knowledge requirements [2, 3]. This sets the context for subsequent sections. Section 3 presents the ontology for the materials engineering domain. In Sect. 4, we discuss the knowledge engineering required for PREMΛP. Section 5 presents the platform architecture and discusses its components. Section 6 discusses data extraction and integration. In Sect. 7 we discuss related work, and Sect. 8 concludes the paper.

2 Sample Design Scenarios

2.1 Gear Design

Figure 1 gives an overview of the gear design process.

This process template is specific to gear design. Similarly other engineering components have their own specific templates. The knowledge base should have the flexibility to store such component specific process templates. It should be possible to easily add new components and corresponding process templates, thus extending the capabilities of the platform.

The steps in Fig. 1 are as follows:

1. Requirements specification: The requirements are specified in terms of parameters such as rated torque, rated speed, reduction ratio, weight, cost and smoothness. Performance requirements such as fatigue life are also specified.

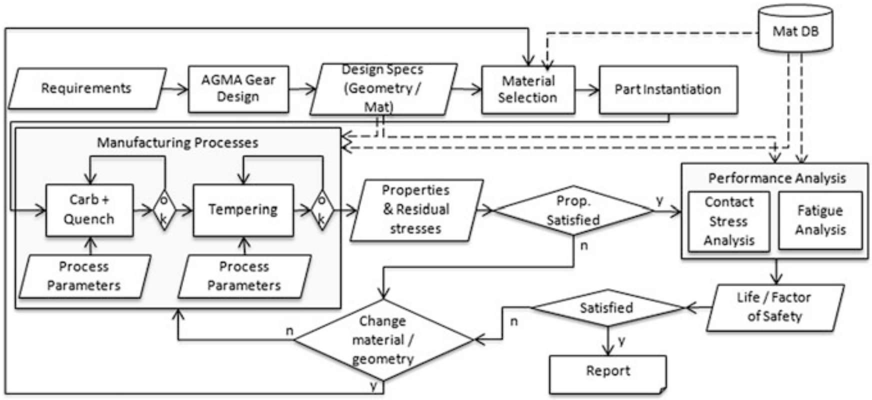


Fig. 1 Gear design process [3]

These are gear specific requirements. Similarly other components will have their own specific requirements. The knowledge base should provide the flexibility to capture component-specific requirements; so that while designing a component we know which requirements to select. There should be an ontology for capturing component specific requirements.

2. Gear design: To compute design parameters such as module, number of teeth, face width, addendum, dedendum, strength and hardness required, American Gear Manufacturers Association (AGMA) [4] guidelines are used. These guidelines are available as a set of rules. Knowledge base should store these rules, and these rules should be invoked when we reach this step in the process. Alternatively one might use an instantiated compromise Decision Support Problem (cDSP) [5] which internally invokes AGMA rules in order to determine the parameters. In [3] we have described this step in detail. We have explored gear geometry and material space using the cDSP construct. Different practical gear design scenarios are created (in cDSP) and solved using DSIDES.
3. Materials selection: Candidate materials for the given strength and hardness are selected. This information should be available in the database.
4. Carburization and quenching: We need to select design parameters such as carburization potential, carburization time, carburization temperature, diffusion time and diffusion temperature. There may be a set of rules that can determine these parameters based on property requirements. Once these parameters are selected, we can simulate the carburization and quenching process using an appropriate simulation model. Therefore, associated with the process step we need several elements in the knowledge base: process design parameters, rules to compute these parameters, an approximate model to compute them, and a simulation model to simulate the process. The knowledge base should be extensible enough to accommodate new processes, design parameters, rules and models. At the end of a simulation run, if we find that the requirements are not met, we may want to repeat the process by changing the design parameters.

There are a set of rules in the knowledge base that determine how the parameters should be changed.

Similar knowledge requirements exist for the subsequent process steps as well.

Another important requirement is an ontology for describing microstructure. The output of several of the simulation steps is a description of the microstructure. For instance, *carburizing and quenching* produces an output microstructure that goes as input to the tempering process. Knowledge about the microstructure consists of elements such as crystal structure, grain size, grain boundaries, vacancies, dislocations, segregations, inclusions and so on. This structure has to be available at the right level of detail so that one can reason (manually or with automation) about it. These indicate the need for an ontology that is specifically designed for modeling the microstructure.

We do not discuss the rest of the process due to space considerations, but the requirements on the knowledge base and platform should be clear from the description above. The design of gear using PREMΛP is discussed in detail in Ref. [3].

2.2 Development of Steel Mill Products

We want to be able to support three different use cases for development of steel mill products. These cases are discussed briefly here.

Case 1: For a given steel grade and requirements, find out a suitable process route, operating parameters and design modifications if any in an existing plant configuration.
Case 2: For a given requirement, find out suitable grades, process route, operating parameters and design modifications in an existing plant.
Case 3: Incorporation of new technology and unit operations for stretching existing plant capacities and suggesting new configuration.

Figure 2 highlights the information flow for these use cases. These three use cases need different information flows, and therefore need three variants of a process template. Hence the knowledge base should support storage of different use cases and use case specific process templates.

The process chain has several processing steps such as ladle, tundish, casting, annealing, rolling, etc. which are discussed in Ref. [1]. The knowledge requirements of these processes are similar to those for carburizing and quenching above. Suffice it to say that for each of these processes we need to capture design parameters, rules/models to set these parameters and simulation models. A part of process chain for development of steel mill products, exploration of design space for slab casting has been discussed in detail in Ref. [2]. We use cDSP to explore the space of design parameters such as super heat, casting speed, mold oscillation frequency, cooling conditions and so on to meet productivity and quality requirements.

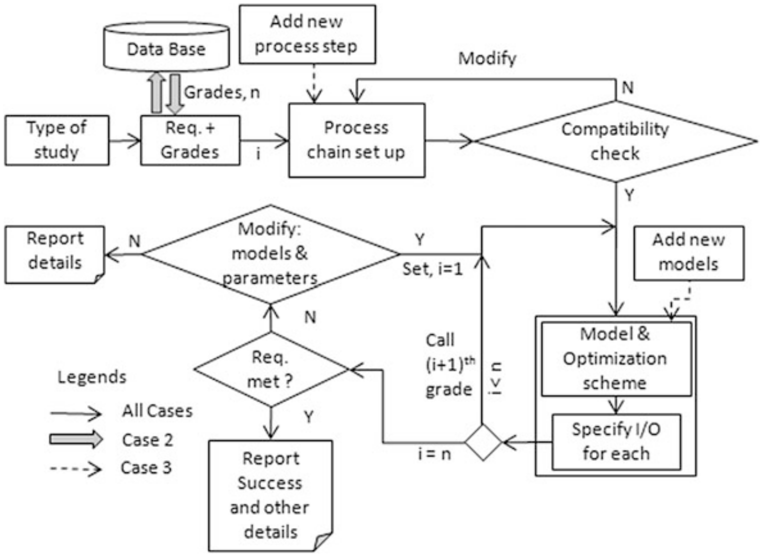


Fig. 2 Development of steel mill products

3 Ontology

The examples above emphasize that PREMΛP needs to extract and store different kinds of knowledge such as material compositions, their properties, material structure, manufacturing processes, their design parameters, rules, models of different kinds (approximate models, simulation models), engineering components, their specifications, component design process templates and use case specific process templates. The foundation to facilitate this can be provided by formalizing the information in terms of an ontology. The ontology can then serve as the basis for building different kinds of knowledge elements and associated knowledge services.

Ontologies are extensively used to capture the shared understanding of a domain by defining concepts, properties and relationships between them. Ontologies are machine-interpretable and enable reasoning. They enable reuse of domain knowledge and provide semantic interoperability between resources, services, databases, and tools [6]. PREMΛP ontology is categorized into Material, Process and Product ontology.

While evolving the ontologies we considered the following view points:

- The engineering goals of the platform, namely integrated design of materials, components and processes
- Views of stakeholders such as researchers, designers and platform builders.
- Physical phenomena that govern the engineering processes.
- Evolutionary nature of structure and properties across multiple length scales.
- Modeling of the above at different levels of precision.

We considered different design scenarios of the two example problems and held extensive discussions with subject matter experts to arrive at the structure and organization of different parts of the ontologies and their relationships.

We are in the process of validating the correctness and completeness of these ontologies by building proof of concept implementations.

3.1 Material Ontology

The Material ontology captures information related to materials, material structure and material properties along with various associations including structure–property relationships. The partial model of the Material ontology is represented using UML notation in Fig. 3.

The *iMaterial* represents the material in its bulk state. It is associated with the *form* (bar, sheet, billet, etc.) and *state* (solid, liquid and gas). The evolution of microstructures and properties of the materials are captured at each *representative unit*. The *representative unit* is classified as *point* and *representative volume element* with specific shape. A *material* and a *phase* within a *material* have specific *composition* which is classified as *element* and *compound composition*. The *composition* of the material is expressed as *element composition*, *compound composition* or both. For instance, the chemical composition of AISI 8620 steel

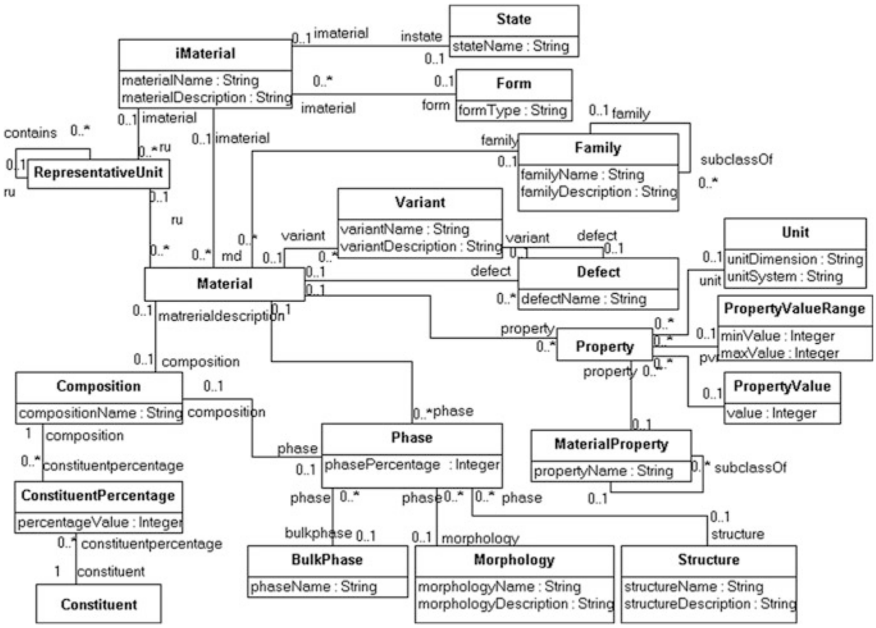


Fig. 3 Material ontology

could be *element*: Carbon (typical value: 0.2 %, range: 0.18–0.23 %) and *element*: Chromium (typical value: 0.5 %, range: 0.4–0.6 %). The constituent percentage of oxides of Aluminum, Manganese, Ferro-chromium or Ferro-manganese is captured. The microstructure of the material consists of *bulk phases* (Ferrite, Martensite, Austenite, Cementite, Pearlite and Bainite), *inclusions* and *precipitates*. Each of these *phases* has attributes such as *phase percentage* and *phase distribution* and is associated with *morphology* (lath, plate), *structure* (crystalline or amorphous) and *composition*. A *material* has specific *properties* which are broadly classified into *mechanical*, *physical*, *thermal*, *chemical*, *electrical*, *biological*, etc. which are further sub-classified. Each property has measurable value or range of values and associated units.

3.2 Process Ontology

The Process ontology explicates material and manufacturing processes along with property-process and process-performance relationships at different length scales (ranging from nanometer onwards to macro). The partial model of the Process ontology is represented using UML notation in Fig. 4.

Process ontology provides placeholders to capture the *processes* and *sub-processes* along with their *inputs* and *outputs*. For instance, *ladle* has *degassing* and *desulphurization* as *sub-processes*. The input and output associated with a *process* is an aggregation of properties and characteristics of one or more *work-material*, *non-work material*, *equipment*, *process* and *simulation tool*. The concepts are further detailed in the ontology to meet the framework's requirements. For instance, *simulation control* is classified as *mesh control parameter*, *time step*, *contact tolerance* and *convergence tolerance*.

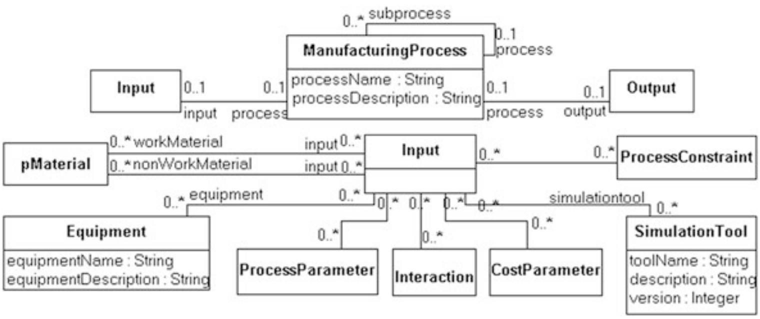


Fig. 4 Process ontology

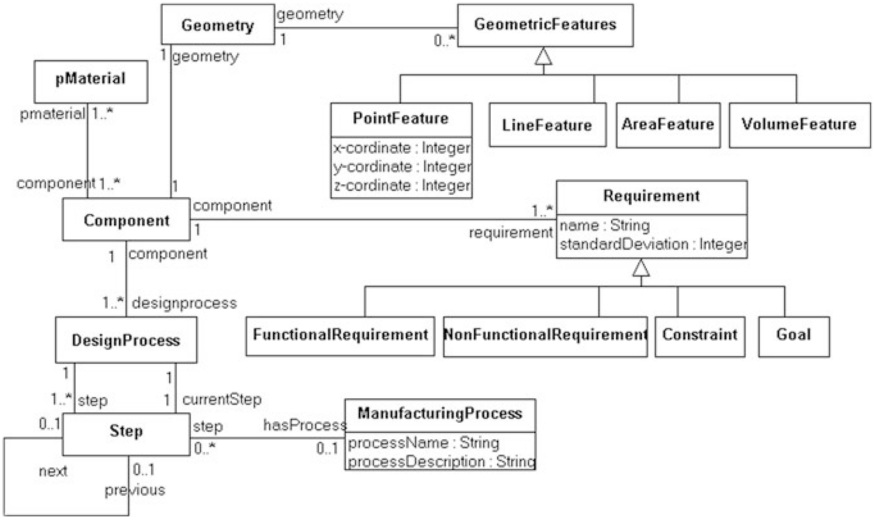


Fig. 5 Product ontology

3.3 Product Ontology

The Product ontology captures the problem description and the product specifications. The focus of the Product ontology is to facilitate product designers to capture the end *requirements* of the components. *Requirements* are classified as *functional requirements*, *non-functional requirements*, *goals* and *constraints*. For example *gear* has *geometry* which has one or more *geometric features* such as *pitch points*, *tip points*, *root points*, *line features*, *area features* and *volume features*. The partial model of the Product ontology is depicted in Fig. 5.

4 Knowledge Services

Knowledge services provide a mechanism to interact with the knowledge base of the PREMΛP framework. These are published as web services so that any authorized external entity can use them to access the knowledge base. Knowledge needs of different stakeholders are discussed in paper 1 [1]. A knowledge service may need to reason across multiple knowledge elements such as rules, cases, equations, models and so on, to satisfy a given knowledge requirement. We have a knowledge service modeling mechanism (Fig. 6) that allows us to compose services that use knowledge elements spanning across multiple representation formalisms. A knowledge service is specified as a procedure with a number of steps, each of which is implemented by a knowledge element. Different knowledge representation mechanisms such as database, rule base, case base, equations and

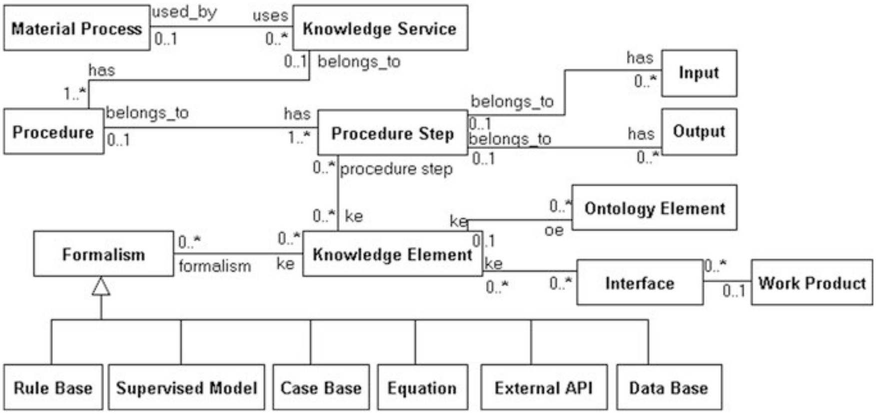


Fig. 6 Knowledge service

models need to be supported. Ontology provides the common vocabulary for expressing knowledge in all these forms.

To illustrate knowledge services, let us consider an example from the gear design problem. The first step in the gear design process is to select gear type such as helical, spur, bevel, etc. depending on requirements for power transfer capacity and direction. The selection is done by using a set of rules. This requires a rule engine to be invoked. We also use a knowledge service to determine design parameters such as billet geometry, austenization temperature, forging temperature, etc. This is achieved by solving a set of equations using an equation solver.

5 Platform Architecture

The PREMΛP platform is designed as a set of components plugged into the central integration bus. Each component offers specific functionality. The integration bus acts as a communication channel between the components. The platform is extensible and enables plug-in of new components to the integration bus to satisfy custom requirements. The newly added components will be able to interact with other components. Figure 7 shows the high level view of the PREMΛP platform architecture.

5.1 Knowledge Base

The knowledge base is the central information repository. It provides knowledge services to access the knowledge. The knowledge pertaining to materials, processes and products are captured in PREMΛP ontology which is classified into Material, Process and Product ontology.

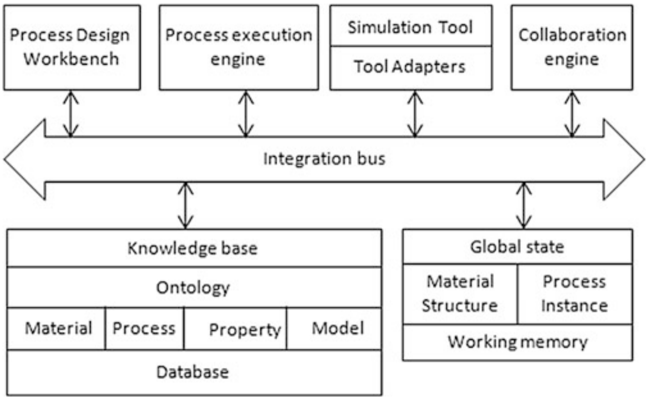


Fig. 7 PREMAP platform architecture

5.2 Process Design Workbench

The process design workbench enables definition of new material engineering processes. Existing process templates can be suitably customized and reused or entirely new processes can be defined. The workbench captures the material engineering processes in a notation similar to business process model notation (BPMN) [7]. Suitable services are bound to the activities in BPMN to enable execution of simulation tools, etc. These processes are executed by the process execution engine.

5.3 Process Execution Engine

This component uses a general purpose business process execution engine. The capabilities of this component are exposed as platform services. There are services to start execution of a defined material engineering process, to abort the execution and to check the status of process execution.

5.4 Global State

Global state is used as a working memory for tracing the evolution of material state during process execution. A process instance reads from and writes to the global state. If the desired state is not achieved one can go back and modify the design parameters and rerun the simulation. At the end of execution, the global state holds the final material state generated by the material engineering process. This information can be verified by an expert and saved to the knowledge base if deemed suitable.

5.5 Tool Adapters

Tool adapters allow the integration of external simulation tools with the PREMΛP platform. The capabilities of the platform can be extended by plugging in new tools through tool adapters. Once the new adapter is registered in the platform, the new tool is available to the platform and the same can be used during process definition.

5.6 Collaboration Engine

The collaboration engine allows various stakeholders such as material scientists, process and product designers to work collaboratively. The collaboration engine addresses the gaps that exist between material scientists and product and process designers by providing an integrated collaborative environment.

6 Data Extraction and Integration

Data comes from a variety of sources such as online databases, manufacturers' catalogues and publications. It is produced in a variety of contexts such as research context, experimental context, application context, and so on. It has to be extracted from all these sources and integrated into the PREMΛP database. Figure 8 shows the architecture of the data extraction and integration component. The component uses ontology mappings as a conceptual framework for integration. PREMΛP ontology provides a unified conceptual view of the data that exists in the database. Each source has a context specific ontology that provides a conceptual view of the data content available at that source. We map these source ontologies to the PREMΛP ontology to specify how their data should be integrated into the PREMΛP database. A source specific wrapper extracts data from the source and presents it as an instance of the source ontology. The architecture provides a flexible means for adding new data sources into the platform.

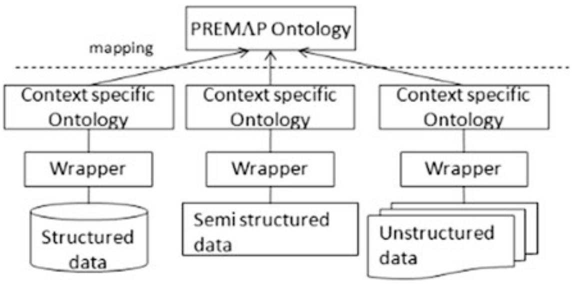


Fig. 8 Data extraction and integration architecture

7 Related Work

Work has been reported on (a) capturing and structuring knowledge for semantic interoperability in materials domain (b) providing an integrated platform for simulation and optimization of materials processing. MATML [8] is a well-known materials markup language proposed for information exchange. MATONTO [9] is based on DOLCE upper ontology [10] and builds on MATML and the works of Ashino [11] and Tanaka [12]. It classifies the knowledge of materials domain in an ontological framework. Materials Ontology [13] captures various concepts of materials structure, property, environment and processes. These models provide a unified representation to integrate heterogeneous data sources. However, they fail to address several important aspects such as microstructure of materials and process-structure–property relationships. Additionally, they do not address aspects relevant to engineering of components. They also do not provide constructs for capturing knowledge elements such as rules, cases, approximate models and so on. PREMΛP ontology addresses these.

Integrated Computational Materials Engineering (ICME) is identified as a strategic approach for future competitiveness [14]. It aims to integrate computational materials science tools into a holistic system that can accelerate materials development and unify design and manufacturing processes. The benefits of ICME have not yet been realized to its full potential in terms of significant reduction in time and cost involved in material and process development [15]. The ICME platform discussed in [16] lacks the product designers' perspectives. It also lacks the capability of knowledge guided process design, and knowledge engineering to learn from data and experimental results. The PREMΛP platform provides these capabilities.

8 Closing Remarks

In this paper, we have outlined the realization of the vision [1] for an integrated materials engineering platform–PREMΛP. To the best of our knowledge this is the first ever attempt that comprehensively addresses knowledge-critical core processes in the materials engineering value chain. In this context, we make three specific contributions to the materials engineering domain at large: (1) Foundational ontologies to formalize and organize domain knowledge, (2) Mechanisms for context-specific data retrieval and presentation and (3) A platform to seamlessly integrate process, data and simulation models.

The foundational ontologies provide a robust and extensible formalism to structure knowledge. The data extraction component maps varied sources of data onto this formalized structure and provides a context-specific view of relevant data to stakeholders. Finally, the platform architecture provides for mapping of target requirements onto appropriate processes, relevant materials knowledge and data needs and thus facilitates exploring of design spaces to arrive at solutions acceptable both in terms of their quality and economy.

The two illustrative examples bring out the need for a flexible and extensible design of a platform such as PREMΛP so that it can be employed to achieve target properties in materials and components in a variety of design scenarios. We have also discussed how PREMΛP can be used to iteratively (1) design engineering processes (2) experiment with process parameters (3) execute processes and verify outcomes.

With realization of PREMΛP, we hope the materials engineering domain can benefit from harnessing available knowledge, learning emerging knowledge and continually creating new knowledge.

Acknowledgments We thank Professor Farrokh Mistree, Professor Janet K. Allen and Dr. Jitesh Panchal for their valuable suggestions and comments.

References

1. Gautham BP, Singh AK, Ghaisas SS, Reddy SS, Mistree F (2013) PREMΛP—a platform for the realization of engineered materials and products. In: Proceedings of the 4th international conference on research into design, IIT Madras, Chennai, India. Paper number: 63
2. Kumar P, Goyal S, Singh AK, Allen JK, Panchal JH, Mistree F (2013) PREMΛP—exploring the design space for continuous casting of steel. In: Proceedings of the 4th international conference on research into design, IIT Madras, Chennai, India. Paper number: 65
3. Kulkarni N, Zagade PR, Gautham BP, Panchal JH, Allen JK, Mistree F (2013) PREMΛP—Exploring the design and materials space for gears. In: Proceedings of the 4th international conference on research into design, IIT Madras, Chennai, India. Paper number: 64
4. "Design Guide for Vehicle Spur and Helical Gears", ANSI/AGMA 6002-B93
5. Rolander N, Rambo J, Joshi Y, Allen JK, Mistree F (2006) An approach to robust design of turbulent convective systems. J Mech Des 128:844–855
6. Chandrasekaran B, Josephson J, Benjamins V (1999) What are ontologies, and why do we need them? IEEE Intell Syst 14:20–26
7. White SA (2004) Introduction to BPMN. BPTrends, July
8. Begley EF (2003) MatML version 3.0 schema. NIST 6939, National Institute of Standards and Technology Report, USA, Jan 2003
9. Cheung K, Drennan J, Hunter J (2008) Towards an ontology for data-driven discovery of new materials. AAAI workshop on semantic scientific knowledge integration, Stanford University, pp 26–28
10. Gangemi A, Guarino N, Masolo C, Oltramariand A, Schneider L (2002) Sweetening ontologies with DOLCE. In: Proceedings of the 13th international conference on knowledge engineering and knowledge management. Ontologies and the Semantic Web. Springer-Verlag
11. Ashino T, Fujita M (2006) Definition of a web ontology for design-oriented material selection. Data Sci J 5:52–63
12. Tanaka M (2005) "Toward a proposed ontology for nano-science", CAIS/ACSI: data, information, and knowledge in a networked world. The University of Western Ontario, London
13. Ashino T (2010) Materials ontology: an infrastructure for exchange materials information and knowledge. Data Sci J 7:54–61

14. Committee on Integrated Computational Materials Engineering, National Research Council (2008) Integrated computational materials engineering: a transformational discipline for improved competitiveness and national security. National Academic Press, Washington, DC ISBN:0-309-12000-4
15. Bradford AC, Backman D (2010) Advancement and implementation of integrated computational materials engineering (ICME) for aerospace applications. Interim Report, DTIC Document, March 2010
16. Schmitz GJ, Benke S, Laschet G, Apel M, Prahl U, Fayek P, Konovalov S, Rudnizki J, Quade H, Freyberger S, Henke T, Bambach M, Rossiter EA, Jansen U, Eppelt U (2009) Towards integrative computational materials engineering of steel components. JOM 61(5):19–23

Bridging the Gap: From Open Innovation to an Open Product-Life-Cycle by Using Open-X Methodologies

Matthias R. Gürtler, Andreas Kain and Udo Lindemann

Abstract Open-X methodologies describe the application of Open Innovation to different stages of the Product-Life-Cycle (PLC). Open Innovation deals with involving external players in a company's innovation process. Those can provide ideas from any stage of the PLC, such as lead users in the development stage or product-users in the utilization stage. These ideas themselves can initiate innovations in any PLC stage. However, this typically affects the development of new products. This means that ideas collected are incorporated into early PLC stages only. There is significant potential in using ideas not only for early stages but also for later stages, which means for existing products. Open-Utilization, as one form of the Open-X methodologies, can create innovations in the form of upgrades or new services for a product. Because respective PLC stages are not equally suitable for Open-X methodologies, this paper presents an assessment concept for evaluating each PLC stage regarding their Open-X capabilities and possible constraints. To illustrate the utility of the assessment concept, this paper identifies two PLC stages which demonstrate exemplary capacity for Open-X methodologies.

Keywords Open-X methodology · Open innovation · Product life cycle

M. R. Gürtler (✉) · A. Kain · U. Lindemann
Institute of Product Development, Technische Universität München,
Boltzmannstraße 15, Garching D-85748, Germany
e-mail: guertler@pe.mw.tum.de

A. Kain
e-mail: kain@pe.mw.tum.de

U. Lindemann
e-mail: lindemann@pe.mw.tum.de

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_106, © Springer India 2013

1 Introduction

Open Innovation opens a company's innovation process to its environment [1]. This means new innovations are no longer solely created in isolated R&D departments but with the support of actively integrated customers, suppliers, other companies or even competitors. We can distinguish between two possible kinds of innovations according to the flow of information: (1) the outside-in innovation, which uses external knowledge for the development of new or improved products, and (2) the inside-out innovation, which specifically gives information to the environment to enable external innovations [2].

Till this point, the research in this area has mainly been driven by economists such as Henry Chesbrough, Eric von Hippel, Ralf Reichwald, Frank Piller and others. These economists normally stopped short of considering the transition from the economic concepts to the technical realization. Engineering research started filling this gap by operationalizing and adapting those concepts in practical use [3, 4]. Currently the main research focus is on the early stages of the Product-Life-Cycle (PLC) such as the Open-Product-Development.

Thus far, examinations of the entire PLC from the perspective of engineering science have been rudimentary, at best. Howard mentions the relevance of considering the entire PLC from the view of the design stage by, for example, collecting information concerning later stages such as disposal [3]. Though the information relates to all stages of the PLC and can be gained from each stage, it is mainly used for the development of new products—which means an application in the early stages like concept or development. An application to existing products—in later PLC stages—is widely neglected, as illustrated in Fig. 1.

In the eyes of the authors this is a huge deficiency: although the early stages are of great importance in determining the costs of later stages, as shown in Fig. 2, these costs primarily appear in later stages. Concepts like Systems Engineering already consider the whole PLC but also only from the point of development.

Mistakes made in early stages might lead to high (changing) costs in later stages. Also, varying customer needs, changing markets or new technologies can

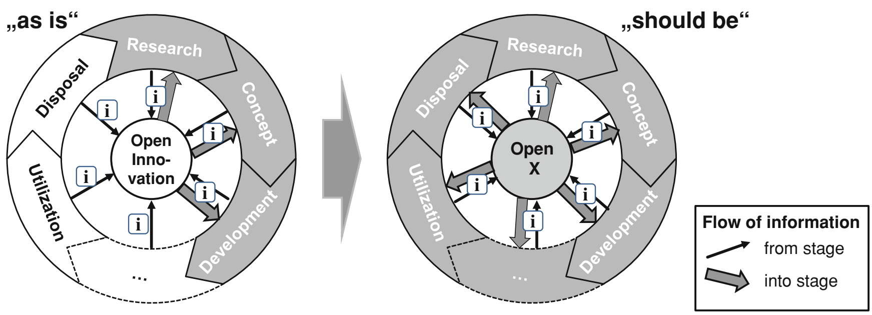


Fig. 1 Application of gained information in every stage of the product-life-cycle

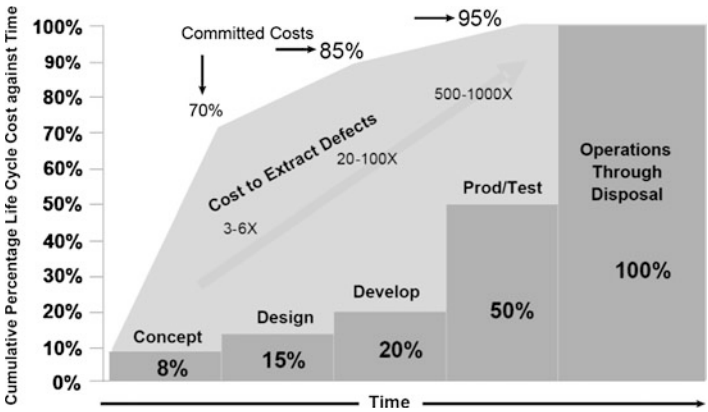


Fig. 2 Committed life cycle cost against time [6, Figs. 2–3]

cause product adoptions. With this, Open-X methodologies bear the potential for near-term improvements in later stages: for example Open-Utilization can help creating product updates or new services. As shown in Fig. 1, information which is gained all over the PLC should be used not only in early stages but across the entire PLC.

However, each stage has its own characteristics and requirements to Open Innovation methods: the range from the internal information being published, the retaining of intellectual property, supporting processes inside the company, and so on. Braun stresses the importance of defining in advance which stages of the innovation process are possible, advisable or necessary to be opened [5]. Due to the complexity that arises when all characteristics are considered, this is not a trivial task. Hence, there exists the need for a method to determine those aspects. This paper presents an evaluation sheet as part of an assessment concept to examine the characteristics of each stage of the PLC and analyze possible points of application for Open-X methodologies.

The following chapter introduces the relevant stages of the Product-Life-Cycle considered in the Open-X approach.

2 The Product Life Cycle

This section briefly presents the single stages of the Product-Life-Cycle (PLC). To design the Open-X approach on a workable foundation it is based on the Systems Engineering concept and its PLC considerations [6]. The Systems Engineering approach is widely accepted and used in research as well as in industry. Thus, the following examination is oriented towards the stages considered in Systems Engineering (shown below).

In this context a product also includes Product-Service Systems which consists of a technical product part and an intangible service part [7], as we expect a broad understanding of a product to support our PLC analysis. Figure 3 illustrates the enhancement of Chesbroughs' innovation process funnel [1] towards an entire Product-Life-Cycle view. The inner cycle symbolizes the company with its PLC stages and superordinate units such as organization, (long term) strategy and structure. The outer cycle illustrates the company's environment. Through the permeable borders innovations can be exchanged.

The following section gives a rough overview of the PLC. Due to spatial constraints the overview is restricted to half of the stages. For more detailed consideration please see the literature referenced in this paper.

2.1 (Product) Development

The purpose of the Development stage is to design a product that meets customers' requirements and is possible within the constraints of the company (e.g. available technologies, special production machines). In a classical innovation process the customer requirements are surveyed by the marketing department, preprocessed and transferred to the development department. This stage also constitutes strategies for integration, verification and validation of the designed product [6].

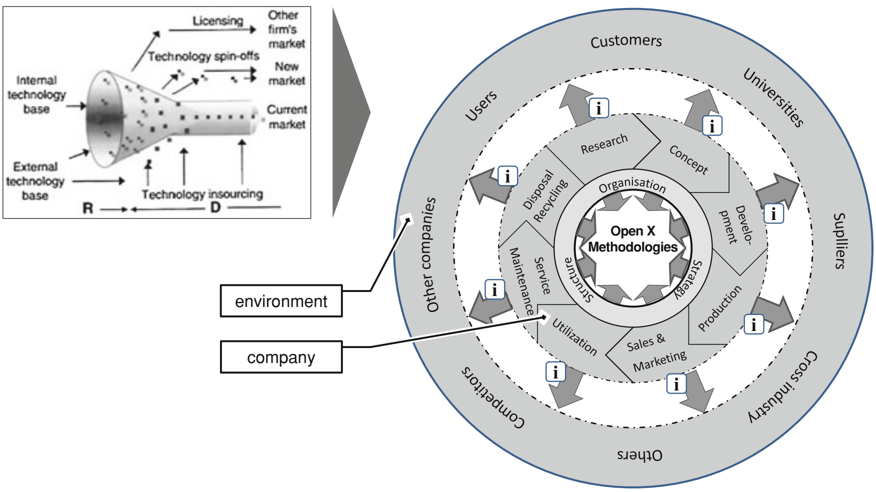


Fig. 3 Enhancement of open innovation towards the entire PLC (left figure after [1, Fig. 1.2])

2.2 Production

In the Production stage the previously designed product is manufactured, single components are assembled and the final product is tested. In some cases it might be necessary to modify the product to resolve production problems or enhance the product's capabilities [6].

2.3 Utilization

"The Utilization Stage is executed to operate the product, to deliver services within intended environments and to ensure continued operational effectiveness." [6]. To enhance the capability of a product upgrades might be designed and applied

2.4 Disposal and Recycling

This stage disposes of old products in an economic and ecofriendly way and provides supporting services. Normally planning for disposal is already part of the concept stage [6]. However, in the case of old products manufactured decades ago the disposal process can be challenging and expensive.

3 The Open-X Evaluation Sheet

As shown above, each stage has a different task in the innovation process, including different players, processes and resources. Thus, methods which are applicable for one stage might not fit to another due to specific characteristics and constraints. It is therefore not possible to give a blanket statement about the applicability of Open-X methods, demonstrating the need for a systematic analysis and assessment of each PLC stage.

The following section describes the structure and setup of the developed Open-X evaluation sheet as part of an assessment concept. The primary goal is supporting research to find possible points of application for Open-X methodologies and potential research areas. In a second step the evaluation sheet can also be used in industry for analyzing the potential benefits and threads of opening a specific PLC stage.

The sheet consists of five main categories which were determined by literature review and projects' experience. They are: actors, classification of innovation, effects, issue and provided information, and risks. Each main category comprises several first- and second-level subcategories, which are explained in more detail below. In this paper we focus on the outside-in innovation process due to its strong awareness in research and industries [8]. Our future considerations will deal with the inside-out innovation process as well.

3.1 Actors

This section describes: who can participate, how they can participate, how a company can access them and if there is a critical number of participants.

3.1.1 Participants

This category classifies the kind of external partner participating in the Open Innovation process in this stage of the PLC. It can be distinguished between random persons or experts [9]. It further differentiates between private persons and institutional participants as well as between direct or indirect customers or suppliers of the regarded company [10].

3.1.2 Accessibility to Participants

Closely linked to the kind of participants is the question of their accessibility. Is it sufficient to involve a random group of people or is it necessary to invite special groups with specific expertise, like Lead Users who might be determined in advance? [11].

3.1.3 Required Number of Participants

Depending on the issue and the stage of the PLC, either a small or a large number of participants might be suitable, which also directly affects cost and complexity.

3.1.4 Type of Participation

Depending on the issue, participants can support the innovation process with ideas/ information, services or even products.

3.2 Classification of Innovation

This section characterizes the types of innovation the opening of a specific stage can enable.

3.2.1 Target of Innovation

The innovation project can aim at a product (e.g. a new or improved product), a process (e.g. an improved distribution process) or an entire business case (e.g. the decision to enter a new market) [12].

3.2.2 Value Gain/Main Objectives

This section describes potential objectives for Open Innovation in this PLC stage. The corresponding Open-X project could target market share (e.g. by modifying the product portfolio), production (e.g. by lowering the costs, more flexibility), better insights in products' application and social and environmental improvements (e.g. less emission).

3.2.3 Type of Innovation

Innovation can either be incremental or radical. Incremental innovations are related to small improvements of existing products or processes, whereas radical or breakthrough innovations go along with fundamental changes [13].

3.3 Effects

Opening one stage can also affect other stages and can influence the whole company itself. These effects are discussed below.

3.3.1 Effects on Other PLC Stages

This category classifies the effect on other PLC stages resulting from changes in the stage being opened. Normally changes in early stages will affect all following stages. But changes in later stages might affect preceding stages, e.g. changes in the Production stage might lead to modified product architecture.

3.3.2 Possible Side Effects

The effects can be further distinguished as internal effects (e.g. on company departments), external effects (e.g. a better PR) and the impact on the company's network (e.g. on the supply chain).

3.3.3 Financial Effects

Each PLC stage should be analyzed as to whether extra value can be added to the product in this stage and if it is possible to gain direct revenue from this stage [adopted by 3].

3.4 Issue and Provided Information

In order to gain potential innovations by Open-X, the company first needs to provide some information by itself. The kind of information and its preparation is classified in the following.

3.4.1 Effort for Issue Definition

This section describes the effort and difficulty to define a suitable issue for an Open–X project and the amount of corresponding information needed to be published to ensure a sufficient result from a project. It also determines the kind of information, e.g. just text, photos, special data or a combination of them.

3.4.2 Complexity of Issue/Task

The complexity of an Open-X issue determines the kind of participants (e.g. a random crowd or a group of experts). Thus, it is essential to analyze the complexity of potential issues in each PLC stage.

3.4.3 Effort for Evaluating Gained Information

During the Open-X project a large amount of ideas and information will be collected. To operationalize them they need to be analyzed and categorized, and have useless items filtered out. Depending on the issue the evaluation can be carried out by a "random" employee, special experts, by a jury, or even by the participants themselves.

3.4.4 Transparency and Accessibility

In each PLC stage the quantity and quality of the information provided to the participants can differ along with the accessibility of information amongst the participants. For example, when considering critical parts or processes it might be expedient to publish little information and filter information gained by participants before giving them to the other participants.

3.4.5 Interaction/Feedback

This section deals with the question of whether interaction and feedback between the participants themselves as well as with the company or special experts might improve the outcome of the Open Innovation process [14].

3.5 Risks

This section describes potential risks that can occur by opening a PLC stage, which should be considered in advance.

3.5.1 Data Security/Knowledge Drain

This category defines the expected amount of information needed to be published to get a sufficient result. It also determines the degree of necessary confidential information.

3.5.2 Replicability of Accessible Information

This aspect deals with the question of whether participants or competitors can use the information provided by the company and the participants for their own business, or even for rebuilding the regarded product or system [3].

3.5.3 Strategic Risks

Here, possible strategic risks are determined. Risks include the drain of knowledge (company's knowhow as well as information from the Open-X project), the partial loss of system's control to participants or competitors [10], uncertainty of gained information, among others.

3.5.4 Possible Operative Barriers

To ensure the success of an Open-X project it is necessary to identify and classify possible interferences with the daily business and its impact on the company's processes and structures.

4 Examples: Open-Product-Development and Open-Disposal

To illustrate the concept and demonstrate its practical use, the Open-X evaluation sheet is applied to two examples from different PLC stages. The first one is located in the Development stage and is based on the experience from industrial idea contests. Here, two companies had developed new pre-products and were looking for innovative fields of application. For this they published a description and photos of their pre-product on an idea contest platform on the internet with the proposition: "What would you make out of…?" Here everyone was able to register and post their ideas.

The second example is generic and located in the Disposal stage. It considers the disposal of an old cargo ship designed and manufactured decades ago without caring about retirement or recycling issues. In this case, the fictitious shipping company looks for efficient, economic and ecofriendly ways to retire the old ship.

The choice of an early and a late stage will serve to emphasize the different characteristics of each stage. Due to space constraints just a part of the categories can be presented in detail (Table 1).

5 Discussion

As we can see, the Open-X methodologies bear great potential. For Open-Development this potential has already been verified by practical utilization in several industrial projects. Open-Development methods support the innovation process not only by gaining ideas for new fields of application, as shown in the prior example, but also with ideas for future products based on real stakeholder needs or solution ideas for challenges during the development process. In the case of retirement, Open-Disposal can contribute to gather both ideas to dispose and recycle an old product (e.g. a cargo ship) in an efficient and ecofriendly way, and maybe also support in becoming acquainted with specialized disposal-companies which offer corresponding services for the whole product or single subsystems.

Additionally, the evaluation sheet exposes similarities but also differences between the two Open-X stages. While in the case of Open-Development a large group of participants without much expertise in a specific field can participate, Open-Disposal requires a group of experts which on the other hand might be smaller. The kind of the expected innovations also differs: for Open-Development, the focus is on new products or business cases. Here, innovations are mainly gained in the form of ideas, drawings or first technical concepts. In contrast, Open-Disposal aims for process innovations in the form of ideas/information for recycling/disposing old existing products, or the consideration of services offered by participants. The type and amount of information provided by the company is also different in each case: when collecting ideas for new applications of a building

Table 1 Comparison of open-development and open-disposal

Category	Open-development	Open-disposal
Actors		
Participants	Due to the low complexity of the task no special expertise is required. Thus, amateurs as well as experts can participate	The complexity of the task requires special expert knowhow which usually only a minority of amateurs possesses
Accessibility to participants	Since the task can be performed by a random crowd the accessibility is relatively easy. This can become more difficult with an increasing complexity of the issue (e.g. solutions for technical problems)	Due to the required expertise, the number of potential participants is limited, which also complicates the accessibility
Type of participation	Primary participants provide ideas for (in this case) possible applications in the form of text, drawings, etc. They might also act as potential partners for realizing their ideas	In this stage, it is likely that participants not only provide suggestions for disposal steps but also for services (e.g. "If you prepare component A and B in a specific way, my company can dispose of it and would even pay you money for these components")
Issue and *provided information*		
Effort for evaluating gained information	Due to the low complexity of the task, the contextual evaluation of the received ideas is relatively easy. Challenges can arise out of an usually high number of ideas and diversity of content and formulations. In some cases, an evaluation by the participants themselves might also be possible	Though the amount of information is smaller, the more complex content increases the evaluation effort required. Normally, an internal expert group needs to perform detailed analysis and calculations to determine whether suggestions are applicable and economic
Risks		
Data security and knowledge drain	The amount of provided information is medium: though the most important properties of the pre-product needs to be published, these might be in a rough level of detail. Additionally no information regarding the manufacturing process is required. This also limits the risk of knowledge drain to a medium level: other companies might adapt some ideas to similar products of their own but they do not gain insights into the production process itself	The disposal of an old and complex product requires a high amount of information and high level of detail, e.g. technical drawings, photos, visits, etc. Due to the age of the product and the contained technology the risk of knowledge drain usually is relatively low. Exceptions might be "top-secret" products like military systems

(*Source* own data)

material or other products, rough information about properties and perhaps some photos are sufficient. For disposing of a product more and detailed data is necessary, such as detailed descriptions, photos and technical drawings. From these examples it is clear that the Open-X methodologies as part of Open Innovation, containing method- and tool-sets, need to be adapted to the characteristics of each stage. At this, the Open-X assessment makes a great contribution to determine these characteristics and the potential and potential barriers of an Open-X project.

6 Conclusion and Outlook

As described in the discussion section, Open-X methodologies bear great potential for a sustainable innovation process. The presented Open-X evaluation helps research to analyze the characteristics of each PLC stage and determine potential research areas and constraints for new methods and tools. In a second step, industry can use it to improve their innovations processes. With this, two levels of focus are possible: (1) a company focus: which PLC stages can be opened, which benefit can be expected doing this and which constraints need to be considered? and (2) a product focus: at which stages of the PLC can the product gain which input?

The illustrated verification of the Open-X evaluation on two PLC stages showed the challenge on finding the right combination of categories and a convenient level of detail. However, despite the first successful results the long-term add value will manifest after multiple applications in practice.

Hence, this paper lays the foundation of a holistic approach to utilize the potential of Open Innovation for the entire Product-Life-Cycle. In the next step we will apply the evaluation sheet to the remaining PLC stages and analyze their potential for Open Innovation. We will also refine and further improve the evaluation sheet and enhance it to inside-out innovations. To ensure applicability, the Open-X evaluation will be verified in further industrial projects. Finally, based on the evaluation results we will develop efficient Open-X methods for each PLC stage.

References

1. Chesbrough H (2006) Open innovation. Researching a new paradigm. Oxford University Press
2. Gassmann O, Enkel E (2004) Towards a theory of open innovation: three core process archetypes. R&D Management Conference (RADMA), pp 1–18
3. Howard TJ, Achiche S, Özkil A, McAloone TC (2012) Open design and crowd sourcing: maturity, methodology and business models. International design conference (Design 2012), pp 181–190

4. Kain A, Kirscher R, Lindemann U (2012) Utilization of outside-in innovation input for product development. International design conference (Design 2012), pp 191–200
5. Braun A (2012) Open innovation—Einführung in ein Forschungsparadigma. In: Braun A et al. (ed) Open innovation in life science. Springer Link
6. Haskins C (ed) (2006) INCOSE systems engineering handbook, version 3
7. Tukker A (2004) Eight types of product-service system: eight ways to sustainability? experiences from suspronet. Bus Strat Environ 13:246–260
8. Gassmann O, Enkel E, Chesbrough H (2010) The future of open innovation. R&D Manage 40(3):213–221
9. Sloane P (2011) A guide to open innovation and crowd sourcing. Kogan Page
10. Enkel E (2009) Chancen und Risiken von Open Innovation. In: Zerfaß A, Möslein KM (eds) Kommunikation als Erfolgsfaktor im Innovationsmanagement. Gabler
11. Von Hippel E, Franke N, Prügl R (2008) Pyramiding: efficient identification of rare subjects. MIT sloan school of management working paper 4719-08, Oct 2008
12. OECD/Eurostat (1997) OSLO manual, version 2
13. Inauen M, Schenker-Wicki A (2012) Fostering radical innovations with open innovation. Eur J Innov Manage 15(2):212–231
14. Ebner W, Leimeister JM, Krcmar H (2009) Community engineering for innovations: the ideas competition as a method to nurture a virtual community for innovations. R&D Manage 39:342–356
15. Thomke S, von Hippel E (2002) Customers as innovators: a new way to create value. Harvard Business Review

Researching Creativity Within Design Students at University of Botswana

Chinandu Mwendapole and Zoran Markovic

Abstract Creativity is considered the mental and social process of generating ideas, concepts, and associations. According to Bingalli (2007) concept generation is critical to the design process because it provides the designer with the necessary tools to picture the qualities of the desired design through the use of words or images. The paper discusses research done at University of Botswana, with 35 students from all years involved. Similar researches were done at several places in past (e.g. Brazil), but we were trying not only to establish students' creativity level, but also to improve our learning environment and curriculum. The Paper addresses our intentions, research hypothesys, basic principles, methodology, preliminary and final results, and conclusions.

Keywords Creativity · Innovation · Concepts · Ideas

1 Introduction

As part of the process of exploring how to create a learning environment that promotes and nurtures creativity we undertook a preliminary study to explore how design students in the Department of Industrial Design and Technology (IDT) understand and experience the concept of creativity. Data collection methods

C. Mwendapole (✉) · Z. Markovic
Department of Industrial Design and Technology, University of Botswana,
Gaborone, Botswana
e-mail: mwendapolec@mopipi.ub.bw

Z. Markovic
e-mail: markovicz@mopipi.ub.bw

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_107,

included the use of observation, practical test and a self administered questionnaire. Findings from the study helped begin the process of mapping or assessing the Department of Industrial Design and Technology as an environment that supports the nurturing of creativity among students.

35 students were involved in the preliminary research. They showed not only their level of the creativity, but also views on the existing learning environment and its ability to nurture creativity. Similar researches were done at several places in past (e.g. Brazil and Estonia), but we are trying not only to establish students' creativity level, but also to improve our environment, physically and as a teaching-learning process. The Paper addresses conceptual frame work, intentions, research hypothesis, basic principles, methodology, preliminary and final results, and conclusions.

2 Conceptual Framework

For the purposes of this research, creativity is defined as the process by which ideas are generated, connected and transformed into things that are of value [2]. In other words, creativity is the production of novel, appropriate ideas in any realm of human activity which includes the sciences, education, the arts, business and everyday life [3]. All though creative people can have certain straits which distinguish them from others, such characteristics can be developed with dedication and practice. Educational research on creativity provides evidence that creativity training can enhance an individual's level of creativity [4].

The term '*innovation*' has its roots from the Latin '*novus*', which means '*new*' and in the broadest context to innovate is "to begin or introduce (something new) for the first time" [5]. Innovation in companies can assume many forms, including incremental improvements to existing products, application of new technology to new markets, and the use of new technology to serve existing markets. We now live in what is viewed as weightless or knowledge economies, where knowledge and information have become important economic resources, and creativity is considered a major asset in the innovation [6].

Since creativity is both an individual and social construct, and design covers a wide range of activities which all include the creative visualization of concepts, plans and ideas, the production of those ideas. They has been a growing number of studies that have began to address issues surrounding creativity processes, thinking skills and environments within design education [7–10]. In keeping with current trends, the authors elected to explore the creative thinking skills of the Department of Industrial Design and Technology (IDT) students and their opinions on creativity and their environment.

3 Methodology

In this study the research was divided into two phases. First, in order to gauge the students creativity a 30 min practical test inspired by the Panamericana School of Art and Design test was given to the 3rd, 4th and 5th year students in the of the Industrial Design and Technology Department. The test was then followed by a self administered questionnaire.

3.1 Practical Test

Creativity thinking skills are defined as a novel way of seeing or doing things, that is characterized by four components: fluency (generation of ideas), flexibility (shifting of perspective, originality (conceiving something new), and elaboration (building on other ideas) [11]. Creative thinking skills include both output and process: creative output is end product of a creative process, whereas the creative process is the methods applied to develop ideas to solve a particular problem [12].

The study made use of a creativity test originally developed by the Panamericana School of Art and Design in Brazil, a simplified version of the Torrence Tests of Creative Thinking—Figural which originally consisted of three activities: picture construction, picture completion and repeated figures of lines and circles [13, 14]. The main function of the original Torrence Test—Figural was to encourage respondents to view the tests as series of fun activities, thereby reducing test anxiety [13]. One of the main aims of the test was to use the results, as a means of gauging the level of the students' creative thinking skills such as fluency, flexibility, originality and elaboration of ideas. In order to assist us in mapping or planning a way forward for the development of a learning experience that enhances the students' creative abilities.

The Panamericana School of Art and Design test focuses primarily on the use of repeated figures of lines and circles. The test requires 30 min of work time, so speed is important and artistic quality is not a relevant factor. The test was developed to understand and nurture the students' capacity for creativity. The practical test consisted of three A4 sheets of papers that included three basic shapes (circle, lines).

The students were then asked to continue the basic shapes drawings with as many different symbols as possible within the allocated time.

3.2 Self-Administered Questionnaire

After the visual test the students were asked to fill in a self-administered questionnaire in order to gauge the students understanding of creativity and their opinions on how their learning experience and environment contributes to their creativity.

The objective of the questionnaire was to suggest how the Department of Design and Technology could create a nurturing teaching-learning environment for the students. The students were therefore asked to self administer a questionnaire in which they had to put a general ranking regarding creativity in design, as per their understanding. Questions were organized in a manner considered to be appropriate and familiar to all students (study year 3–5). Contrary to the Practical Test, here the students had to show their understanding of creativity and to recommend, as per their understanding, how the teaching-learning environment could be developed to nurture in creative learning. The questionnaire was divided into two sections, two ranking comments and part open for suggestions.

The first section comprises eleven situation/approaches/intentions and students were asked to rank the level of creativity in each of them. From "Problem identification" to "Ability to communicate new ideas to others", students had to recognize creativity and its level in each of them.

The second section was connected to factors that had a bearing on the Practical Test, which was given to them previously. Students had to choose between different areas of knowledge, creative thinking skills and motivation, and to rank them. In order to not only show their understanding of the whole research, but also to indicate factors that had an impact on their perceptions of creativity in the design and learning process.

The third part content only two questions and students have to rank (from 1 to 10) their impression of the test, but also influence and impact of the learning experience and environment in promoting their creativity. This was the main point of the research.

Students were intentionally given unlimited time for questionnaire. The idea was to create environment without limitation, including time-concern, so students would fully feel free to express themselves.

4 Findings

Immersion into data allows the researcher to identify patterns, possibly surprising phenomena and also to become sensitive to inconsistencies such as the divergent views offered by different groups of individuals [15]. Since this study was primarily about the students abilities and experiences of creativity. Grounded theory was therefore considered the most appropriate choice for analyzing data from the study. This was because it provided a flexible framework to sort out the ideas, issues and themes emerging from the raw data for analysis and interpretation.

4.1 Practical Test

Creativity requires a certain baseline of intelligence, it also requires domain relevant skills… Domain relevant skills include a minimum level of factual knowledge and technical proficiency [16]. Since creativity is considered the ability to imagine, explore, synthesize, connect, discover, invent and adapt information.

The analysis of the drawings from the practical test was divided into three categories:

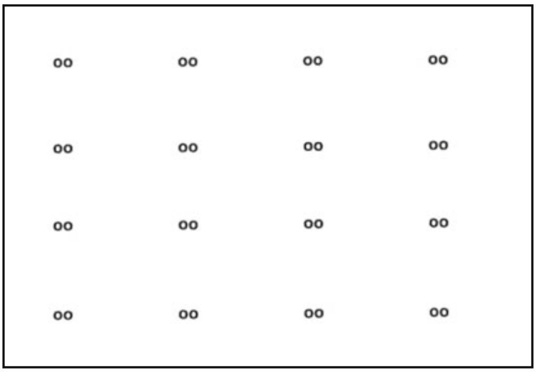
1. The level of fluency—the number of relevant ideas produced by the students
2. The level of originality—the ability to produce uncommon or unique responses
3. The level of elaboration—the students ability to develop and elaborate on ideas.

The practical test showed that the students could draw a wide range of images from one basic shape. Observing the images the researchers found that with regard to fluency or the number of relevant ideas produced by the students the 3rd year students rated much higher than the 4th and 5th year students. It was interesting to note that they all made an effort to draw images using all three basic forms (circles and lines). Examples of drawings included eyes, stop signs, faces and bicycles (see Figs. 1, 2).

The ability to produce uncommon or unique responses as an indicator of originality was high in the drawings by the 3rd and 5th year students and medium for the 4th year students. Examples of uncommon or unique responses drawings included: cherries, cats air pump and the use of words (see Figs. 3, 4).

The ability to elaborate and build on ideas was consistently high in the 3rd and 4th year students and medium for the 5th years. Examples of drawings that included the elaboration of the basic shapes into larger images included: a chair, man with a hat, digital clock and house (see Figs. 5, 6). Overall the practical test seemed to indicate that the 3rd year students were consistently high in all three categories, while the 4th were high in the elaboration of ideas and 5th year students were high in the ability to produce uncommon or unique responses (Figs. 7, 8, 9).

Fig. 1 Empty test "00". *Source* research team



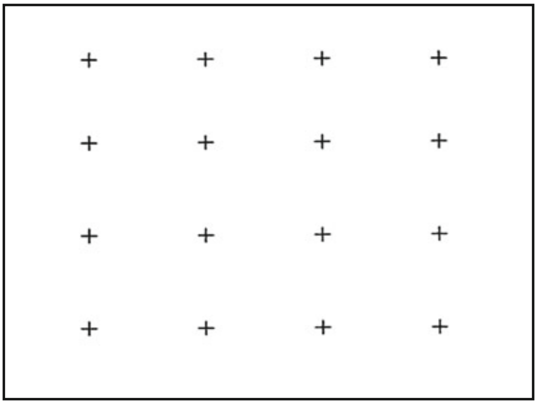


Fig. 2 Empty test "+". *Source* research team

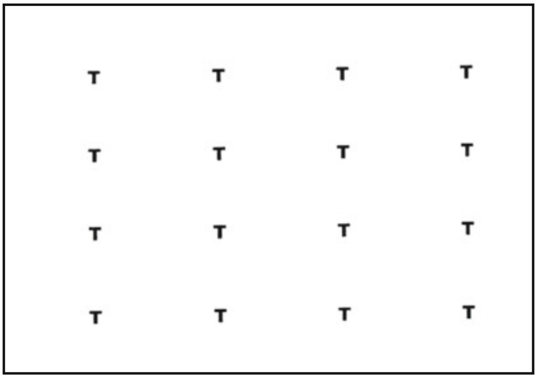


Fig. 3 Empty test "T". *Source* research team

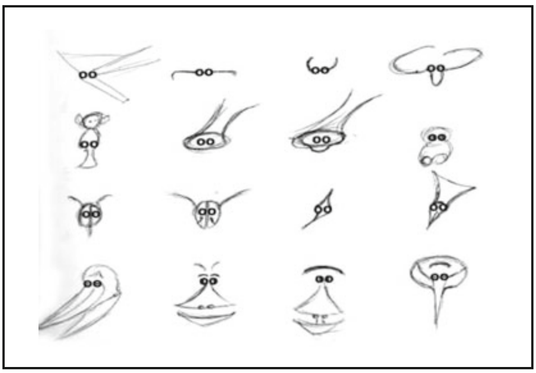


Fig. 4 Test showing fluency. *Source* research team

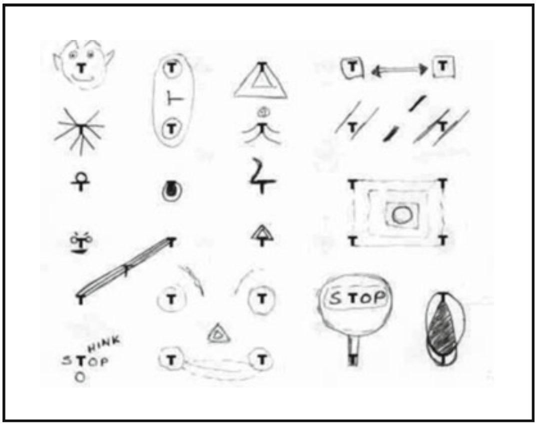


Fig. 5 Test showing fluency. *Source* research team

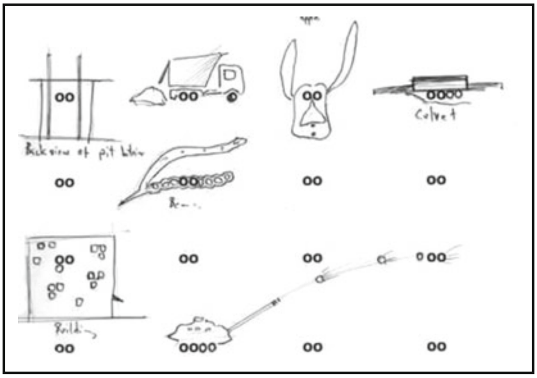


Fig. 6 Test showing originality. *Source* research team

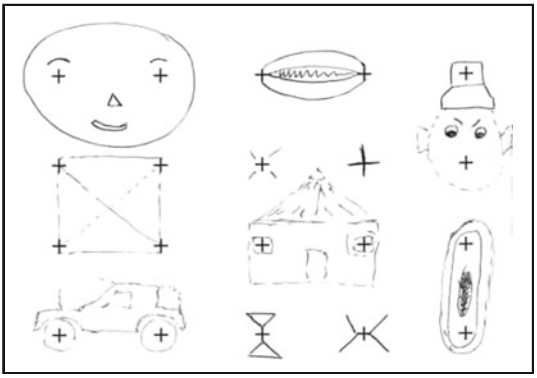


Fig. 7 Test showing originality. *Source* research team

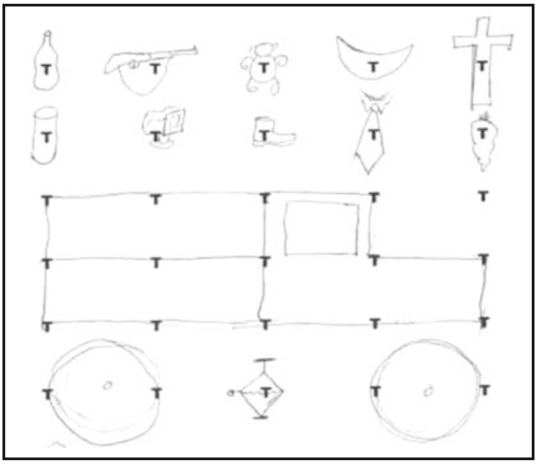


Fig. 8 Test showing elaboration. *Source* research team

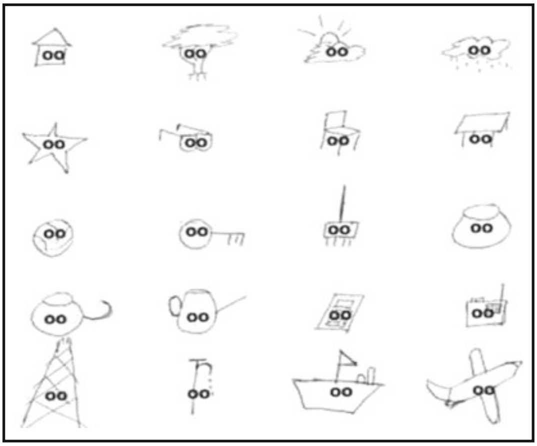


Fig. 9 Test showing elaboration. *Source* research team

4.2 Self-Administered Questionnaire

The questionnaire was administrated amongst students from the 3rd, 4th and 5th year of study, in the Department of industrial Design and Technology. Design students were chosen due to their developed interest and knowledge regarding creativity. The questionnaire was distributed separately to different groups, during a regular class, in classrooms and without time-limit. So students felt free and answers were more objective. However, a large majority of the students finalized the questionnaire within 20 min.

Results were analyzed separately per years of the study, and a final comprehensive schedule was prepared. It is very interesting that results per groups show very little differences.

Table 1 Final result for all groups (year 3, 4 and 5), summary

University of Botswana
Department of Industrial Design and Technology

Creativity: The purpose of this questionnaire is to collect information about the students understanding of creativity. The results of this survey will be published by the department of industrial design and technology, university of botswana and they will be availed to participants upon request

Total number of the participants: 35 (3rd year: 7; year 4th: 14; year 5th: 14) Results: all groups

A	In your view which of the following best demonstrates creativity	Strongly agree		Agree		Neutral		Disagree		Strongly disagree		Average
1	Problem identification or articulation	12	34,3 %	5	14,3 %	8	22,9 %	5	14,3 %	5	14,3 %	2,60
2	Ability to identify new patterns of behaviour or new combination of actions	10	28,6 %	6	17,1 %	7	20,0 %	6	17,1 %	6	17,1 %	3,06
3	Integration of knowledge across different disciplines	10	28,6 %	10	28,6 %	6	17,1 %	3	8,6 %	6	17,1 %	2,57
4	Ability to originate new ideas	13	37,1 %	7	200,0 %	3	8,6 %	7	20,0 %	5	14,3 %	2,54
5	Comfort with the notion of no right answer	7	20,0 %	8	22,9 %	13	37,1 %	5	14,3 %	2	5,7 %	2,63
6	Fundamental curiosity	7	20,0 %	9	25,7 %	6	17,1 %	8	22,9 %	5	14,3 %	2,86
7	Originality and inventiveness of work	13	37,1 %	5	14,3 %	8	22,9 %	3	8,6 %	6	17,1 %	2,54
8	Problem solving	12	34,3 %	6	17,1 %	4	11,4 %	6	17,1 %	7	20,0 %	2,71
9	Ability to take risks	12	34,3 %	5	14,3 %	6	17,1 %	8	22,9 %	4	11,4 %	2,62
10	Tolerance of ambiguity	4	11,4 %	11	31,4 %	13	37,1 %	6	17,1 %	1	2,8 %	2,69
11	Ability to communicate new ideas to others	10	28,6 %	9	25,7 %	3	8,6 %	7	20,0 %	6	17,1 %	2,71
	Which of the following factors do you think contributed to your responses to the panamericana creativity test	Frequently		Often		Sometimes		Seldom		Never		Average
	Knowledge											
1	Procedural–cultural factors	3	8,6 %	14	40,0 %	9	25,7 %	4	11,4 %	5	14,3 %	2,82
2	Intellectual-thinking skills	14	40,0 %	7	200,0 %	6	17,1 %	5	14,3 %	3	8,6 %	2,31
3	Technical-drawing skills	6	17,1 %	7	200,0 %	11	31,4 %	7	20,0 %	4	11,4 %	2,89
	Creative thinking skills											
1	Intuition	12	34,3 %	7	20,0 %	6	17,1 %	6	17,1 %	4	11,4 %	2,51

(continued)

Table 1 (continued)

University of BotswanaDepartment of Industrial Design and Technology													
2	Imagination	12	34,3 %	11		31,4 %	2	5,7 %	5	14,3 %	5	14,3 %	2,43
	Motivation												
1	Intrinsic-inner passion	15	42,9 %	7		20,0 %	7	20,0 %	3	8,6 %	3	8,6 %	2,20
2	Extrinsic–monetary reward	2	57 %	7		20,0 %	10	28,6 %	5	14,3 %	11	31,4 %	3,46
B. Overall impression of the creativity test (tick only one)													
	How would you rate the Panamericana test on creativity, on a scale of 1–10 (1 being poor, and 10 being excellent)	1	2	3	4	5		6	7	8	9	10	Average
		1			1	2		5	10	9	7		7,14
		2,86 %	0 %	0 %	2,86 %	5,71 %		14,21 %	28,57 %	25,71 %	20,00 %	0 %	100 %
C. How would you rate the role of your learning experience and environment in promoting your creativity													
	How would you rate your current learning experience and environment in promoting creativity on a scale of 1–10 (tick only one)(1 poor and 10 excellent)	1	2	3	4	5	6	7	8	9	10	Average	
				1	2	2	4	8	8	8	2	7,34	
		0 %	0 %	2,86 %	5,71 %	5,71 %	11,43 %	22,86 %	22,86 %	22,86 %	5,71 %	100 %	
D. Suggest one thing that you think could contribute to a more creative learning experience and environment for students in the department of design and technology													

Source research team findings

General findings were that majority of the students had similar impressions regarding the questionnaire. Younger students (3rd year) already have a strong opinion regarding creativity, the learning environment and process. Majority of the latter years of study students followed the same pattern. The final matrix is shown under Table 1.

The results we split in two groups—Part one addressed the students' understanding of creativity. Part two the students' opinions of the existing teaching-learning environment.

Originating new ideas, inventiveness of work, problem identification and articulation, problem solving and ability to take a risk were on the top when students had to indicate areas which demonstrate creativity. Interesting is that students ranked tolerance of ambiguity very low. Also, students preferred creative thinking skills to knowledge, and when talking about motivation inner passion was rated higher than monetary rewards.

Regarding existing teaching-learning environment, students have a positive opinion, with an average ranking of 7, 34 (from 100 %). However, they recommended several improvements, for the teaching process (more design oriented courses and less theory) to physical environment (better organized design studios). This shows students' understanding of multifaceted approach of creativity. To develop students' creativity and nurture a creative learning and teaching environment, the Department of Design and Technology has to improve their curriculum, consider a more creative delivery of information and invest in a learning environment that encourages creativity.

5 Conclusions and Recommendations

Creativity and innovation are generally recognized as vital to commercial success in the 21st century. In order for Botswana to achieve its vision and strategic position of moving more toward economic growth and diversification, the design and technology curriculum must engender creativity and innovation. Because new products, new services and new manufacturing processes, no less than artistic works or scientific advances, have an idea as their origin.

The study on students in the Department of Industrial Design and Technology (IDT) offers us the opportunity to understand and experience the concept of creativity through the experience of the students. The students' responses to both the practical test and self administered questionnaire indicated the students' creative strengths as well as their personal opinions on their understanding of creativity and how the current learning experience and environment nurtures that creativity.

Since the most difficult skills for a design student to learn is the ability to develop a concept for a design, because concepts require a leap from written data or needs to communication of a design [1]. The study offers an opportunity to develop a plan that will help the Department of Design and Technology to nurture and harness the creativity of students in the 3rd, 4th and 5th year. There is a need for a curriculum audit that addresses the contribution of the different strands to the innovation process possibly with the end result of developing strategies that engenders creativity, innovation and technical proficiency.

The recommendations of the researchers are as follows:

- Create a learning environment that includes creative spaces and curriculum innovation
- Review the current curriculums teaching of creativity form the 3rd–5th year
- Encourage creative behavior amongst the students and lecturers.

References

1. Binggeli C (2007) A survey of interior design. John Wiley and Sons
2. United Nations conference on trade and development (UNCTAD) 2010 Creative Industries, Creative Economy Report
3. Amabile TM (1997) Motivating creativity in organizations: on doing what you love and loving what you do (Creativity in Management) 40(1):39–58
4. Evans JR (1991) Creative thinking in the decision and management sciences. OH: Southwestern Publishing Co, Cincinnati
5. Mutlu B, Alpay E (2003) Design innovation: historical and theoretical perspectives on product innovation by design. Barcelona Conference paper
6. Smith K (2000) What is the knowledge economy? Knowledge-intensive industries ad distributed knowledge base. Paper prepared as part of the project innovation policy in a knowledge based economy commissioned by the European Commission, Oslo
7. Wylant B (2008) Design thinking and the experience of innovation. Massachusetts Inst Technol Des Issues 24(2):3–14
8. Magano C (2009) Explaining the creative mind. Int J Res Rev 3(1):10–19
9. Glaveanu VP (2011) Creating creativity: reflections from fieldwork. Integr Psychol Behav Sci 45:110–115
10. Runco MA (2007) Creativity, theories and themes: research development and practice. Elsevier Academic Press, New York
11. Alvino J (1990) A glossary of thinking-skills terms. Learning 16(6):50
12. Csikszentmihalyi M (1996) Creativity: flow and the psychology of discovery and invention. Harper Collins, New York
13. Kim HK (2006) Can we trust creativity tests? A review of the Torrence test of creativity thinking (TTCT). Creativity Res J 18:3–14
14. http://www.toxel.com/inspiration/2009/05/06/school-of-art-and-design-creativity-test
15. Nonaka I, Teece D (2001) Managing industrial knowledge: creation, transfer and utilization. Sage Publications
16. Hammersley M, Atkinson P (1995) Ethnography: principles in practice. Routledge

Role of Traditional Wisdom in Design Education for Global Product Development

Ar Geetanjali S. Patil and Ar Suruchi A. Ranadive

Abstract Tradition is the codified research over centuries—with tremendous feedback. It is important to realise that tradition is a result of research with feedback over the centuries, Joseph Allen Stein. For Indians the concept of globalization is not new. India has been trading partner to various nations since ages. What is new is the speed and the borderlessness of the transactions characterizing the present cache of globalization, made possible in large measure by the networking technologies, and in part by the object of such transactions, viz., information and knowledge, and the ensuing new economy. India being an old civilization with kaleidoscopic variety and rich cultural heritage, faith in the idea of growth and change remains the driving force of modern India. The material evidence of art crafts and architecture inevitably becomes the principal source for understanding the historical and cultural context. Our culture's ability to sustain uniform and repetitive means of production and reproduction, and implicit in this uniform repeatability its high level of technical coordination. Design education needs to integrate these existing knowledge systems with the emerging knowledge economy, especially standing as we are at the threshold of forces of a globalization, and the opportunities that this could throw up for the traditional sectors. Design education has to redefine itself as the response to fast changing scenarios on the global front. Collaborative cultures form a invariable aspect of design studio. The interdisciplinary dialogues and debate nourish the atmosphere in the design studio. This paper intends to understand the ability of traditional societies of assimilation and reflection of various cultural and technological changes which result in the plurality of Indian architecture, culture and craft, which forms one of

A. G. S. Patil (✉) · A. S. A. Ranadive
MVP'S College of Architecture and Centre for Design, Nashik, India
e-mail: geetashri@gmail.com

A. S. A. Ranadive
e-mail: suruchiranadive@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_108, © Springer India 2013

the major aspects of the global product development. Various examples from the different design fields like architecture and product design are taken for presenting the connect between the traditional wisdom and global product development..

Keywords Traditional wisdom · Environmental coherence · Design education · Global product development

1 Introduction

Design like all creative disciplines, involves an explorative process. A problem is posed or need is identified, then through a complex series of questions, thinking and actions, a solution or answer is identified and realized. Where once industrial designers focused primarily upon form and function, materials and manufacturing, today's issues are far more complex and challenging. New skills are required, especially for such areas as interaction, experience, and service design.

India is a multi-cultural society existing in different time zones. It is one of those countries where many centuries are telescoped into one and which has a multicultural society united by a deeply shared experience. Sustainable development is the core emerging issue in the field of design.

Since traditional environments are created in a field of tension between reason, emotion and intuition, design education should be viewed as training toward the manifestation of the ability to conceptualize, coordinate, and execute the idea of building/product rooted in tradition.

The profession and its education today face severe challenges that threaten this traditional role of the designer. This paper has attempted to understand and analyze the role of traditional craft and structure, and it is done with case studies of the two design oriented disciplines via architecture and the product design.

1.1 Understanding Traditional Wisdom

When we look into the architectural heritage of India, we find an incredibly rich reservoir of mythic images and beliefs all co existing in an easy and natural pluralism. Centuries of contemplation and synthesis have gone into traditional architecture and design to maintain its environmental coherence. The surrounding and the built form, products are both attuned to each other. Traditional environments are those that enhance, celebrate, and support human activities, those that reflect behavioural and cultural norms defined by society, those that ultimately integrate economy, ecology, and society into those everyday environments.

Traditional wisdom is born out of the assimilation of the various experiments and experiences of the individuals and the group over centuries. Tradition and modernity are not opposed to each other but part of continuous process. Modernity functions as an economic and social tool to achieve some wealth, flexibility and innovation for individuals and groups.

Therefore study of the traditional craft design should form an integral part of the designer's education. One should try to understand the character of the traditional environment where the design of artifacts and structures form a integral part of each other. As design educators seek to develop new curricula and adopt new teaching methodologies that transcend the regional barriers, we need to emphasize the relevance of well-established design philosophies, regional traditions, and cultural sensitivities.

1.2 Tradition Verses Modernity

Modernity functions as an economic and social tool to achieve some wealth, flexibility and innovation for individuals and groups; Tradition functions, partly and at times largely, as a mythological state which produces the sensation of larger connectedness and stability in the face of shockingly massive social change over last half century. One might also say that modernity is an economic force with social, cultural, and political correlatives; Tradition is a cultural force with social, economic, and political correlatives.

1.3 Role of Traditional Wisdom

Many changes we now experience in our environments, communities, identities, and requirements are an impact of globalization. Although driven by economic practices, globalization is to a significant extent enabled by design. While the debate of what the overall benefits and drawbacks of globalization are continues, we are faced with designed changes that challenge and celebrate our understandings of place and identity.

The powerful product semantics in India governs the use of objects not only in religious rituals but also in daily life, not just in the forgotten past but also in the living present. The material products of a culture can never be regarded as user independent in function or separately understandable entities. They acquire meanings in use, become integrated in everyone's whole life experiences, and interact with the mythology from which they derive their symbolic strength. They collectively participate in and carry forward the message of what that culture is about.

Traditions are not only part of history which far from being a factual representation of the past but also is a man made cultural construct for the process of selection.

2 Environmental Coherence

Traditional settlements are excellent examples of the man and nature relationship in terms of planning and crafts. The centuries of assimilations of the knowledge and skill is actively used in the traditional settlements where sustainability is the inherent character of the lifestyle.

Rural houses, in contrast to urban houses are built on lines evolved over thousand years of aesthetic traditions, indigenous techniques and judicious use of local material such as mud, grass, bamboo and cane. The Kutch desert houses, for example are built with thick walls and small openings, and narrow passages between the houses to overcome the gale of strong winds, the dust and heat. Vernacular building traditions all over the world display remarkably mature thermal adaptation. Early builders consistently used forms and materials that effectively moderated prevailing climatic conditions. By 400 BC, Persian engineers had mastered the technique of storing ice in the middle of summer in the desert. The ice was brought in during the winters from nearby mountains in bulk amounts, and stored in a Yakhchal, or ice-pit. These ancient refrigerators were used primarily to store ice for use in the summer, as well as for food storage, in the hot, dry desert climate of Iran.

3 Design Pedagogy

Tagore's education marked a novel blending of the ideas of the East and West According to Tagore, teaching should be practical and real but not artificial and theoretical. As a naturalist out and out, Tagore laid emphasis on the practicality of education. That will definitely increase the creative skill within a learner. As one of the earliest educators to think in terms of the global village, Rabindranath Tagore's educational model has a unique sensitivity and aptness for education within multi-racial, multi-lingual and multi-cultural situations, amidst conditions of acknowledged economic discrepancy and political imbalance.

If design education is going to assert that designers should have an impact on the development and performance of the design involved with today's markets and communities, then we must consider how designers can resolve the increasing tension between the global and local that is experienced in a growing number of communities around the world.

The way design performs determines much of our environment, experience, behaviour, emotions, motives, desires, understandings, identities, etc. This makes it necessary for design curricula to provide interdisciplinary and multidisciplinary exposure to gear up students to tackle design problems with a holistic approach and to make things work within practical constraints.

Today most of the design schools are found in urban areas. Urban cities show standardization in many aspects where as the rural areas carry forth with age old traditions in place. It becomes then necessary for design school to accommodate the Indian context and concern for the integration of built form and landscape. To achieve this, the interface between students and the actual site is essential. The material evidence of architecture and crafts inevitably becomes the principal source for understanding the historical and cultural context of these settlements.

4 Global Product Development

Globalization is associated with new dynamics of re-localisation. It is about the achievement of a global–local nexus, about new and intricate relations between global space and local space. Globalisation is like putting together a jigsaw puzzle: it is a matter of inserting a multiplicity of localities into the overall picture of a new global system (Morley and Robins 1995, p. 116).

Rapid advancement in the field of information technology has led to the emergence of the knowledge economy as the new power house. In this context, it is only natural that design education should address the new and emerging socio cultural and economic aspects.

A designer like all other professionals is first a human being and then a professional. His skills must stand firmly on this “human base” lest he becomes a “human robot.” The human base is becoming increasingly necessary because the technological advances of the present are such that the skill part of the human activity is being rapidly replaced by mechanical and electronic gadgets ever more efficiently than before. What is now required more and more is not a skilled designer (by skill I mean knowledge and aesthetic sense included) but a broad based, socially well integrated, humane designer with a broad global vision.

5 Case Studies

The case studies which we have considered provide us with an example of transformation of the product in the global and the local scenario. The Case studies of the Ceramic Water Filter and Stone Grinder was result of a study conducted for indigenous technologies used for product design in the college. The Turkish Teapot is selected for its transformation in terms of form and technology used for brewing. The architecture case study talks about the basic necessity of need to create with the reference with the local traditions, was conducted as a part of settlement study in architecture studio.

Fig. 1 Evolution of the Turkish teapot from local to the global level

5.1 Turkish Tea Pot

The interesting point about teapot designs are, as tea has become a tradition, or is thought to be a tradition in Turkey, teapot might be said to be a traditional or archaic device, in the sense of the ways of brewing and preparing has been an outcome of years experience. The teapot could be said to have gone through certain transformations due to the changing technology, ways of life, new needs, products and functions. What is kept stable is the basic functional structure of the object that is water is boiled in the pot that is underneath the one in which brewing is done. The top part, whether of porcelain or metal is heated by the boiling steam applied from under.

Sameness is transferred into difference by the new setup. While it could be seen as divergence in the global market, as the marketing of a different product; it is convergent in the local market by turning the already different, culture-specific teapot set into a combination of the Western typologies of objects on top of a tray (Fig. 1).

5.2 Stone Grinders For Dosa, Idlis

Stone Grinders viz sil batta, ragda etc. have formed the integral part of Indian kitchen. The food processor and the mixer grinders where supposed to be standard

Fig. 2 Transformation from ragda to stone grinder

answers for the same. The revival of the practice of using ragda for preparing wet batter was done by industries like Ultra Grind. The tradition of the using stone grinders is revived through the mechanical designed ragdas (Fig. 2).

5.3 Ceramic Pot Filters

Study about indigenous techniques for water purification is gaining importance all over the world and is being promoted by WHO for creating user friendly products using the same.

Purpose of using the traditional techniques is because they are; Sustainable, local, natural availability of material, suitable for climatic condition, made by local people or craftsman, developed by experimentation n logics and need, cost effective, ecofriendly, gaining knowledge from traditional wisdom, reviving techniques, Regional influence, character.

The ceramic water pot (CWP) was identified as a product that provides an excellent potential for improvement through optimizing materials and processes as well as an opportunity for creating an updated design with greater aspirational appeal for consumers. Locally produced ceramic pot-style filters have the advantages of being relatively inexpensive, low-maintenance, portable, effective, and easy to use. The filters remove microorganisms from water by gravity filtration through porous ceramics, with typical flow rates of 2–3 liters per hour 6.

The design for the portable water filter has to fulfill easy manufacturing process, economic and have the aesthetic component which is not alien in the user

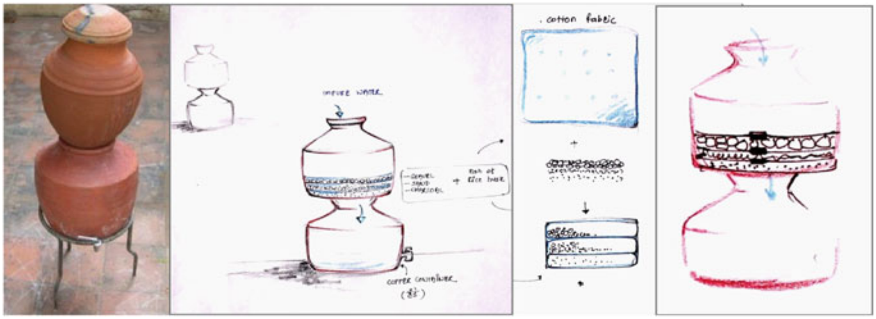


Fig. 3 Explorations done in the college using the local variation

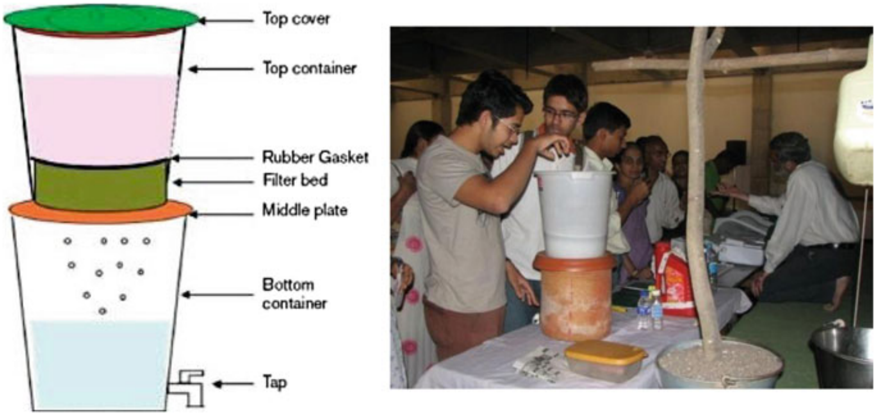


Fig. 4 Arogya water filter, vardha

environment. We present a few explorations done in the college using the local variation of mixing rice husk and crushed laterite for the formation of the filter bed (Figs. 3, 4).

5.4 Settlement Study: Pragpur

Architecture practices have often voiced concerns that schools of architecture do not provide students with the right set of skills needed in practice. The students need to connect to the environment prevalent not only in urban India but also rural India. Urban cities show standardization in many aspects where as the rural areas carry forth with age old traditions in place.

This is also an opportunity to establish links that provide enduring benefits by mobilising students, faculty, and neighbourhood organizations to work together to find new solutions to problems, while borrowing from the old.

With a view of sensitizing the urban students with the rural set up, its needs and understanding of sustainable dwellings and environment responsive architecture a design problem is set every year which is based on the study of a settlement carried out by the students on site. The settlement chosen is at least 200 years old. The settlement has to support a traditional craft as a means of livelihood for its residents. This can be weaving, pottery, toy making, handicrafts, leather goods etc. which are traditional arts and a part of the fabric of its residents. These are traditional skills which are handed down from one generation to another. The various aspects of the settlement are then studied by plotting and mapping the growth of the settlement over the years. The sections into which the settlement is divided is on basis of caste, work patterns etc. The students are made to understand the cultural context, imagery, roots, the health and educational facilities which are currently available. Various settlements have been studied by the students of CANS Nashik. The documentation and analysis of Pragpur shown herewith is a representation of similar towns spread over the country.

Pragpur, a small village near Dehra sub division of Kangra distt. of Himachal Pradesh is India's only officially declared heritage hamlet. Pragpur is located in the lush green Kangra valley in Himachal Pradesh surrounded by snow covered Dhauladhar mountain range.

Pragpur was declared as the country's first "Heritage Village" in December 1997, credit for which goes to villagers who have preserved their rich history and heritage with such a dedication and determination Pragpur village still have cobbled stone streets, mud-plastered walls and slate-roofed houses (Fig. 5).

Since the settlement of Pragpur is built in the hilly region, the streets are sloping. The buildings are a judicious mix of single and double storied dwellings. The cobbled streets are interspaced with interactive spaces which lead the visitor on an interesting journey.

Taal and its surroundings. The water level of Pragpur was extremely low before the 1800s. Nahar community directed the overflow of the nearby village of Lag-Belgana. They constructed a canal system using bamboo and supplied the excess water to Pragpur. The Taal was constructed to accommodate this overflow. The

Fig. 5 *Left* Taal and surrounding area. *Right* The Taal

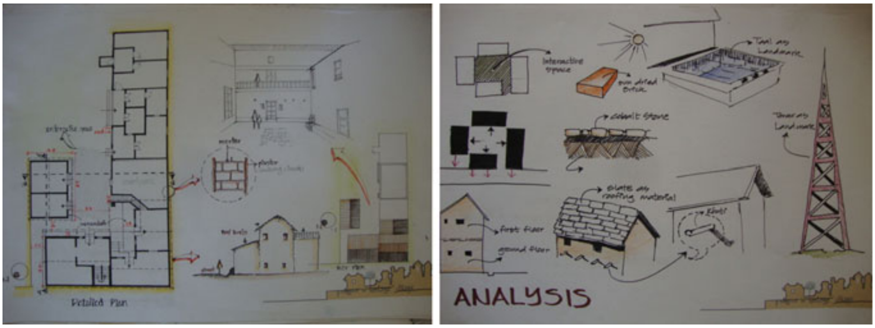


Fig. 6 *Left* Typical cluster. *Right* Analysis

surrounding area of the Taal developed over the years and is today an important public space (Fig. 6).

Typical dwelling Unit. Typical houses in Pragpur have the superstructure made of sun dried bricks. Foundations use local stone for stability. The walls are plastered either with mud or a mixture of cow dung and husk. Small windows towards the external walls restrict wind during the cold winters and also allow diffused sunlight into the interiors.

The houses are clustered around a central court which while acting as an interactive space also serves to act as an wind breaker.

Thatched roofs are used which are tied with a rope to a wooden member projecting from the wall.

Analysis. The various striking elements of the settlement were analysed. The play of light and shadow was emphasized due to the varying building heights. The cluster, the Taal and the various environmentally cohesive structures were the basis of analysis.

6 Conclusion

Nature, culture and society are endless resources for designers' inspirations, in the past, today and in future. Cultural variety is of equal importance as biological diversity. Global reflection and knowledge can create more global awareness. It will provide us with an opportunity to deepen the understanding on the values of the cultural diversity and the natural environment, and to learn to better "live together." Helmut Langer.

Any design with a carefully considered performance potential can be a powerful and sustainable influence within particular local places and identities. With a developed understanding of design as a performance in context, designers can design for local context with a respect for its values, use of its resources, and knowledge of its various dynamics and patterns of change and stability. This protection from the arbitrary influences of globalization comes from contextual design's ability to perpetuate what is essential within a culture while adapting what is new into a relevant form that is beneficial for the design with global sensitivity.

Acknowledgments 1. MVP s College of Architecture. Centre for Design Nashik, S Y BArch (2010-11).

2. Pranjal Duberkar (2010–2011)

References

1. Stein JA (1998) Building in the garden. In: White S (ed)
2. Norman D Why design education must change. http://www.core77.com/blog/
3. Balaram. Thinking design
4. Michael C, Salama AM () Design education: explorations and prospect for a better built environment
5. Yatin P () Concepts of space in traditional Indian architecture. Majun Publishing
6. Kenn F (2003) A critical pedagogy of space. Doctoral Dissertation, Flinders University
7. Timur Ş (2001) Reading material culture: an analysis of design as cultural form March
8. Standardized manufacturing practices–path. www.path.org/projects/safe-water-standardized-manufacturing.php
9. Langer H (2005) The world challenge for a global designers generation, design education, tradition and modernity, DETM 05

Color Consideration for Waiting Areas in Hospitals

Parisa Zraati

Abstract Color is one the most important factors in the nature that can have some affects on human behavior. Many years ago, it was proven that using color in public place can have some affect on the users. Depend of the darkness and lightness; it can be vary from positive to negative. The research will mainly focus on the color and psychological influences and physical factors. The statement of problem in this research is what is impact of color usually applied to waiting area? The overall aim of the study is to explore the visual environment of hospitals and to manage the color psychological effect of the hospital users in the waiting area by creating a comfortable, pleasant and cozy environment for users while spend their time in waiting areas. The analysis concentrate on satisfaction and their interesting regarding applied color in two private hospital waiting area in Malaysia.

Keywords Hospital environment · Human psychology · Color · Waiting areas

1 Introduction

This research will be the application of color and how to apply to public areas in hospitals should take account of the emotional and psychological factors which can affect their well-being at waiting room. The skillful use of color can help to overcome the sensory deprivation caused by lack of visual stimuli associated with

P. Zraati (✉)
Malaysia University of Science and Technology (MUST), No.17, Jalan SS 7/26, Kelana Jaya, Petaling Jaya 47301 Selangor, Malaysia
e-mail: p.zraati@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_109,

drab or monotonous environments. Hospital has a wide range of users with different requirements, from the elderly to the very young. A well-designed visual environment can be particularly helpful to visitor with partial sight [1].

Color can play a major role in creating accessible environments. Color contrast can identify obstacles and hardware that might prove difficult to negotiate. It is important to address the subjective needs and preferences of the users especially in buildings of anthropogenic character and service oriented building such as hospitals. Viewing environment as requires us to address the issues between living and lifeless spaces, life renewing nourishing and life sapping spaces [2].

This research will mainly focus on the color and psychological influences and physical factors. Research in environmental psychology has demonstrated that different environmental stimulus can affect on both mood and behavior [3, 4]. The effect of the physical environment can be part of importance in healthcare setting, where people experience a relatively high degree of uncertainty, fear and stress. Possible effects of the physical healthcare environment on the healing process of patients have received some attention [5–7].

The primary objectives of this research are:

1. To study the color consideration for waiting areas in hospitals.
2. To determine whether color consideration could influence on mood and behavior of users in waiting areas.
3. To determine what are the most suitable color scheme to consider for waiting areas in hospitals.

In this research, researcher was able to study relationship between color and emotional on waiting areas in hospitals and also study is to establish current color application in the design of hospitals, revealed a wide range of literature presenting mixed evidence on this aspect of color as well as a diversity of strategies for color usage in interior design of the public area.

2 Color

Color is the visual perceptual property corresponding in humans to the categories called red, green, blue and others. Color is considered informative and a way to interpret and understand meaning of designed environments [8].

Color has a strong impact on our emotions and feelings [9, 10]. The relationship between color and emotion is closely tied to color preferences, i.e. whether the color elicits a positive or negative emotion. Some color may be associated with several different emotions [11], and some emotions may be associated with more than one color [12]. Emotions can be divided into moods and feelings. A mood is a state of mind, an attitude, or a disposition that may take into account memory, language, context and physiological state. A feeling is an emotional state that is the result of sensation, a more immediate perceptual Response.

2.1 Colors in Healthcare

The color of our surroundings can both create stress and ease the stressed in life. Many of the effects of color on our moods may be the result of social and psychological associations with a particular color.

Color as property of designed environments may not have intrinsic meaning. Much research has demonstrated that healthcare occupant-patients, users and staff experience considerable stress, and one of the major stresses is produced by poorly designed physical environments [13]. Research has shown that certain colors directly affect human emotions, human feelings and human behaviors. To better explore this belief, researchers developed a theory called the psychology of color which is concerned with the effects that specific colors have on individuals' moods, emotions and behaviors as they perceive colors.

As a fundamental element f the physical environment, color in healthcare setting is increasingly considered as an environmental factor that can impact users' and staffs' stress, safety, fatigue and way finding. On the contrary, color palettes have also been found to positively affect people's healing processes as well as increase the work efficiency of healthcare staff [14, 15].

2.2 Color Design for Waiting Areas

Color design for waiting area covers all materials and surfaces. Furniture, color and lighting can do much to alleviate stress and enhance those areas. Good design can provide a visually calming environment. Comfortable seating with flexible configurations of small group arrangements could provide a friendly, welcoming atmosphere. Daylight and a view out, particularly of planting, make a waiting area much more pleasant and should be provided wherever possible [1].

Image of nature, shown in number of studies to distract patients, reduce stress and alleviate pain, can be used to great advantage [16]. The color of walls should be soft earth tones, yellows, greens or blues, which all promote a calming effect.

In waiting areas, this device can be interesting and engaging. However, care should be taken with over-enthusiastic flooring designs as people may tire of two dominant a design and find these motifs unfashionable or even annoying after some time.

3 Methodology

This part explains the methodology, which was used in achieving the research objectives.

Main methods of investigation comprised of:

- Interviews with patients and staff
- Conducting literature reviews
- Observation and gathering information from site.

Observations of the physical attributes of the waiting areas were taken. Photographs and note related to emotional and psychological of using color in this area were documented.

Each of waiting area of the hospitals was interviewed based on their willingness to participate.

3.1 Conducting the Study

This study has been conducted on two private hospitals' waiting areas in Malaysia, Subang jaya (A) and Bandar Sunway (B) cities. Table 1 shows the characteristics of the two waiting areas for each hospital (Figs. 1, 2).

Table 1 Characteristics of waiting area

Hospitals	Waiting areas	Design characteristics
Hospital A	Public waiting area	The study witnessed an attempt to create a comfortable waiting area with the play of soft and pastel colors for the walls, seats, floor, screen, view to outside and lack of light
	Outpatient waiting area	To create more comfortable waiting area compare with public waiting area. Mini artificial garden corner, though the attempt is admirable but it creates a lifeless environment due to the artificial plant used and its non strategic location
Hospital B	Public waiting area	There was an attempt to design the interior space but still lacks aesthetic input and coziness to the feel. However, comparatively more comfortable that the outpatient waiting area
	Outpatient waiting area	Enclosed outpatient waiting area with seats arranged linearly in rows which does not encourage social interaction among users. The interior was purely functional and lack aesthetic and coziness

Fig. 1 **a**, **b** Sunway Hospital: In General waiting area has been used more of *orange* and *light brown* color also sofa and furnished are in same color, as a harmonic of colors. There was an attempt to design the interior space with artificial plant, so it created a lifeless environment. Applying of television and windows to view outside; make more welcome feeling to users (**c**, **d**) Sunway Hospital: Outpatient waiting area. Enclosed waiting area with row of seats in narrow corridor which does not encourage social interaction. The interior was purely and can see lack of aesthetic. Color of furnish is not harmony with area

Fig. 2 **a**, **b** Subang Hospital: General waiting area. Use more artificial garden corner, though the attempt is an admirable but it created a lifeless environment due to the artificial plant. Cold color used for furniture and hot color used for painting wall. Make area bright, friendly, and cozy and relax (**c**, **d**) Subang Hospital: outpatient waiting area. Used warm and cold color for design seating area and wall painting. Design square shape with most artificial nature design for decoration, but use of weak range of light that make this place not bright

3.2 Data Collection

The data sources were classified into prime sources and secondary sources. Primary research was carried out to enable the collection of data that fits the exact purpose of this research and to increase the reliability of the information. The methods used to collecting data form face-to-face interview and observation of two waiting areas.

Interviews were conducted only with those who were willing to participate. The secondary sources are journals, books and previous study, articles and paper which has been published or available online. The study recorded the responses by taking note from in view of the relatively number of respondents (n = 20) selected for each hospitals. The users Age ranged are 20–55 years old. The users were from various religious and gender and races. Table 2 presents the main interview questions.

Base on question 2 of interview, we indicate users emotional responses to five principle hues(i.e., red, yellow, green, blue, purple) and five intermediate hues (i.e., yellow-red, green-yellow, blue-green, purple-blue, and red-purple), and three achromatic colors (white, gray, black). Table 3 shown the Munsell notations.

4 Data Analyze

4.1 Color Consideration for General Waiting Areas in Both Hospitals

4.1.1 Overall Layout

As discussed in literature review chapter, color design for waiting area covers all materials and surfaces. Furniture, color and lighting can do much to reduce stress in waiting area. Good design can provide a visually calming environment. Based on observation, most warm color has been used for sofa, floor, wall and ceiling lighting in Sunway hospital. Yellow color which has been applied for walls make self-confidence and encourages optimism to area and feelings of fear. Brown color that used for furniture and carpet will bring feelings of stability and security.

Table 2 Interviews questions used in the study

Interview questions	Research objectives
1. Which color do you prefer for applying in waiting area? Why?	1
2. How do you feel in the waiting area? What emotional response do you feel with this color?	2
3. Are you satisfied with the color scheme that used in waiting area? What's your suggestion?	3

Table 3 Munsell notations for color samples

Color	Hue	Value/Chroma
Red	5R	5/14
Yellow	7.5Y	9/10
Green	2.5G	5/10
Blue	10B	6/10
Purple	5P	5/10
Yellow--red	5YR	7/12
Green-yellow	2.5GY	8/10
Blue-green	5BG	7/8
Purple-blue	7.5 PB	5/12
Red--purple	10RP	4/12
White, Gray, Black	N/9, N/5, N/1	

In Subang hospital, most used light color especially pink and blue for sofa, floor, wall, ceiling lighting for waiting area thus we feel relaxed and calmed and light blue that used for floor make patients and staff feels quite and away from the rush of the day. In Subang hospital consideration on interior design and make place more welcoming for visitors and patients comparing with Sunway hospital.

4.2 Color Consideration for Outpatient Waiting Areas in Both Hospitals

4.2.1 Overall Layout

Color which has been observed in waiting areas is; green, gray and white color combines for color of sofa, floor, wall, and ceiling in Sunway hospital. Furthermore used suitable lighting make area bright but in Sime Darby Hospital mostly apply green color for furniture and type of lighting that used, make waiting area darker. Both hospitals used white color painting for wall.

As discussed in literature review, the color of walls should be soft tone, like yellows, greens or blue, which all promote a calming effect. Too much white color can give feelings of separation and can be cold and isolation.

In Sunway hospital has been used gray color for carpet. Plastic and ceramic finishing for floor combined variety range of colors such as; dark and light blue, green, light yellow in Subang hospital. As discussed before, well-maintained flooring could be light in tone and preferably warm in color.

Nature elements and artwork using in Subang hospital, are providing for more positive energy. Both nature and artwork help users having a greater "sense of well-being" where spaces lend themselves toward contemplation and feeding the senses.

4.3 Color Emotional Analysis

Base on the color has been used in both hospital The finding outcome from the users' of the waiting areas, shows the green color had the maximum number of positive emotions (85 %), comprising the feelings of relaxation, comfort, hope, peace, and happiness. The second color which had more positive emotional was yellow (80 %) including clear thinking, memory, and self-confidence and encourages optimism. The third number of positive emotions was given for the color blue (70 %); Blue was associated with the sky and so comprising relaxing and calming effect and make us feel quite and away from the rush of the day. The color purple attainted 50 % more than color red positive emotion (45 %). Purples have been used in the care of mental of nervous disorders because it help balance the mind and transform obsessions and fears. Red has been associated with love and blood, but result showed that red was not a favorite color.

For the achromatic colors, white had a highest amount of positive responses (62, 5 %), compared with color gray 30 % and black respectively. Freedom, uncluttered openness, peace and hope have been associated with color white. The gray color tend to independence and self-reliance also feeling of sadness, depression, although usually through of as a negative color. The color Black was also negative emotions color such as darkness, fear.

4.4 Staff and Visitors Perception

One of the most important things in design color scheme in waiting area is whether visitors, patients and staffs satisfy. This research gathers some statistic information where users were interviewed at random on their satisfaction in 2 waiting areas in both hospitals. Figures 3 and 4; shows staff and visitors satisfaction in both waiting areas.

5 Conclusion

The mainly purpose of this research was to determine factors that must be taken into consideration colors in waiting areas in two private hospitals in Malaysia from users satisfaction perspective, to identify which impact of color most commonly applied in waiting areas and to determine whether color consideration could influence on mood and behavior of users in waiting areas in hospitals.

Comparison that done for two mention hospitals in waiting areas specified that general waiting area in Sunway Hospital applied modern design with harmony of color for each parts. Therefore result is leading to relax and pleasant environment combining with calming, cozy, quiet, nice, home comfort but the outpatient

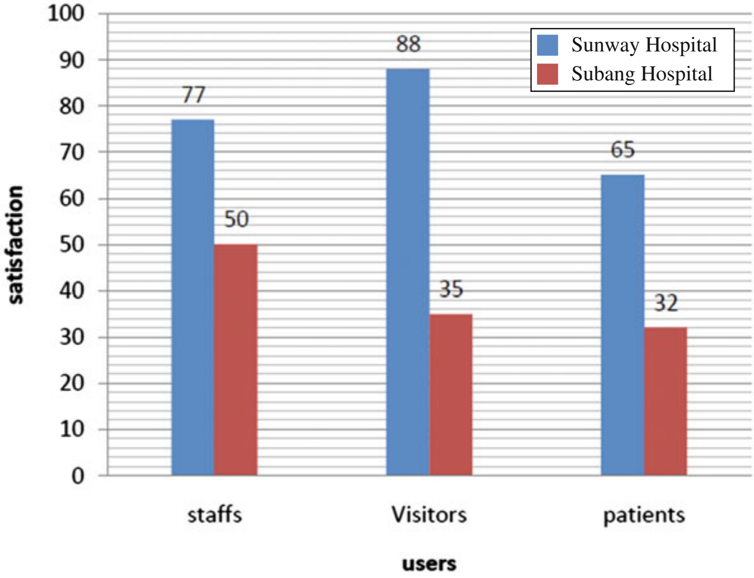


Fig. 3 Users satisfaction in general waiting areas in both hospitals

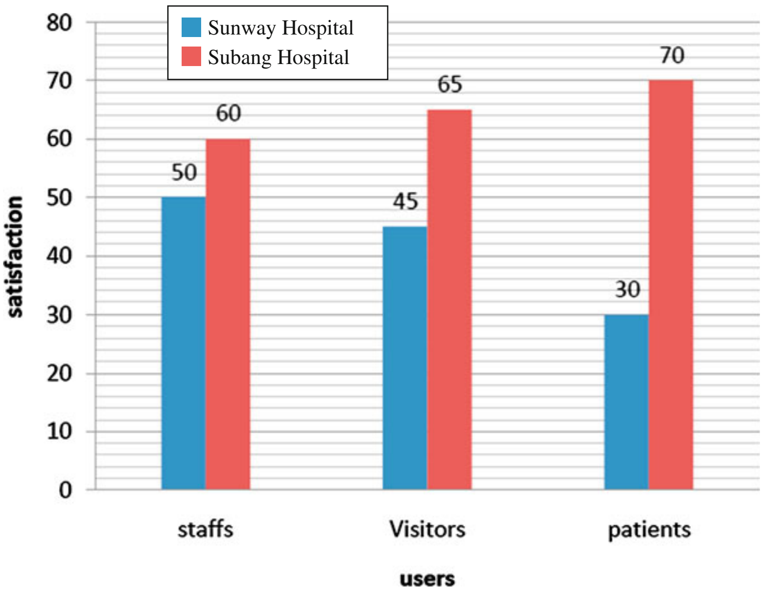


Fig. 4 Users satisfaction in outpatient waiting areas in both hospitals

waiting area is so simple, lake of design, narrow and quite boring area. Both waiting areas in Subang Hospital used lighter color for floor, wall and ceiling. In waiting areas of both hospitals can see artificial garden that it created a lifeless environment due to the artificial plant. After observation can say waiting areas in Subang Hospital are inviting, cheering, fresh that get arousing affective quality.

Color in architecture has multiple applications. Warm color can be used to reduce scale of area and cold colors visually enlarge a space, making it less confining. It can make appearance of space boring or pleasant. That's why color and emotion relationship is closely tied to color preferences.

It is recommend that, the color use, both in the interior and lighting must be an important factor in the waiting area. The color of the interior is makes an area pleasant and welcoming. It is also one of the things that remained people of being at home.

According to interview, users prefer warmer colors more positively rather than colder colors. Colors of a warmer temperature, such as yellow-brown, make the room feel warmer. Strong colors like red-orange are used to decorate the waiting room increase the patient's patience level which lead them to be restless while they wait in the room.

Floor color is better use a lighter shade of color like; white, cream and light gray tone. Light colors were consistently preferred or all objects such as ceiling, wall, floor, furniture. It should be emphasized that even white was a desirable color for ceiling.

For future study, we can develop this article in: direct communicators, the arrangement of the furniture, color use and messages that communicate the waiting room is a nice place to be.

Acknowledgments I would mainly like to thank my thesis supervisor, for this invaluable time spent to providing me guidance, suggestions, comments and encouragement. Also, I wish to express my appreciation to the staff and management of both hospitals for having guided and assistance me at searching and collecting data in the hospital.

References

1. Dalke H, Littlefair PJ, Loe DL (2004) Lighting and color for hospital design. London South Bank University, pp 351–356
2. Mariah W, Harun W, Ibrahim F (2009) Human—environment relationship study of waiting areas in hospitals. In: Journal of international association of societies of design research, proceedings of IASDR 2009, Seoul, pp 691–700
3. Kenz I () Effects of color of light on nonviable psychological processes. J Environ Psychol, pp 201-2-8
4. Leather P, Beale D, Santos A, Watts J, Lee L (2003) Outcomes of environmental appraisal of different hospital waiting areas. Environ Behav 35:842–869
5. Schweitzer M, Gilpin L, Frampton S (2004) Healing spaces; elements of environmental design that make an impact on health. J Altern Complem Med 10(Supplement 1):S71–S83
6. Ulrich RS (1992) How design impacts wellness. Healthcare Forum J, pp 35, 20–25, 1992

7. Arneill AB, Devlin AS (2002) Perceived quality of care: "the influence of the waiting room environment". J Environ Psychol 22:345–360
8. Mahnke F (1996) Color, environment, human response. Van Nostrand Reinhold, New York
9. Boyatzis CJ (1994) Children's emotional associations with colors. J Genet Psychol 155:75–85
10. Hemphill M (1996) A note an adults' color emotion associations. J Genetic Psychol, pp. 157, 275–281
11. Wexner LB (1954) The degrees to which colors are associated with mood-tones. J Appl Psychol 38:432–435
12. Linton H (1999) Color in architecture: design methods for buildings, interiors and urban spaces. McGraw Hill, New York
13. Clark PA, Maline M (2006) What patients want: designing and delivering health services that respect personhood. In: Marberry SO (ed) Improving healthcare with better building design. Health Administration Press, Chicago, pp 15–35
14. Malkin J () Medical and dental space planning: a comprehensive guide to design, equipment, and clinical procedures, 3rd ed. Wiley, New York
15. Ulrich RS (1991) Effect of interior design on wellness: theory and recent scientific research. J Health Care Interior Des 3(1):97–109
16. Ulrich RS, Zimring C et al (2008–2009) A review of the research literature on evidence based healthcare design. Health Environ Res Des J 2(2):61–125

Hybrid ANP: QFD—ZOGP Approach for Styling Aspects Determination of an Automotive Component

K. Jayakrishna, S. Vinodh and D. Senthil Kumar

Abstract Styling of automotive products is a vital issue and it need to be imbibed with increased customer expectations during every stage of product design. In order to achieve effective styling, it is necessary to apply quality function deployment (QFD) approach which is an effective product and system development tool. This study presents a decision framework where analytic network process (ANP) integrated with QFD and zero–one goal programming (ZOGP) models are used in order to resolve the design requirements which are more efficient in achieving aesthetic design. The first phase of the QFD is the house of quality (HOQ) which transforms customer requirements into product design prerequisites. In this study, after determining the sustainable requirements named voice of the customers (VOCs) and Engineering metrics (EMs) of an automotive component, ANP has been employed to determine the importance levels in the HOQ considering the interrelationships among EMs and VOCs. Additionally ZOGP approach is used to take into account different goals of the problem. A case study was presented to exemplify the approach.

Keywords Analytic network process · Quality function deployment · House of quality · Zero–one goal programming

K. Jayakrishna (✉) · S. Vinodh · D. Senthil Kumar
Department of Production Engineering, National Institute of Technology, Tiruchirappalli 620015 Tamil Nadu, India
e-mail: mail2jaikrish@gmail.com

S. Vinodh
e-mail: vinosh_sekar82@yahoo.com

D. Senthil Kumar
e-mail: dvsenthilkumar.mit@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_110, © Springer India 2013

Nomenclature

QFD	Quality Function Deployment
ANP	Analytic Network Process
ZOGP	Zero-One Goal Programming
HOQ	House of Quality
VOCs	Voice of the customers
EMs	Engineering Metrics
CRs	Customer Requirements
ECs	Engineering Characteristics
EPE	Environmental Performance Evaluation
DEMATEL	Decision Making Trial and Evaluation Laboratory
MCDM	Multiple Criteria Decision-Making
TOPSIS	Technique for Order Preference by Resemblance to Ideal Solution
LOC	Location of the component
U	Uniqueness
R	Reliability
EF	Enhanced functionalities
E	Ergonomics
I	Illumination
A	Aesthetics
D	Durability
W	Super matrix representation of the QFD model
W2	Matrix that denotes the influence of the VOCs on each EMs
W3	Matrix that represents the inner dependence of the VOCs
W4	Matrix that represents the inner dependence of EMs
WVOCs	Interdependent priorities of the VOCs
WEMs	Interdependent priorities of the EMs
WANP	Matrix that represents the overall priorities of EMs
wES	Weight vector of environmental sustainability
wM	Weight vector of manufacturability
wE’	Adjusted weight vector of environmental sustainability
wM’	Adjusted weight vector of manufacturability
ω	Matrix that represents the relative importance weights of the goals
C	Unit cost of EMs
UC	Adjusted unit cost vector

1 Introduction

Designing and manufacturing aesthetic products is a major, high-profile challenge to the industry as it involves highly complex, interdisciplinary approaches and solutions. Most research and applications so far, however, have not heavily focused on styling of aesthetic products. By designing a product with styling parameters in mind, companies can increase profit by reducing the cost incurred for their brand publicity, advertisements etc. Capturing and translating VOCs is a tough and tedious job. In modern challenging environment, QFD act as a key strategic tool to aid companies in developing stylish products that can satisfy customer needs. The fundamental concept of QFD is to interpret the requirements of customers i.e. VOCs into EMs and consequently into parts features, process strategies and production needs. HOQ is a type of intangible record that offers the means for efficient planning and communication [1]. In this case study, a methodology for determining the influential EMs that are to be considered in styling of a automotive product by integrating analytic network process (ANP) and zero–one goal programming (ZOGP) decision making techniques. ANP helps to bring up the interdependences among the VOCs and EMs. ANP was used for calculating the final relative importance of the EMs with maximum probable consideration of the EMs in the design phase as goal. Consideration of other metrics, such as cost budget, environmental sustainability and manufacturability of EMs marks the uniqueness of this study. Environmental sustainability quantifies the improvement of one EM over the other in styling improvement of the product. Manufacturability measures the degree of possibility of manufacturing the product with respect to one EM over the other. The relative importance weights of these goals are determined by pair wise comparisons. The ZOGP model is solved to determine the EMs, which will be considered in the design phase, in order to minimize the chances of divergences from the prioritized goals. The proposed framework adds quantitative precision to the judgmental decision process of product styling of the case assembly.

2 Literature Review

The literature was reviewed from the perspectives of applications of QFD, ANP and ZOGP

2.1 Review on Applications of QFD

An extensive practice in industry to cope with global competition is the adoption of Quality Function Deployment (QFD), which is well known as a customer-driven product development method originated in Japan in the late 1960s [2]. QFD is a planning and problem solving tool that is gaining growing acceptance for translating customer requirements (CRs) into engineering characteristics (ECs) of a product [3]. The QFD technique is a systematic procedure for defining customer needs and interpreting them in terms of product features and process characteristics. The systematic analysis helps developers avoid rushed decisions that fail to take the entire product and all the customer needs into account [4]. It is a process that involves constructing one or a set of interlinked matrices, known as "quality tables." The first of these matrices is called the "House of Quality" (HOQ). The Quality Function Deployment (QFD) is a well-known and a systematic method which is based on the idea of adapting technology to people [5]. QFD analysis method can be compared to 'participatory ergonomics' where the end-users are involved in developing and implementing the technology [6]. QFD has been used successfully by many Japanese firms, most notably Toyota [7]. Toyota halved their design costs and reduced product development time by a third after they started to use QFD [8]. Yang et al. [9] proposed a framework based on QFD for Environmental Performance Evaluation (EPE) to improve the environmental management system. QFD helps to identify the key performance indicators by transforming the environmental requirements to quantitative indicators. Rough set theory is integrated to analyze the incomplete and vague information. They remarked that QFD provide a systematic way to determine the performance indicators.

2.2 Review on Applications of ANP

ANP can produce priorities of technologies with consideration of their direct and indirect impact and was utilized in a systemic approach towards identification of core technologies from the perspective of technological cross-impacts [10]. The advancement of pair wise comparison matrices, employment of interdependencies among decision levels and expansion of more consistent results are considered as the unique features of ANP. Wu this paper proposed a combined ANP and DEMATEL approach to evaluate and select KM strategies. KM strategy selection is a multiple criteria decision-making (MCDM) problem. ANP deal with all kinds of interactions systematically and the Decision Making Trial and Evaluation Laboratory (DEMATEL) convert the relations between cause and effect of criteria into a visual structural model helps to handle the inner dependences within a set of criteria. The application of the proposed method is explained through empirical study. ANP approach can be used for choosing, evaluating, prioritizing and ranking etc., if mutually dependent relationships have considerable impacts on the decision model and have been used for developing an expert selection system to select ideal cities for medical service ventures jointly with technique for order preference by resemblance to ideal solution (TOPSIS) [11].

2.3 Review on Applications of ZOGP

Badri et al. [12] developed a project selection model for health service institution which incorporates all of these factors such as decision maker priorities and preference, benefits, cost, project risk. The model is formulated as mixed 0–1 goal programming and validated by using a real world Information System (IS) project selection data. Lee and Kim [13] suggested an improved Information System project selection methodology which reflects interdependencies among evaluation criteria and candidate projects using analytic network process (ANP) within a zero one goal programming (ZOGP) model. The authors concluded that exploiting project interdependencies is one way of saving IS costs and frugality resources.

3 Case Study

The case study has been carried out in an automotive plastic component manufacturing organization located in Bangalore, India (hereafter designated as XYZ) with the help of a cross functional team involving participants from the organization and customers. XYZ was facing the problem of generating new stylish components for their customers including their valuable ideas into product design and development.

Step 1 *Identification of VOCs and EMs*

The cross functional team revealed the most important VOCs of the product under study with respect to styling as, Location of the component (LOC), Uniqueness (U), Reliability (R), Enhanced functionalities (EF) and EMs as, Ergonomics (E), Illumination (I), Aesthetics (A), Durability (D)

Step 2 *Consideration of interdependencies among VOCs and EMs within HOQ and resolving the overall precedence of the EMs by ANP approach*

The super matrix representation of the QFD model proposed by [14] (Eq. 1) is used in this case study to imbibe the dependencies inherent in QFD process into analysis.

$$W = \begin{array}{r} Goal\,(G) \\ Voice\,of\,Customers\,(VOCs) \\ Engineering\,Metrics\,(EMs) \end{array} \begin{pmatrix} 0 & 0 & 0 \\ w_1 & W_3 & 0 \\ 0 & W_2 & W_4 \end{pmatrix} \quad (1)$$

where, $\mathbf{w_1}$ is a vector that represents the influence of the goal, namely improving the styling aspect of the product based on VOCs. $\mathbf{W_2}$ is a matrix that denotes the influence of the VOCs on each EMs, $\mathbf{W_3}$ and $\mathbf{W_4}$ are the matrices that represent the inner dependence of the VOCs and EMs respectively. The interdependent priorities of the VOCs ($\mathbf{W_{VOCs}}$) and the interdependent priorities of the EMs ($\mathbf{W_{EMs}}$) are computed by using Eqs. 2 and 3.

$$\mathrm{W_{VOCs}} = \mathrm{W_3} \times \mathrm{w_1} \quad (2)$$

$$W_{EMs} = W_4 \times W_2 \quad (3)$$

The overall priorities of the EMs ($\mathbf{W^{ANP}}$) which imitate the interrelationships within the HOQ are computed by using Eq. 4, as

$$W^{ANP} = W_{EMs} \times W_{VOCs} \tag{4}$$

$$W^{ANP} = \begin{pmatrix} 0.550 \\ 0.269 \\ 0.104 \\ 0.079 \end{pmatrix}$$

The ANP analysis results indicate that the most important design feature is the ergonomics (E) with a relative importance value of 0.550.

Step 3 *Identification of the metrics*

Cost budget, Environmental sustainability, manufacturability of the case product were selected as the metrics by the cross functional team. The weight vector of environmental sustainability ($\mathbf{w^{ES}}$) and the weight vector of manufacturability ($\mathbf{w^{M}}$) are calculated by pairwise comparisons.

Step 4 *Determination of preference ratings of the EMs with respect to metrics by pair wise comparisons*

The cost budgets of all the EMs are limited to Indian National Rupee (INR). 90 in this case study by the cross functional team. The unit cost **(C)** of EMs were estimated based upon the actual possible cost that will be incurred to implement the respective EMs. Table 1 presents the **C** of the EMs.

Step 5 *Computation of weight vectors of EMs with respect to the metrics for dependencies encountered in the HOQ*

To infuse the adjustment for dependencies, the adjusted unit cost vector (**UC**) is calculated by multiplying the inner dependence matrix of the EMs ($\mathbf{W_4}$) with the unit cost vector of the EMs (**C**) as shown in Eq. 5.

$$UC = W_4 \times \ C \tag{5}$$

Correspondingly the adjusted weight vectors of the environmental sustainability and manufacturability are computed using Eqs. 6 and 7 respectively, as

$$w^{E'} = W_4 \times w^{ES} \tag{6}$$

$$w^{M'} = W_4 \times w^{M} \tag{7}$$

Table 1 Unit cost of the EMs

EMs	Cost in INR (C)
E	25
I	15
A	40
D	10

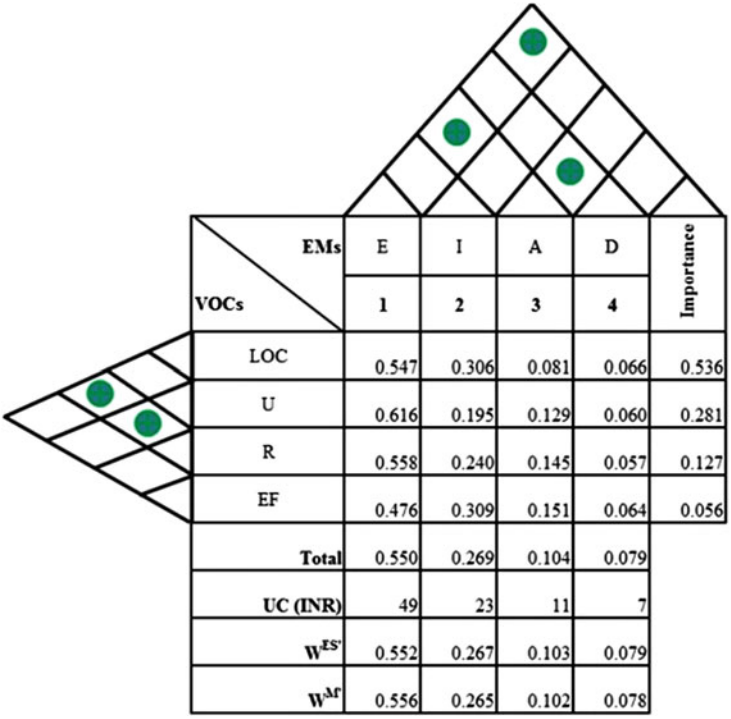


Fig. 1 HOQ presenting the dependencies of EMs with metrics

$$w^{E'} = \begin{pmatrix} 0.552 \\ 0.267 \\ 0.103 \\ 0.079 \end{pmatrix}$$

$$w^{M'} = \begin{pmatrix} 0.556 \\ 0.265 \\ 0.102 \\ 0.078 \end{pmatrix}$$

The HOQ attained using all the above data from the earlier steps would resemble as illustrated in Fig. 1.

Step 6 *Calculation of relative importance weights of the goals using pairwise comparisons*

In this step, the relative importance weights (ω) of the goals are considered in enhancing the product styling of the case product which are computed by pairwise comparison matrix as shown in Table 2.

Table 2 Computation of ω for goals

Goals	WANP	U	WES	WM	Relative importance weights (ω)
WANP	1.000	3.000	5.000	5.000	0.537
U	0.333	1.000	3.000	7.000	0.289
WES	0.200	0.333	1.000	3.000	0.117
WMFG	0.200	0.143	0.333	1.000	0.058

Table 3 Group of EMs selected by integrated hybrid approach

EMs	ZOGP solution
E	x1 = 1
I	x2 = 0
A	x3 = 1
D	x4 = 0

Step 7 *Development of ZOGP model and solving to determine the EMs to be consider in the process of product styling*

The generic form of ZOGP model as proposed by [15] is used in this case study. The ZOGP model developed using Eq. 8, based on the results computed is shown below, The ZOGP model developed with the data acquired from the previous steps was solved using LINDO software

$$\min 0.537 d_1^- + \left(\frac{0.289}{800}\right) d_2^+ + 0117 d_3^- + 0058 d_4^- \tag{8}$$

Subjected to,

$$0.550x_1 + 0.2698x_2 + 0.104x_3 + 0.079x_4 + d_1^- - d_1^+ = 1$$

$$49x_1 + 23x_2 + 11x_3 + 7x_4 + d_2^- - d_2^+ = 90$$

$$0.552x_1 + 0.267x_2 + 0.103x_3 + 0.079x_4 + d_3^- - d_3^+ = 1$$

$$0.556x_1 + 0.265x_2 + 0.102x_3 + 0.078x_4 + d_4^- - d_4^+ = 1$$

$$x_j \in (0, 1), j = 1, 2, \ldots\ldots, 4 d_i^-, d_i^+ \geq 0, \quad i = 1, 2, 3, 4.$$

Table 3 shows the group of EMs selected by integrated ANP and ZOGP approach include Ergonomics (E) and Aesthetics (A).

4 Conclusions

The ever increasing market dynamism, forces modern organizations to practice integrated approach as they remain the need of the hour to survey. The integrated approach illustrated in this case study aims to quantify the interdependencies and multiple objectives inherent in the styling design problem in a systematic way based on expert opinions, considering goals, resource limitations and metrics, appears as an effective solution support. The study also revealed that ergonomics and aesthetics as the major EMs to be more concentrated in developing the design of the case automotive product. The integrated approach presented in this paper can be extended for real time applications by considering goals, additional resource limitations and design metrics.

Acknowledgments The authors are thankful to Department of Science and Technology (DST), New Delhi, India for sanctioning the fund towards the execution of project titled "Development of a model for ensuring sustainable product design in automotive organizations" (Ref. No.SR/S3/MERC-0102/2009). This research study forms a part of this major research project.

References

1. Hauser JR, Clausing D (1988) The house of quality. Harvard Bus Rev 66:63–73
2. Cristiano JJ, Liker JK, White CC (2000) Customer-driven product development through quality function deployment in the US and Japan. J Prod Innov Manage 17:286–308
3. Akao Y (1990) An introduction to quality function deployment. Quality function deployment (QFD): integrating customer requirements into product design
4. Cohen L. (1995) Quality function deployment: how to make QFD work for you. Addison-Wesley, USA
5. Andersson R (1991) QFD—ett system for effektivare produktframtagning. Studentlineratur, Lund, Sverige. (In Swedish.)
6. Imada AS, Noro K (1991) Participatory ergonomics. Taylor and Francis, London
7. Lochner RH, Matar JE (1990) Design for quality. Quality resources, New York and ASQC Quality Press, Wisconsin
8. Bergman B, Klevsj B (1994) Quality from customer needs to customer satisfaction. McGraw-Hill, London
9. Yang YN, Parsaei HR, Leep HR, Chuengsatiansup K (2000) Evaluating robotic safety using quality function deployment. Int J Manuf Technol Manag 1(2/3):241–256
10. Kim CH, Lee H, Seol C (2011) Identifying core technologies based on technological cross-impacts: an association rule mining (ARM) and analytic network process (ANP) approach. Expert Syst Appl. doi:10.1016/j.eswa.2011.04.042
11. Ayag Z, Ozdemir RG (2009) A hybrid approach to concept selection through fuzzy analytic network process. Comput Ind Eng 56:368–379
12. Badri MA, Davis D, Davis D (2001) A comprehensive 0–1 goal programming model for project selection. Int J Project Manage 19:243–252
13. Lee W, Kim SH (2000) Using analytic network process and goal programming for interdependent information system project selection. Comput Oper Res 27:367–382
14. Saaty TL, Takizawa M (1986) Dependence and independence: from linear hierarchies to nonlinear networks. Eur J Oper Res 26:229–237
15. El-Gayar OF, Leung PS (2001) A multiple criteria decision making framework for regional aquaculture development. Eur J Oper Res 133:462–482

Kalpana: A Dome Based Learning Installation for Indian Schools

Ishneet Grover

Abstract For children in India, the day of visit to a science center brings lot of fun and curiosity about the observed installations. But they visit this learning playground only once or twice a year. This kind of learning experience is missing in schools. In this project we attempted to bring the experience of science centers to schools. We propose "Kalpana"; an interactive dome based learning installation. It empowered students to visualize the phenomenon that sun changes its trajectory in the sky with change in location or time of the year. Students could interact with the physical model and corresponding changes were observed on dome supported with contextual audio feedback. This installation based teaching method was evaluated against conventional paper based and software based applications. It found to be significantly better and entertaining for students.

Keywords Learning installation · Dome based learning · Indian school education · Astronomy for kids · Interactive installations · Science museum

1 Introduction

There are 13,62,324 (provisional as on 30th Sept 2011) number of Primary Schools in India as stated by National University of Educational Planning and Administration under District Information System for Education (DISE) [1]. In contrast to the number of schools there are only 27 science centers throughout India (under National Council of Science Museum) [2]. Science Center, an excellent place for effective experiential learning is either out of reach of students

I. Grover (✉)
Interaction Design, Industrial Design Center, IIT, Bombay, India
e-mail: ishneetgrover@gmail.com

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_111, © Springer India 2013

or they have insufficient time during their visit. In India, students visit a science center, once or twice a year. There also, they just move around in a hurry to complete the visit and do not have sufficient time to experience the phenomenon or to understand the rationale. Personal experience from a visit to a science center motivated us to answer the question: "How can we bring experience of Science Center learning to schools?" and hence we started exploring in this area.

2 User Studies

The project started with reviews from five experts in the field of design, teaching, cognitive psychology and learning. The group introduced us to various methods of teaching, education system in schools and installations in science centers. Following this, a detailed study was conducted in two stages:

2.1 Contextual Inquiry at Science Centers

User studies were carried out at four different science centers in Bangalore, Mumbai and Pune. The purpose of these studies was to understand the effectiveness of learning environment that a science center provides through physical and digital installations. *Observational study* was carried to figure out characteristics of installation that could attract students the most. This was followed by *informal discussions* with students and teachers to gather insights on aspects of installation they like and don't like. *Contextual Interviews* were carried out with 12 students, 4 accompanying teachers, and 2 science center managers. A typical interview lasted for about 15 min. 10 out of 14 interviews were good and interpreted. The interpretation was done on the same day.

In science centers students were in a learning environment where they could interact with the content and discover new things (Fig. 1). This encouraged students to actively use their intuition, imagination and creativity [3]. Students could relate better to the topics already covered in schools. As quoted by one of the teachers "Children respond better after their visit to science center" [4]. A lot f installations at science center required teamwork, which encouraged students to work together (Fig. 1). The use of audio and visual feedback in installations helped students to understand the content being explained. It also allowed students to compare different results on the go.

During visits a short *survey* was conducted and it was found that 34 out of 40 students were visiting this place after a year. Sometime, there were instances when students felt need of assistance to understand the installation and so they preferred company of an elder, teacher or friends rather than visiting alone. A few sections in the science center were underutilized (Fig. 1). According to the Science Center Manager, these installations explained topics that are taught only in higher

Fig. 1 (*left* to *right*) Student interacting with installations at science centers, students playing together with the installation in a group, least visited computer section in science centers, teacher explaining using static models

secondary e.g. logic gates. Students could connect very fast to the installations if it shows familiar content.

2.2 Contextual Inquiry with Students and Teachers in Schools

This study was conducted at six different schools that include government, private school and international schools from Mumbai, Mohali and Bangalore. A total of twenty *contextual interviews* were conducted with over ten students (of class vi–vii), eight teachers (teaching science, social science and math) and two school principals. The interviews were conducted like an informal discussion. The purpose of the study was to understand the actual learning environment, problems faced by teachers while teaching and problems faced by students to understand abstract concepts.

Master apprentice model of interviewing was adopted for interviews with two teachers. Teachers were asked to teach us "What to teach and How to teach the class in their absence". It was found that teachers were not able to communicate and explain clearly certain topics using just textbook and blackboards; static models helped little, but confusion still remained (Fig. 2). Teachers tried to take help of external resources like YouTube videos and Internet based applications. These videos and applications were helpful, but there was difference between actual topic that was to be taught and the focus with which the video/application was made. Hence, the topic was not efficiently explained with required more emphasis. Students faced lot of difficulties especially when they had to imagine and visualize 3-dimensional information. Some of the private schools used e-Beam technology and interactive board equipped classrooms. These type of technological interventions enhanced teaching but 3-dimensional abstract concepts mentioned above still remained unclear.

3 Available Learning Modules

Parallel product survey was done to understand what kind of products are available that are used for teaching abstract 3-dimensional concepts (Fig. 2). Below is the analysis (Table 1) explaining the advantages and disadvantages of few products.

Fig. 2 (*left* to *right*) Do it yourself kit, electric bell from Iken, mechanical model, Stellarium (software) and Taramandal installation

Table 1 Evaluation of existing products, which teach scientific concepts

Product	Advantages	Disadvantages
Do it yourself kits astrolabe and planetary probe	Teaches interesting concepts using simple day-to-day objects	Product quality is crude, does not provide feedback, lacks fun element
Mechanical model	Simulates the actual process of rotation mechanically	Limited content; requires assistance, no instruction set available, labels on the installations were not correct
Online applications Stellarium [5] and Celestia [6]	Very informative and flexible to use. Gives complete control in the hands of the user, interesting and exciting to use	Too much information and options, difficult to grasp due to panoramic views that are confusing for students
Physical installations Taramandal and mini planetarium	Very good immersive learning medium with fun element. Mini-planetarium is portable and thus can be carried around	Purely observational in nature, lacks interactivity, manually operated by staff, information is hard coded and thus limited information

4 Content Selection

Rotation, revolution and the sun's trajectory are factors that form the basis for few important concepts. Seasons on earth, Time zones, day/night, solar/lunar eclipse, etc. are some of the phenomena affected by this. Through our preliminary survey we realized that these concepts were not clear to many students. Important for the selection of this phenomena as the subject to be taught were reasons for this were:

- It's 3-dimensional in nature,
- It's abstract since it can't be observed and
- It takes long duration of time say years/months to observe these changes in reality.

More precisely the exact subject that was finally chosen as the subject matter was: "Sun changes its trajectory in the sky with change in location or time of the year". Such topics are taught in schools and appear in NCERT books of class vi, Social Studies subject Chapters 2 and 3 of *The Earth is Our Habitat*. Below are some of the images from the book [7] (Fig. 3).

In order to explain this concept effectively to students, the content was restricted and following points formed the basis for designing content:

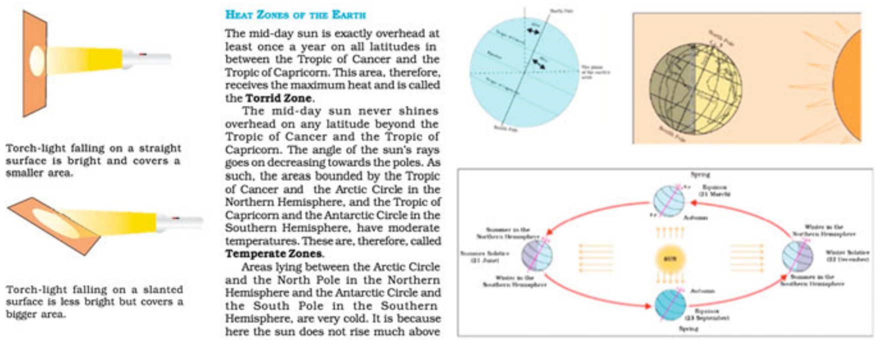


Fig. 3 (*left* to *right*) Image of NCERT book explaining heat zones formed, rotation, revolution and seasons [7]

- These concepts should be taught with reference to the "Observer's location on earth" in addition to "Space" as the viewpoint.
- The concept should be taught by comparing sun trajectories of two locations or two different times of the year.

Following tables explain the content redesign in detail: A set of basic principles was derived which were later used in the final design (Table 2).

Table 2 Basic principles and comparisons of sun's trajectory at two locations

Phenomena	Reason	Examples	Diagrammatic representation
Two different locations have same seasons and same sun's trajectory	Two places have same latitude and are in same hemisphere	New York and Kashmir	
Two different locations have opposite seasons and mirror image sun's trajectories	Two places have same latitude values but are in opposite hemispheres and in opposite time of the year	Red sea and Madagascar	
Two nearby locations have similar seasons but prominent changes in sun's trajectory	Two places are near same poles but little distance apart	North Pole and Greenland	
Sun's trajectory is perpendicular to horizon	The place is on the equator	Singapore	
Sun's trajectory is parallel to horizon	The place is on any of the poles	North Pole	

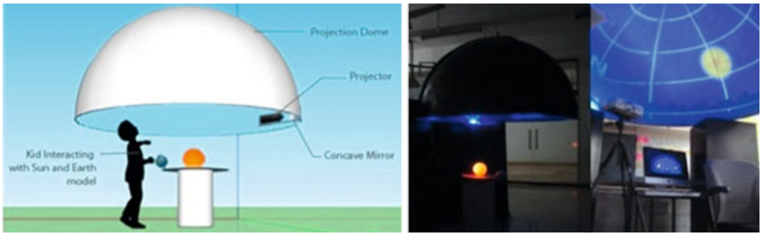


Fig. 4 (*left* to *right*) Diagrammatic representation of Kalpana, actual life size prototype

5 Proposed Solution

Based on the insights from user study and principles derived from the content; an immersive installation of size (2 × 2) was proposed. Hence, we designed *Kalpana*, an immersive dome based, learning installation for schools that allows students to interact using tangible objects (Fig. 4). *Kalpana* is made using one projector, a spherical mirror, a hemispherical projection surface and replica models of earth and sun. Students interact with the physical model to select location on the earth and change time of the year. This in turn shows them the sun's trajectory, which is projected on the surface of dome. For the purpose of evaluation a high fidelity prototype was developed [8].

The system consist of:

1. *Physical Model*, for input
2. *Visual Response* and
3. *Audio Response*

Figure 5 shows the basic workflow of the installation.

5.1 Physical Model (Interactive Input System)

A physical model was constructed using known objects like a sun (represented by glowing ball) and a globe. It was made interactive using simple buttons. At any time during interaction student could give two types of input.

5.1.1 Location Input

Student can select the location by pressing the button on the globe (Fig. 6).

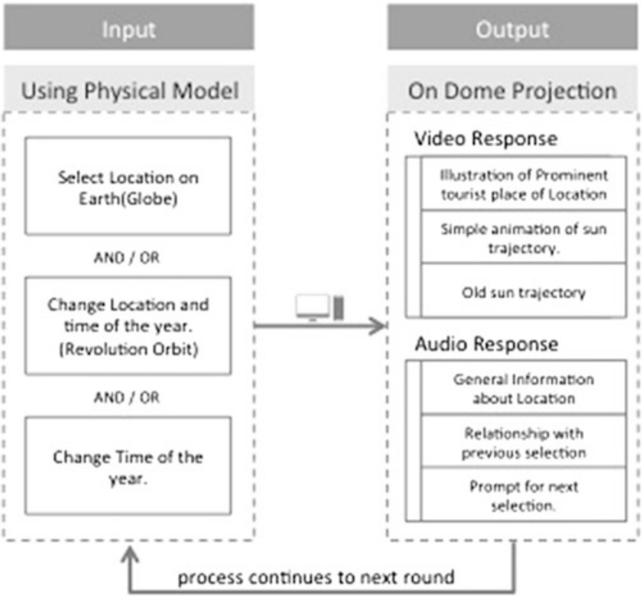


Fig. 5 Interaction flow diagram of Kalpana

5.1.2 Time Input

Student could select the time of the year by revolving the globe around the sun. It could be revolved only in one direction replicating the revolution of Earth. The base of the model was labeled with four prominent months of the year. [Summer Solstice (21st June), Autumnal Equinox (22nd September), Winter Solstice (21st December), Spring Equinox (21st March)]

5.2 Visual Response

The visual response projected on dome showed three things:

- Illustration: Location and a visual showing the prominent tourist place/monument of that location e.g. Statue of Liberty for city New York (Fig. 6).
- New Trajectory: The trajectory of the sun path with simple line animation (Fig. 6).
- Old Trajectory: The trajectory of the sun for the previous selection to show comparison (only if relationship exists).

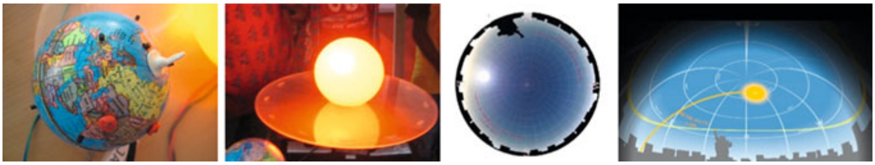


Fig. 6 (*left* to *right*) Globe with buttons to select location, model that allows student to revolve the earth around the sun to select time of the year, Output visual of New York as seen on the dome (polar grid), video screenshot of New York with sun's trajectory warped for projection on dome

> *"We are watching the March sky in North Pole. It is the northern most ti p of the earth located at 90 degrees N latitude. In the month of March the sun encircles on the horizon in clockwise direction.*
>
> *Did you notice? The sun did not set, even at the end of the day. This is because at Poles, sun rises only once in 12 months. Which means they experience 6 months of long days. However At North Pole, when the sun is about to rise, it is about to set at SP. At NP the sun will set only in the month of September. [pause]*
>
> *At poles sun is always parallel to the horizon. As we move towards the equator the path of the sun starts becoming angular and we see the sun higher in the sky. Tr y and observe this in Greenland, which is located south of NP at 72 deg ree North latitude.*

Fig. 7 Example of an audio script for North Pole in month of June

5.3 *Audio Response*

An audio feedback was given to explain the reasons of the observed sun's trajectory (Fig. 7). Depending on the last two inputs given by the user, the audio response for any input will have all or some of the following audios:

- Information about the Location.
- Information about the sun's path at that location.
- Comparison of sun's new trajectory with previous path (only if relationship exists).
- Triggers to prompt the student for the next Input.

6 Usability Evaluation

Kalpana, Paper based learning method and Stellarium (screen based learning method) were evaluated with students. Students of class VI scoring average marks in Social studies were shortlisted and distributed into three groups. The goal of the evaluation was to compare paper based learning method, Stellarium and Kalpana

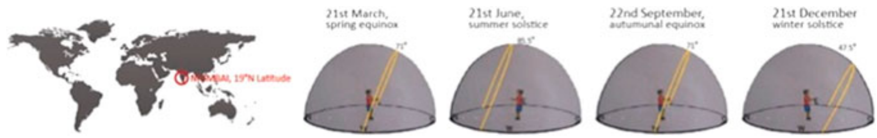


Fig. 8 Clip from the chapter prepared for paper based module

Fig. 9 (*left* to *right*) Evaluation of paper based, Stellarium, Kalpana

with respect to understanding of the concept (Fig. 9). For the evaluation of Paper based method an improved version of book chapter, a well-labeled world map and worksheets (to indicate their answers) were used (Fig. 8).

In all eighteen students participated in the study, with six students per learning method. Initially a 10 min orientation of the concept was given to each student for the method being evaluated. After this, an informal question and answer session (pre-test) was conducted with each student to evaluate understanding of the concept. In all, total of six parameters were defined to evaluate. The pre-test included the evaluation concepts such as: *Latitude Change*, *Longitude Change*, *both Latitude and Longitude*, *Month Change*, *Extreme cases* (E.g. North Pole, South Pole, Equator, Tropic of Cancer, Tropic of Capricorn). The sequence in which the parameters were evaluated was the same but the questions were framed as per the user to make the student feel comfortable and not to make them feel as if it is an exam.

6.1 Findings

Table 3 summarizes the success rate of the students for each method. Kalpana scored the maximum score per student (92 %). The difference between Kalpana and Paper based method was significant beyond $\alpha = \mathbf{0.01}$ (one tailed). The difference between Paper based and Screen based was not significant with $\alpha = \mathbf{0.17}$ (one tailed).

The installation based learning environment empowered students to visualize easily. Physical model helped students to see the over all picture and visual projection on dome to give location specific view. It helped student to relate the content to their day-to-day life and thus easier to remember. The support of audio

Table 3 Success rate of students for each method

	Paper based module	Stellarium	Kalpana
Correct answers (average out of six)	2.16 (S.D 0.4)	3.17 (S.D 1.6)	5.5 (S.D 0.8)
Percentage (%)	36 %	53 %	92 %

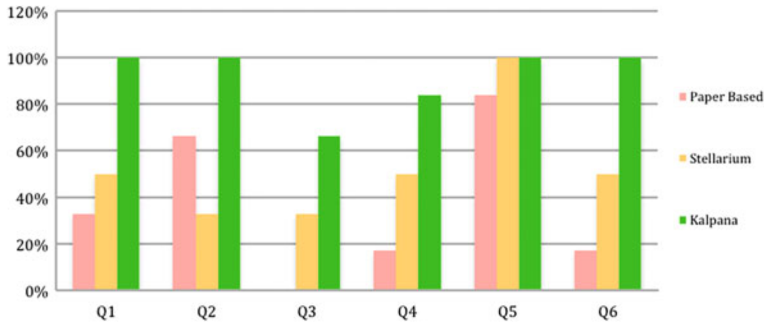


Fig. 10 Graph showing the comparison of the three methods w.r.t each evaluation parameter. (x evaluation parameter, y percentage of questions answered) (n = 6)

feedback helped students to learn more about the location. Prompts were useful to guide the student for the next input. When the data is reviewed as per the evaluation parameters, the average performance of students using Kalpana increased drastically when compared to average performance of students using Paper based method (Fig. 10).

7 Conclusion

'Kalpana'—meaning imagination, made students fantasize about traveling to different places on earth and observe changing trajectories of sun. It helped them to learn about earth's tilt, the changing sun's trajectory and how this change affects their city; with an immersive medium. Kalpana proved to be significantly better teaching method when compared to other paper and screen based methods. This was result of physical models of globe and sun, which gave a bird's eye view in combination with dome projection that gave actual view of how it would look in real sky. It helped student to relate the content to their day-to-day life and thus it became easier for them to remember and explain the concept. The support of audio feedback helped students to learn more about the location and ensure message is conveyed clearly. Students were actually enjoying the installation while learning was automatically happening.

However, a set of evaluation and comprehensive feedback session with teachers who would be actually using this installation at schools is yet to be done. The initial set of feedback from school stakeholders threw light on more interesting challenges such as; need of installation to be modular in nature, incorporate different kind of contents/concepts which can taught using similar setup, etc. The cost of the setup was one of the major challenges and with the availability of low cost projectors; we are trying to make it affordable for every school.

8 Future Work

The project can be developed on two front product design and other applications:

8.1 Product Design

The dome in ‘Kalpana’ prototype was made of FRP (Fiber Reinforced Plastic). When this prototype was tested it was found that there is a need to make the dome portable and foldable with minimal complications to setup. Also, there is need to make the whole installation visually attractive and robust for children.

8.2 Other Applications

Kalpana can also be used to teach other concepts that can be understood better by children through interactive immersive installations. For Example:

- Earth-Sun relationship: Shadows, weather.
- Astronomy: direction of starts, constellations.
- Concepts of electromagnetism: directions of lines of force, and many more.

All of these concepts would require a lot of study and expertise to develop.

Acknowledgments We thank Prof. Anirudha Joshi for his constant guidance throughout the project that helped a lot. We would also like to express sincere appreciation for Prof. B. K Chakravarthy, Prof. Sudesh Balan and Prof. Mandar Rane for their help to design the prototype and Prof. U. Athavankar to enable me to think at a broader perspective. We also thank the teachers and students at Kendriya Vidyala, IIT Bombay, all participants, users who provided feedback. We would also like to thank Shant Sagar, Chitra Chandrashekhar, Nikhil Autade, and Kumar Ahir for their help.

References

1. Mehta AC (2010–2011) Progress towards UEE—Elementary education in India. District information system for education, India, Analytical Reports
2. National council for science museums (2011) http://www.ncsm.gov.in
3. Brune J (1996) The culture of education. Harvard University Press, Cambridge
4. Grover I (2010) Interview with teacher at Nehru Science Centre, Mumbai
5. Stellarium (2011) http://www.stellarium.org/
6. Gregorio F (2011) http://www.shatters.net/celestia/index.html
7. NCERT (2010) Social science: earth our habitat, 10 July
8. Brouke PD (2005) Using a spherical mirror for projection into immersive environments. Graphite (ACM Siggraph), Dunedin Nov/Dec 2005

Design and Development of Hypothermia Prevention Jacket for Military Purpose

S. Mohamed Yacin, Sanchit Chirania and Yashwanth Nandakumar

Abstract This article discusses the design of a jacket that will help the military personnel stationed at the extreme cold climatic conditions to prevent going into hypothermia, a medical condition where in the core body temperature drops below 35 °C (95 °F), which causes shivering, mental confusion and ultimately leads to death. Our aim is to develop an external heating system in the form of heating pads that will aid the body to avoid going into hypothermia state. The set of three heating pads are controlled through a programmable microcontroller and temperature sensors. The pads are allowed to get heated only within the set range i.e. 37–45 °C. All these components are finally embedded in a polar fleece jacket which is an ideal substitute for wool and is much lighter than its predecessor. An inner layer of styrofoam and copper sheet lining helps in further distribution of heat evenly to the rest of the body surface. Thus, a virtual environment (around 37 °C) is created around the human body and does not allow it to lose heat further. This reduces the hypothermic effect on the body by preventing the loss of heat from the body to the cold surroundings, and hence makes the individual feel much better in such harsh climatic conditions and prevents any adverse effects from happening.

Keywords Hypothermia · Heating pads · Microcontroller · Sensor

S. Mohamed Yacin (✉) · S. Chirania · Y. Nandakumar
Biomedical Engineering, Rajalakshmi Engineering College, Thandalam, Chennai, India
e-mail: s_yacin@yahoo.co.in

S. Chirania
e-mail: sanchit.chirania.2008.bme@rajalakshmi.edu.in

Y. Nandakumar
e-mail: yashwanth.n.2008.bme@rajalakshmi.edu.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_112,

1 Introduction

Environmental temperature and humidity play an important role in the maintenance of body temperature [1]. Humans are Endothermic species of animals and maintain their body temperature within a range so that it will assist in carrying out the metabolic activities of the body. Mainly the temperature maintenance of the body is controlled by the preoptic area of the anterior hypothalamus of the brain, which is responsible for recognizing alterations in the body temperature and responding appropriately [2]. Hypothermia is very common condition that occurs in the cold climatic conditions where the outside temperature is so low that the body begins to lose its internal heat to the surroundings in the form of radiation as well as convection. Despite all this, the human body tries its best to adapt to the situation and does numerous activities listed below to avoid any fatal condition.

1. Sweat stops being produced.
2. The minute muscles under the surface of the skin called erector pili muscles contract, lifting the hair follicle upright. This makes the hairs stand on end which acts as an insulating layer, trapping heat.
3. Arterioles carrying blood to superficial capillaries under the surface of the skin can shrink, thereby rerouting blood away from the skin and towards the warmer core of the body. This prevents blood from losing heat to the surroundings and also prevents the core temperature dropping further.
4. Shivering of muscles increases heat production as respiration is an exothermic reaction in muscle cells. This means that less heat is lost to the environment via convection.
5. Mitochondria can convert fat directly into heat energy, increasing the temperature of all cells in the body.

Despite all the efforts put by the body, sometimes it will not be able to generate the necessary heat or loose that extra bit of heat in order to keep the stable normal internal temperature. This is when hypothermia sets in and causes fatal issues, which needs to be attended immediately. Although many traditional methods are there to help the people revive back from hypothermia but very few methods to prevent it.

1.1 Existing Technologies

The existing technologies include the equipments that are used to bring back the person who has already been affected by hypothermia and helps the victim to return to normal condition. The following subsections will discuss in detail about all the equipments used today for reviving the victim from hypothermic state.

1.1.1 Blizzard Survival Blanket

The blizzard blanket consist of a extra large blanket made up of Reflexcell^{TM} materials that is used to wrap up the casualty and it reduces the risk of heat loss from the patient. This is another way to cover up the casualty completely from head to toe thereby preventing any more loss in body temperature. It provides the total warmth and weather protection with the help of Reflex cell^{TM} material, thereby reducing shock and the risk of hypothermia in all conditions [3].

1.1.2 Res-Q-Air

This technique involves administering warm air to the person who has gone into hypothermia; by which we can increase the body temperature internally. The system functions exactly like that of a ventilator, the only difference being the temperature at which the oxygen is administered is warmer in this case [1]. The inlet oxygen is heated and humidified to a temperature of 42 °C. Thus, it requires an oxygen cylinder.

1.1.3 Hot IV Fluid Bag

In this method hot IV fluid bags are placed in the weak points of the body, i.e. the neck, arm pits and the groin. These are the points where maximum heat loss takes place. Thus tapping the heat would result in overall increase in the body temperature [1]. This method can only be used in the case if the person is suffering from mild hypothermia.

All the three above methods may provide some benefit; however, for massive transfusion therapy counter-current heat devices seem more effective maintaining the temperature of infused fluids and blood to higher than 33 °C. Thus preventing a person to fall in hypothermia in cold climatic conditions is a challenging task and requires a specially designed system which should maintain the normal body temperature and metabolism.

1.2 Challenges and Difficulties in Designing a Preventive Jacket for Hypothermia

Treating hypothermia is a multi step procedure and is usually performed by trained doctors or nurses using some assist devices, which is cumbersome and takes the more time to do. So preventing the person from going into hypothermia is better than reviving a person after he/she has gone into a hypothermic condition. The main objective of our work is to design a system which prevents the interaction of human body with external cold condition without affecting the normal phycological functions of the body. This will actually minimize the heat loss from the body to the outside cold surroundings.

The first attempt of developing a Hypothermia Prevention jacket was by using Infrared radiation. Infrared has a unique property that it can pass through the human tissues causing minimum side effects. During this process, it tends to increase the blood supply in the region it passes through. The increased blood supply results in increased temperature of the body, thus serving the purpose. This seemed to be the best possible solution to the problem of providing a controlled external heating. When we started designing, the problem that surfaced was the infrared source. The infrared LED’s that is available in the market is of the range below 1 μm (NIR). But to have the desired effect quickly, the infrared source should be in the range of 1.5–5 μm (FIR) and none of the sources matched the above specifications were small enough to be fitted inside the jacket. Using such a small LED’s to pass infrared radiation for providing external heat to the body became very difficult.

The next thing that could possibly be used for heating up any object is a heating pad (for e.g. Sauna belt). Usually all the heating pads run on direct AC supply which hinders its portability. Thinking on similar lines we got the idea of having Nichrome as our heating material which has the capability of heating up to 100 °C that too when the source of current is D.C. Because of this, Nichrome became the perfect material to be used for our heating purpose.

The biggest hurdles here were the cost and the availability of a heating pad made up of Nichrome that could work in the required temperature ranges desired. The sizes of the pads were also an issue as increasing the pad size would increase battery consumption. DC run heating pads were used and with the introduction of a programmable microcontroller coupled with a MOSFET drive, the heating pads were made to work in the required temperatures. To reduce the pad size, a policy of retaining the maximum temperature was employed. Special fabric setup was designed constituting components like Polar fleece, Styrofoam and copper sheets lining.

2 Proposed Design for Hypothermia Prevention Jacket

The aim of hypothermia prevention jacket is to protect the user from the cold surroundings and at the same time prevent him from going into hypothermia. The making of the jacket can be easily divided into fabric technology and electronic circuit’s part. Both are explained in detail in the following subsections.

2.1 Electronic Circuit

This section discusses the electronic circuits and components used in the making of the control unit for the jacket. This includes microcontroller (PIC 16F877A), temperature Sensor (LM35), metal oxide semiconductor field effect transistor (MOSFET—FQPF 5N60C), voltage regulator chip (7805) and heating Pads.

The microcontroller clock is generated by an external 10 MHz crystal. It produces a single instruction cycle time of 0.4 μs. This times all the circuit operations of the PIC IC effectively. A stable 5 V operating voltage is supplied to the controlling circuit using a voltage regulator (7805) followed by rectifiers, help avoid any further peaks that tend to be produced by a Lithium battery. MOSFET's are used as an electronic switch that's used to switch ON or OFF the heating pads. Also, heat sinks are used with the MOSFETs to remove the excessive heat generated from them. The temperature sensor (LM35) are placed in four different body locations three of which are placed on the heating pads to monitor their temperature and the fourth on the free armpit (Left) to read the body temperature. All the LM 35 are serially connected to the control unit. The control unit will house the microcontroller and its connections, LCD to display the temperatures of pads, body temperature and outside temperature, an On/Off switch, and a mode selector to switch between automatic and manual modes. Dimensions of the box being 17 × 10 cm made of iron and coated with rust proof paint. A specially developed algorithm is used by the programmable microcontroller [4] that controls the operation of the circuit and hence maintains the virtual environment in between the body and jacket preventing hypothermia.

2.2 Theoretical Calculations

This section discusses the theoretical calculations on heat generation and transfer of that through the body surface [3]. The amount of heat generated must be capable of maintaining the required outside temperature (in between jacket and body) and allow the body to perform its physiological functions. The temperature at a point is related to the heat density at the point as follows:

$$\text{Heat density} = \text{Mass density} \times \text{Specific heat} \times \text{Temperature} \tag{1}$$

Differentiating with respect to time:

Rate of heat density change = Mass density × Specific heat × Rate of temperature change

$$Q = M \times Cp \times dT \tag{2}$$

where, M—Mass of the air/body (approx. 70 kg), C_p—Specific heat of air/body (C_p for human body = 3,470 J/kg.K), dT—Change in temperature acquired (here, 1 °C).

This equation gives the amount of heat in Joules required to raise the temperature of the object. Now substituting for the various values in the equation,

$$Q = 242,900\,\text{J} = 242.9\,\text{kJ} \tag{3}$$

Convection is the transfer of thermal energy from one place to another by the movement of fluids or gases. Convection is usually the dominant form of heat transfer in liquids and gases [5–7]. Although often discussed as a distinct method of heat transfer, convection describes the combined effects of conduction and fluid flow or mass exchange. The amount of heat required is describes as,

$$Q = U \times A \times dT \tag{4}$$

where, U—heat transfer coefficient, A—Area of contact, ΔT—Temperature gradient, Q—Amount of heat required in watts.

This equation gives us the exact area of contact required to increase the body temperature. First step towards this is to calculate the temperature gradient and is given by,

$$\Delta T = \Delta T_1 - \Delta T_2/\ln(\Delta T_1/\Delta T_2) \tag{5}$$

In this case, the value were taken from the heat transfer coefficient for transfer of heat from heated car seats to driver or passengers and it was assumed that the same rate of heat flow to take place ($\Delta T = 3.47$ K). Q here has to be taken in watts and hence we have to convert the Q got in the above equation from calories to watts. The point here to be noted is that for conversion we need a time factor. The cold water survival of humans is more than an hour. To be on a safer side, we take the time for the exposure of heat to be 15 min. Then the Q becomes, 269.88 W. After substituting all the values in the equations, A becomes 0.539 m^2. Now this is the area of contact required for raising the temperature of the body by 1 °C.

Various calculations have been published to arrive at the body surface area (BSA without direct measurement. The formula that was used for the calculation by Mosteller formula:

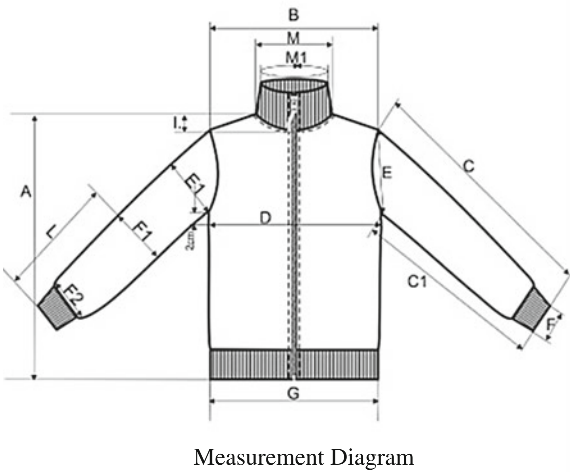
$$\text{BSA}\left(m^2\right) = ([\text{Height(cm)} \times \text{Weight(kg)}]/3{,}600)^{1/2} \tag{6}$$

Therefore, assuming weight = 70 kg and height = 180 cm. We have, Surface area = $70^{0.5} \times 180^{0.5}/60 = 1.87\ m^2$. Thus, by the above calculation the area required for the heat transfer to raise the body temperature by 1 °C is 0.539 m^2. As per the design, the Surface area of the pad is 0.0735 m^2. The difference in values can be compensated by other means, i.e. by using copper sheets, etc. to increase the re- radiating heat. The above calculations are in ideal conditions, whereas practically considering the body is covered with the clothing and there is re-radiating heat that compensates for the above.

2.3 *Jacket Fabrication*

The jacket fabrication consists of keeping several layers of different fabrics together to get the desired result. The different materials used for fabrication of

Fig. 1 Jacket measurement diagram



jacket were: (a) polar fleece which is a soft napped insulating synthetic fabric made from polyethylene terephthalate (PET). It is soft, lightweight and warm in nature. It is hydrophobic and retains very less water, making it moisture free and thus the best material that can be used in winter times. The fabric weighs 300 g/m^2 and is 300 g/m^2 thick. (b) Single jersey which is a type of knit textile made from cotton or a synthetic blend. It is made from a light weight yarn but it still maintains a very stretchy outlook because of it single knitting, flat at one side and piled on another. In this jacket, 140 g/m^2 thick single jersey materials were used.

The outermost layer of the jacket was kept as the polar fleece material. Its excellent insulation capability helps in trapping the heat generated inside and prevents it from escaping to the surroundings. The second layer was kept as the pads that are going to generate the heat necessary for maintaining the temperature of the body. The last and the final layer will be that of the copper sheet, whose main purpose is to distribute the heat effectively and uniformly throughout the jacket thus increasing the surface area of heat transfer by tapping the heat on the other side of the pad. The Fig. 1 shows the drawing of the standard size of the jacket selected for the work. In this study, the size of large (L) was considered for stitching process.

The fabrication was done using a skilled tailor and materials were supplied as per the design and requirement. The various stages of the fabrication are shown below (Figs. 2, 3).

2.4 Testing

The fabricated jacket was tested in an environment where a constant temperature of 18 °C was maintained. Faculty and student volunteers in the age group of 19–

Fig. 2 Copper strips used for heat transfer and placed in the fabric

Fig. 3 Placement of the pads in the fabric and the completed one with the control unit

35 years were considered for this study. The set point of 42 °C was kept in the control unit. Standard thermometers were used for temperature measurements. During testing, the volunteers were asked to lie in supine position for nearly 1 h without doing any physical activity. The readings were recorded one from the inside of the jacket (T_1) and the other from the body (T_2, thermometer kept under the tongue) at two instances of time with the gap of 30 min. The following table shows the readings taken from the volunteers (Table 1).

Table 1 Temperatures recorded inside the controlled room

Volunteers	T_1	T_2	T_{12}	T_{22}
1	39.50	34	39.52	34
2	38.5	34	39	34.2
3	39	33	39.4	33.2
4	38.4	33.6	39	33.8
5	38	34	39	34.2
6	39	34	39.2	34
7	38.2	33.2	38.8	33.6
8	38.4	33.6	38.8	33.8
9	38.6	34	39	34.4
10	38.8	33.8	39.2	34.2

Temperatures are recorded as °C, T_{12} and T_{22} are recorded after 30 min after first reading

3 Conclusions

In this article, a hypothermia prevention jacket for military purpose was proposed, fabricated and was tested to meet the desired parameters. The findings show that the virtual environment created by the proposed jacket maintains the normal body temperature without any discomfort to the subjects. The challenges we faced in this design, was the life of the battery. The battery quite often drains due to the long durations of the circuit operation. If the life of the battery preferred was long, then the size of the battery becomes big and heavy to carry. It is very difficult to recharge the battery in the battle fields or any cold environments where the soldiers are stationed for a long period. Hence it is necessary to think of other alternate ways for recharging the battery.

4 Future Works

Probable use of lightweight solar panels for recharging the battery. The size of the battery and the controlling unit may also be reduced, to bring down the overall weight of the jacket. Also, embedding the Nichrome material in the inner part of the jacket will help in avoiding the numerous wires used inside. The embedding of the nichrome will also include proper contact with the copper strips which extend to both the upper and lower limbs thereby increasing the area of heat generated and in turn increase the efficiency of heat retaining capability. Commercially, the jacket can also be modified for use by civilian people in the northern parts of India during heavy winter, where many deaths are reported every year due to the harsh cold climate.

Acknowledgments The authors sincerely thank the management of Rajalakshmi Engineering College, Chennai for their support and encouragement while carrying out this work. We also thank Mr. G. Loganathan, Managing Director, The Imperial Pvt. Ltd, Tiruppur, and his colleagues for their technical support in the fabrication of the jacket.

References

1. Sessler D (1997) Mild perioperative hypothermia. N Engl J Med 336:1730–1737
2. Morrison SF, Nakamura K (2011) Central neural pathways for thermoregulation. Front Biosci 16:74–104
3. http://www.blizzardsurvival.com/product.php/105/blizzard-survival-blanket as on July 29
4. Predko M (2007) Programming and customizing the PIC microcontroller. McGraw-Hill, New York
5. de Dear RJ, Arens EA, Zhang H, Oguro M (1997) Convective and radiative heat transfer coefficients for individual human body segments. Int J Biometeorol 40:141–156
6. Thome JR (2004–2010) Wolverine tube heat transfer data book, pp 21–24
7. Boutelier C, Bougues L, Timbal J (1977) Experimental study of convective heat transfer coefficient for the human body in water. J Appl Physiol 42(1):93–100

Decoding Design: A Study of Aesthetic Preferences

Geetika Kambli

Abstract When implementing a global product development approach, it becomes important to note that local aesthetic preferences and cultural semiotics can play a leading influence on brand preference and purchase behaviour. While much has been done to gain a broad understanding on culture and its impact on design, efforts to specifically map local certain aesthetic preferences has been limited. This paper seeks to create such a mapping for the Indian consumer. Armed with this understanding, global design efforts may gain empowerment to create appealing aesthetics that provide the right messages to Indian consumers. Thereby addressing issues related to local implementation, which is an important aspect of global product development. Moreover, this paper uses a mixed methods approach, (though rooted in strong established theory), which encourages the construction of new models to understand and map creative practice.

Keywords Semiotics · Design research practice · Global product development · Aesthetic preferences · Culture · India · Industrial design

1 Introduction

Much work has been conducted to address semiotics and industrial design.

Griffin [1] speaks of products as carriers of meaning. He proceeds to explain that the process of understanding unfamiliar products involves a knowledge-based and an emotion-based reaction. It is clear that thoughts, beliefs and values form an important part of this reaction. Therefore, it can be understood that beliefs and

G. Kambli (✉)
Future Factory LLP, Mumbai, India
e-mail: geetika@futurefactory.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_113,

values form a cultural perspective, and therefore help give meaning to products by virtue of the cues that their designs emanate. The study and application of such an intersection of culture, meaning and design will be useful to study and map. As this has direct implication on product design for marketing and commercial purpose.

This paper extends such an implication to map these meanings (semantics) and their relation to certain product cues (through product design). It therefore aims to use established theories to put together the two faculties of semiotic research and industrial design, with specific relevance to commercial implementation in Indian markets.

1.1 Objectives

The study aims to assist global product development in its design efforts by:

(a) Mapping specific aesthetic preferences; especially mapping form, shape color and finishes, to reflect preferences of the Indian consumer
(b) Understanding the semantics of sub-cultures with specific reference to certain groups that may emerge
(c) Arriving at a set of design principles that can assist in local customization to drive consumer preference.

1.2 Challenges

The study of semiotics has largely remained a marginal and academic field with limited acceptance in commercial research work. It remains limited to the area of social studies and societal impact, with most influence on the community of academia bad least on industry and global commerce.

This seems like a missed opportunity, as the faculty of semiotics offers significant opportunity to supplement tradition communication and marketing communities which today hold a strong influence on industry. By exhibiting a collaboration between the faculties of design & social sciences, this study works towards a wider acceptance of these faculties and tools.

2 Methodology

The study was rooted in a strong theoretical framework and soundness of research practice, but with a certain experimental approach to the interviewing methods. Specifically, it uses a mixed methods approach of integrating ethnographic practices and simulation of shopping behavior.

Reference [2] have been made to the practice of ethnography and its application to industrial design and on how the practice of ethnographic research for design is different from that used in academia by anthropologists. The objective of working on commercial applications and the strong need to arrive at results that address real market requirements brings a shift in the approach used by industrial designers when practicing ethnographical research. Therefore, adaptations of a strong theoretical methodology such as ethnography is usually accepted in the practice of industrial design. Here, in this study, the method of ethnography has been adapted for such a purpose.

While maintaining its identity as an observation based tool, this methodology allows the observer freedom to map his findings by integrating another widely practiced method—the simulation of shopping behavior [3]. Modeling shopping behavior often uses techniques to measure consumer choices and evaluate buying behavior. By using instrumented technologies in virtual supermarkets, researchers record customer actions and mine data to map reactions to products on shelves. While such technological methodologies map reactions, they often don't yield reasons or motivations for such reactions. A qualitative adaptation of evaluation of shopping behavior may be modeled as a "product exposure test" where consumers are exposed to a set of pre-decided products and their responses and choices are measured and evaluated. In this study, such a test has been integrated with the process of ethnography to arrive at a methodology that is rooted in strong social science theory but is generative and exploratory in its application to industrial design.

The study therefore operated with mixed methods interspersing detailed ethnographic interviews with several product exposure tests modeled on shopping basket experiences. Such a combined methodology allowed for real insight generation to work alongside a large sample base for application to a wider scale. The large sample was specifically important because it allowed a closer examination of specific sub-cultures and smaller geographies.

2.1 Selection of Stimuli

The stimuli were chosen by a team which consisted of industrial designers, graphic artists and design researchers. The stimuli reflected a wide variation on choices of, color, finish etc. and was pre-selected to allow designers to help analyze winning products on specific design aspects. Given that the study aimed towards understanding aesthetic preferences for implementation of successful product design for Indian markets, there was a strong need to consider artifacts and their relation to semiotics. According to Krippendorff [4], we are "perceptually guided" by the visual appearance of the object in order to fetch the right cognitive model for its use from long term memory. This may cause conflict sometimes. For instance when the product aesthetics cue both known and unknown functions at the same time. The study selected a set of stimuli while acknowledging the possibility of such instances to allow a complete set of stimuli and make analyses more reliable.

2.2 Interviewing Techniques

The interview guides were designed around cognitive models that would allow for insight generation and yet allow collection of useful data around groups that emerged during the study.

2.3 Methods of Analysis

Methods for analysis were mostly means-end analysis [5] using value-cues research [6] typically used in communication applications. Inherently, such analysis has been used towards arriving at key motivations that drive consumer choices. They are qualitative and generative in nature, mapping all intermediate motivations and exposing the cues that lead to the messages of product communication.

For the purpose of this study, such a methodology was adapted to product cues (generated by design) instead of product communication. It was then used to generatively map the motivations and messages leading to the product cues; a method often used by paint companies when modeling color forecasts and trends. Such analysis was mostly qualitative with scores assigned for progressing the trend towards the conclusion. Also for the ethnographic work, metaphors were analyzed towards generating insights that could help frame hypotheses for the exposure tests. Designers worked with the analysis team to evaluate the progression of the trend in terms of specific design learnings.

3 Findings

Results proved that semiotics play an important roles in defining aesthetic preferences and that different subcultures in India have distinct aesthetics choices. What is of real relevance is how aesthetic preferences differed across groups of Indian consumers and what defined these groups to be different.

3.1 General Perception

There is a general perception of design preferences in India markets, which is assumed by managers in marketing positions and sometimes even by Indian designers. There are largely 2 broad tenets to this general perception:

(a) Common perception of design in India is that style needs to be accentuated and that which is bold and overstated is appreciated.

(b) It is also commonly believed that quiet sophistication and mild curvatures are easily overlooked, as it is believed that Indian sensitivity to design is weak.

The study found that such a generalized assumption is largely incorrect and mostly insufficient.

For example,

When the study examined results for even Tier-2 towns, it showed that consumers were sensitive to the slightest change in texture, or finish. These differences were obvious in consumer choices across products in the exposure tests, and this result disproved the notion that for Indians—style needs to be accentuated and overstated designs are appreciated.

Moreover, the generalized assumptions are insufficient for the following reasons.

3.2 Geographical Clusters

The diversity of India causes distinct geographies to behave as sub-cultures. This is because settlements have mostly grown around singularly large cultural groups. However, it may be insufficient to state that each geographical cluster seems to exhibits a specific style preference. It is more important, to examine the elements of such a style preference: (specifically—form, shape, color, finishes) and explain how they differ across geographies.

One clear finding that emerged was that specific geographies prioritizing form over graphic content. This has specific relevance to design in commercial practice. In places where form gains a clear priority over two dimensional aspects such as graphic content and color, design calls for more investments in tooling to deliver superior form. In other places, global product investments are more efficiently disbursed by compromising tooling for visible, striking graphic and color design effort. Understanding which geographies need form, and assessing their contribution to the business, will help decide whether to tool up, or to invest instead in a focused graphic design effort.

Another clear trend is that within specific geographies, similar cultural values prevailed. Therefore, the use of a specific color (in it's semantic sense) may gain high scores in some geographies and may completely fail in another. The commercial application of such a result, is that the application of color needs a fair consideration for cultural implication during the process of design. Specifically, this has strong relevance as during the study, most designers were found to use their own semantic construct when applying color. Which might have been very distinct from the culture in which the product would eventually find use.

However, some patterns were applicable across geographies.

For example, one finding clearly showed how Indian consumers were drawn towards gloss and sheen. Products with matt finishes were often overlooked and not considered "attractive". As a design sensibility this emerged pan-India for the category of small appliance products.

3.3 Product Clusters

More importantly, by applying the same aesthetic to different categories of products, the consideration changed and the means-end analysis threw up a different assignment.

For example, across most markets in India, clear transparency in plastic won a high preference score when associated with technology products as the aesthetic was associated with a value-cue related to technological advancement. However, when associated with shelving in refrigerators plastic transparency implied fragility and possible breakage. Therefore, the same aesthetic elicited different metaphors when associated with different objects (read: categories).

Such findings seem to validate the semiotic premise by Kippendorff [7] and Wickstrom [8] where meaning in design is defined as an object's features being connected to the context of use or where the design is self-instructing. So the semantic meaning is obvious in its design implication. By means of the cognitive model.

3.4 Demographic Clusters

India's progressive economy has caused large shifts in consumer demographics. Such shifts are surprising and contrary to popular belief. For instance: consumer segments grouped by similar income showed huge variance within the group on important semiotic aspects of belief and behavior.

It is possibly for these reasons, that the hypotheses on aesthetic preferences that succeeded in geographic clusters, failed when the geography held diverse demographic groups. This demanded that grouping aesthetic preferences be regarded independently, across consumer segments as well.

While such a detailed examination might be too exacting, a preliminary analysis yielded some broad findings. It emerged that within India, one specific consumer demographic groups behaved like global consumers reflecting global trends in their aesthetic preferences. Interestingly, this trend was noted across categories of products giving strength to the premise that global consumers have lower semiotic attachment and cultural ties are weaker.

4 Success and Critique

The study finds strong use in implementing localized styling efforts to globally developed products for successful launch in India. Specifically it has vast data on geographic, demographic, and category-wise preferences in form/shape/color/finishes. Which when applied can help effectively allocate design and tooling investments for global companies looking to leverage investments across countries.

The study was also successful in implementing a mixed methods approach, which combined theoretical frameworks with experimental adaptations. Also, the methodology was true to the profession of design, incorporating a strong ethnographic approach to the interview technique despite an extraordinary high sample size.

However, the lack of a specific quantitative tools might be seen as a lost opportunity especially given the large sample size. The advantage in using statistical significance or variance, may prove more reliable when examining micro-trends, or those that have a serious implication on design application.

This study is expected to be repeated for recency and relevance to new context, during which a quantitative tool may be considered.

Acknowledgments The author wishes to express her appreciation to: Designers at Future Factory for their countless, patient discussions on design research methods. The support and co-operation of the team at Futuring, where she floated the first version of this study. Prof. Navalkar, who encouraged the basis of semiotic study in her early research years.

References

1. Griffin T (1999) Semantic communication through products
2. Jonathan V (2011) The industrial designer as a mediator and semiotic translator: mediating clients' and users' needs. Hebrew University of Jerusalem, Bezalel Academy of Arts & Design, Israel, pp 75–76
3. Schwenke C (2010) Simulation and analysis of buying behaviour in supermarkets, (ETFA 2010). IEEE conference department of technical information system, Dresden University of Technology, Dresden, Germany
4. Kippendorf K (1989) On the essential contexts of artifacts. In: Margolin V, Buchanen R (eds) The idea of design, vol 1995, pp 156–184
5. Reynolds TJ, Gutman J (1988) Laddering theory, method, analysis, and interpretation. J Advert Res,
6. Zaltman G (2003) How customers think–essential insights into the minds of the market
7. Kippendorff K (1992) Transcending semiotics: towards understanding design for understanding. In: Vihma S (ed) Publication series of the University of Industrial Arts, Helsinki
8. Wikström L (1996) Methods for evaluation of products' semantics. PhD Thesis, Chalmers University of Technology, Sweden

Earthenware Water Filter: A Double Edged Sustainable Design Concept for India

M. Aravind Shanmuga Sundaram and Bishakh Bhattacharya

Abstract Approximately 1.5 million children die annually in India, before they attain 5 years in age. The deaths are mainly attributed to pneumonia and water-borne diseases like dysentery and cholera. Unavailability of clean drinking water is the root cause of the problem. Apart from sources of water being equally available to the masses, unavailability of extensive filtration systems, either at the point of distribution (POD) or at the point of use (POU), is a reason for consumption of impure water. An affordable water filter (POU) that can effectively kill all the disease causing pathogens will help in stemming the infant deaths. In India, earthenware pottery dates back to 1500 BC. Currently, potters are almost facing extinction because of changes in society. This paper, explores the possibility of using the skills of the Indian potter in making water filters out of earthenware with cheap filter substrate and provisions for germicidal UV based disinfection system powered through energy harvesting from transducers.

Keywords Water filter · Potter · Earthenware · Sustainability · Affordability

1 Introduction

The number of live births in India is estimated to be around 12 million per annum which almost accounts to 20 % of the world's birth [1, 2]. However, India also contributes to more than 20 % of child deaths in the world. India loses

M. Aravind Shanmuga Sundaram (✉) · B. Bhattacharya
Design Programme, Indian Institute of Technology Kanpur, UP, India
e-mail: aravind@iitk.ac.in

B. Bhattacharya
e-mail: bishakh@iitk.ac.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_114,

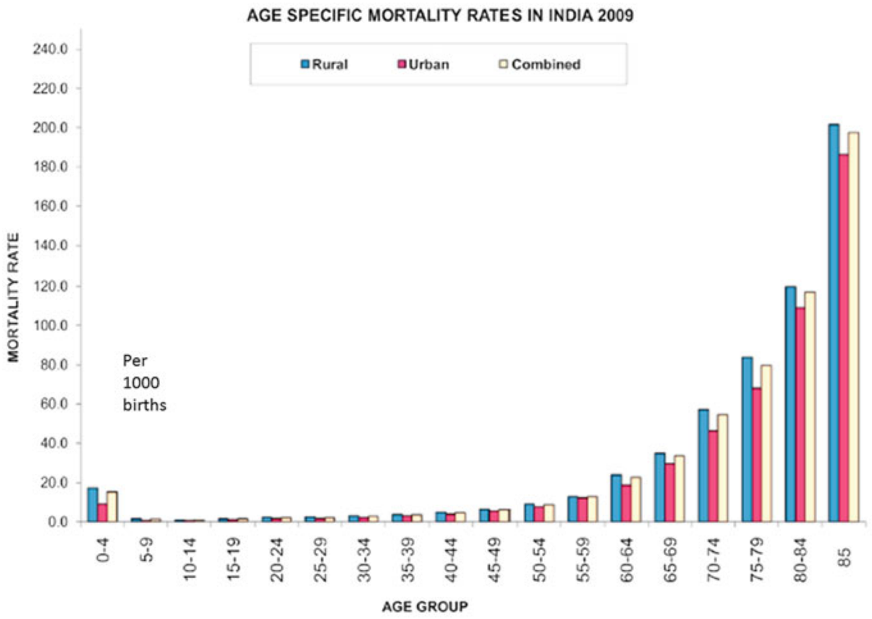


Fig. 1 Latest mortality census [2]

approximately about 1.83 million children before they reach 5 years of life [1]. A majority of the deaths are due to preterm births [2]. Even though preterm birth is a global nemesis, South Asia and Africa contribute to 60 % of the deaths that happen and India's contribution to this is 15 % [1–3]. The infant mortality rate (number of children dead per 1,000 live born) in India is 50 [2]. The under 5 mortality rate (U5MR) in India is around 65 [2]. 88 % of the deaths are due to preventable communicable diseases like Pneumonia and Diarrhoea [1]. Other diseases like Cholera, Typhoid and Hepatitis A contribute to deaths as well. Most of these diseases are water borne. Majority of these deaths occur in rural and urban poor, where the living conditions are very conducive to easy spreading of infections (Fig. 1) [2].

Lack of clean portable drinking water is a major reason for infections to spread. Infected water sources are often shared, ensuring widespread infection in the community. State controlled water supplies are usually guarded against these infections by having effective filtration systems at the PODs. The reach of these supply lines are not usually extensive and does not reach to every corner of the populated topography. Urban population has been on the rise and metro cities have their own pockets of high density areas where the supply is close to zero. In such places, people are forced to use water from uncontrolled to unmonitored water sources like private suppliers or local sumps which are open to contamination because of drainage or industrial waste. In rural areas, the water sources are mostly open wells, rivers or canals which are again easily polluted. Use of effective

Type of need	Quantity	Comments
Survival (drinking and food)	2.5 to 3 lpd	Depends on climate and individual physiology.
Basic hygiene practices	2 to 6 lpd	Depends on social and cultural norms
Basic cooking needs	3 to 6 lpd	Depends on food type, social and cultural norms
Total	7.5 to 15 lpd	Lpd : Liters per day

Fig. 2 Water needs per person per day: WHO [5]

filtration methods will help in stemming the progress of infections in these societies. The prevailing problem is lack of awareness and that of affordable filtration apparatus. Most of these households cannot afford the contemporary water filters that are being sold in India. The average water filter is far beyond the reach of the majority of Indians. This leaves majority of Indian population vulnerable to preventable diseases. This paper explores the ways of making the water filter an affordable commodity. Contemporary water filter manufacturers in India are aiming for cost of ten paisa per litre [4] on the basis of one single unit output.

The average water needed for a person to survive a day as per WHO standards is a minimum 7.5 L (Fig. 2) [5]. The minimum quantity of water to be consumed per person is at 2.5 L per day [5]. WHO India too recommends the same based on Indian conditions.

For Rural India, the water need per capita is as given below (Fig. 3) [6]. The rural average is more than the recommended average of 2.5 L for drinking water. 3 L per day is the stipulated need. The average size of Indian household is 5.3 [2] (approximated to 6). Based on this, the average need for drinking water per family in India would be 18 L per day.

Fig. 3 Average water needs per person per day in India

Type of need	Quantity (lpd)
Drinking	3
Cooking	5
Bathing	15
Washing utensils	7
House ablution	10
Total	40

2 Sustainability: The Need of the Hour

Many factors like changes in environmental conditions resulting in skewed monsoon behaviour, increased temperatures, failure of crops and dwindling of agricultural prospects and economic factors like globalisation, open market economy has led to a marked exodus of people from rural areas to urban cities. This has created an imbalance in the demographic dynamics of India. The divide between the affected and the not so affected is widening. The affected people form the majority and are poor. The market driven economic practises mostly concentrate on to the needs of the affordable masses and price points are fixed based on their purchasing power. The ballooning urban scene has given rise to unforeseen contention for resources like water, energy and space. The rural areas have become further alienated. The need of the hour is to attain sustainability in all possible fronts, whether be it demographic shifts, energy consumption, or environmental impacts. From a machinist view, all the events are causal and hence this intertwined complexity can be solved or controlled, only by adapting little sustainable parts that sum up to a bigger sustainable whole. This model is portable and can be replicated in an identical situation, but a radically different practise. For example, similarities could be drawn between the traditional mud pots giving way to metal utensils and the dhobi's services being overtaken by washing machines that consume and contaminate more water per cloth than the traditional way. A sustainable solution that could meet the demand of the changing scene as well as a sustainable livelihood of the famished potter or the dhobi is the need of the hour.

2.1 The Case of the Indian Potter

Pottery has existed in India ever since civilisation could be historically accounted in the subcontinent. Earthenware pottery has been in existence since 1500 BC in India. They had mostly started from being storage instruments to other artifacts like ornaments, idols and toys. Pottery in India has been influenced and improved by many influences from Persia to Mongolia. Some of the artisans who belonged to the invading armies from these parts of the world made India their home and have enriched its pottery practise [7]. India has wide variety of clay soil which had a big influence in the evolution of pottery. The government of India has also played its role in improving the condition of pottery by industrialising it [7]. It was the first big deviation that was attempted to improve the prospects. Second World War created new demands and also brought in western influences resulting in mushrooming of lot of ceramic industries. These industries were able to employ a certain amount of skilled and unskilled labourers. However, the plight of the Indian potter took a hit with changing life styles. The traditional and ubiquitous earthen pot gave way to utensils made of metals like aluminium and stainless steel wares. The potter has been relegated to cater the needs of traditional occasions like

Sl. No.	Category of Pots	No. of families	No. of pots produced / annum	Cost of clay in Rupees	Cost of burning	Total Cost	Average cost in Rupees.	Average Revenue (Price) in Rupees.	Average No. of pots produced per family per annum	Average Income per day in Rupees of a family from the occupation
1	Up to 1000	72	50050	25550	35900	61450	1.22	9.36	695.13	50.48
2	1000 - 1500	23	29500	15100	18800	33900	1.14	9.55	1282.60	78.11
3	Above 1500	5	9300	5100	7700	12800	1.37	10.43	1860.00	93.26

Fig. 4 Income of potters in Warangal, AP [8]

festivals and other obeisance. The potter was also a vital cog in the wheel of agricultural setup of India, making storage utensils and also huge terracotta idols which the local farmer revered a lot. The deterioration of agriculture had its effect on the potter too. Many have migrated to cities in search of other menial labour destroying his family fabric. The plight of the potters of Warangal, Andhra Pradesh is a good sample to elicit the tough times the community is going through [8]. The average salary for a potter's family per day is around 50 Rs (Fig. 4). This goes up based on the number of pots produced. But their per capita income with 5.3 as the household average size [2], are very much below the poverty line by any standards. This has mostly resulted in the Indian potter moving to urbanised societies in search of employment.

With minor design interventions, the potters could be made to regain their lost ground. A different product line by the potter meeting to the current demand is needed. Similar exercises where rural communities can stay in their rural setup yet get connected to the dynamics of changing societies through a new product relationship [9] have been explored in many places.

3 Current Point of Use Filtration Systems in Use

There are a multitude of POU filtration systems that have been put forth in the market. Most of them use reverse osmosis as a means of filtering assuring effective filtration. These setups are augmented with an Ultra Violet chamber in which most, if not all pathogens are killed. Some of them have additional chemical systems to soften the water and to improve the taste as well. These are state of the art systems and would cost on an average, 10,000 Rs (Fig. 5) based on the quantity of water through put. From a sustainability point of view, the water wasted and the power consumed to produce one litre of pure water is phenomenal. The capital and operational cost of these systems are not easily affordable by all.

Other forms of filtration like boiling, chlorination are also done. These affect the taste of the water but are effective against pathogens. Old filtration systems use ceramic based filter units that provide filtration of suspended impurities only. Pathogens are not effectively removed. The ceramic candle filtrate is expensive.

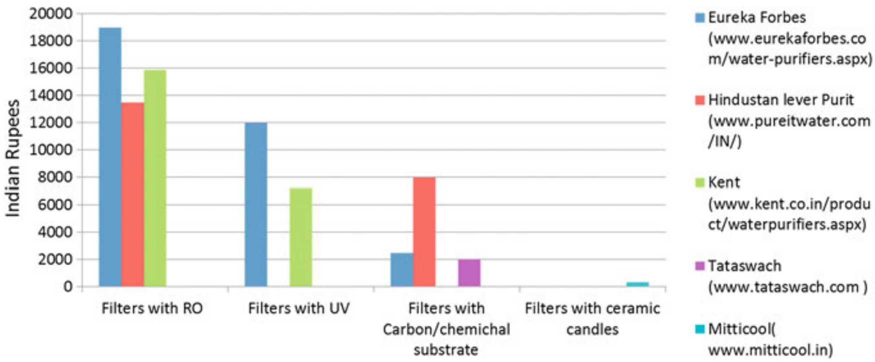


Fig. 5 Comparison of water filters in Indian market

Sand bed filters like fast sand filters and slow sand filters have been used extensively in POD centres. Fast sand filters are effective in filtering suspended impurities. Since fast flow of water disturbs the growth of bacteria that filter, they are not effective against pathogens. Slow sand filters ensure effective filtration of pathogens and chemical impurities. The process is very slow. Most of the water filtration plants adapt this method of water filtration since they are very effective and can treat large amount of water. Slow sand filters [10] are gaining ground amongst the impoverished societies of the world as a household filter (Fig. 6). The filtrate is acquired in the POU.

4 Proposed Solution

Design in the context of alleviation of the poor has not received much attention or has been pursued earnestly by design practitioners both at the industry as well as in academic levels [11]. States and voluntary organizations have attempted to find a market for the artifacts produced by the poor by organising selling points in the form of national and international fairs. They have not proved to be sustainable. Huge communities cannot be effectively included in this practise. The artifacts produced have strong cultural identities, since most of them are elements like ornaments, cloths like scarfs, toys and idols. These have a very sporadic demand. If consumables made by the artisans, that meet a steady demand, it will be sustainable. Design interventions will have to be made through out the supply chain [9, 10]. An earthen ware water filter could be made this way (Fig. 7).

The proposed water filter (Fig. 9) will have earthenware shell which could be easily made by the potter. The filtrate shall be slow sand bio filter that shall be made up of washed sand at an average of ten micron in size to create a dense filtrate medium. This shall be rested on a thick and thinner brick chip bed. In addition, the water chamber shall have a germicidal UV powered by poly-

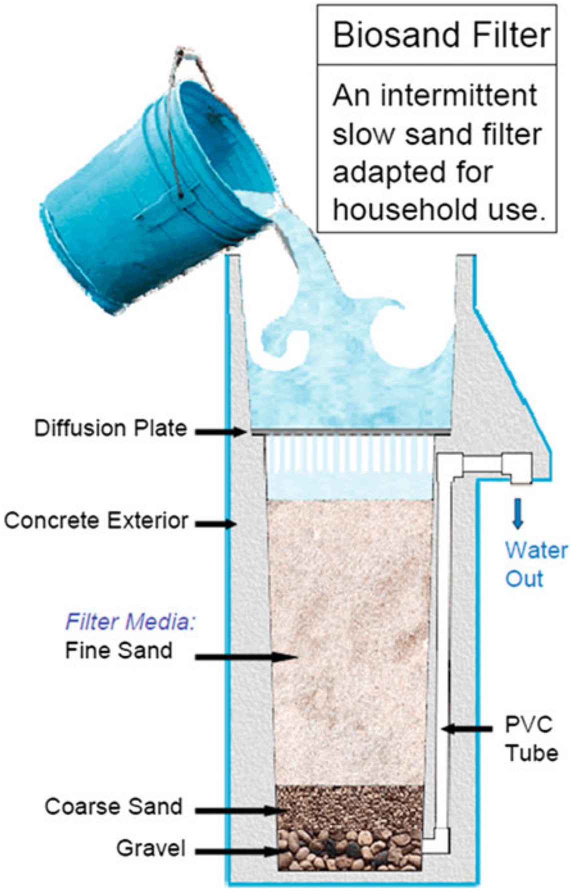


Fig. 6 Bio sand filter for home use (www.cawst.org)

crystalline solar cell array. Effective, disinfection can be ensured by using germicidal UV. The germicidal UV has two single watt lamps accounting to four watts of power need. These are provided by a solar panel made of four polycrystalline solar cells. Poly crystalline solar cells are far cheaper as compared to monocrystalline solar wafers (Fig. 8). The water has to be maintained in the UV reservoir for a maximum of 30 s for all the pathogens to be killed effectively. The water chamber is a 20 L container. A participatory design process needs to be adhered here to enable the chambers being made as per design and assembly of the electronic elements to be incorporated in the body. Once the process is matured, the potter would be able to replicate the design.

The filter substrate comprises of sand available at the point of use that could be washed and used. Initially the filter needs to be curated for beneficial bacteria for a week. The water would be usable after a week. The sand should not be disturbed or changed frequently for substantial results.

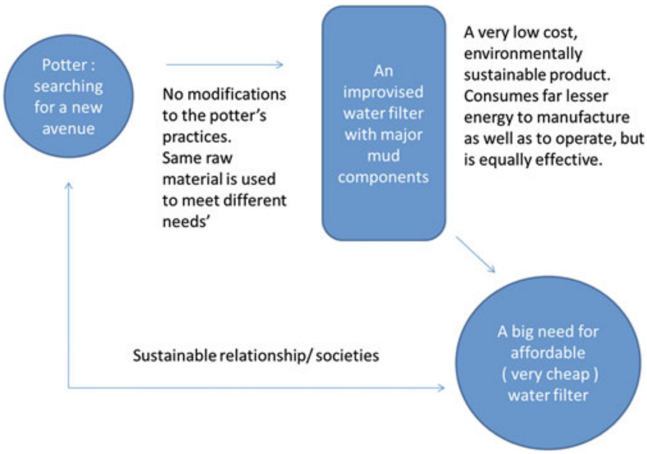


Fig. 7 Sustainable supply chain: earthenware water filter

Element	Property
Solar panel	7.8 V polycrystalline solar module
Battery	6.6 V
UV lamp	Wavelength 240-255 nm, 3V (2 numbers)

Fig. 8 Preferred configuration for the components of the filter

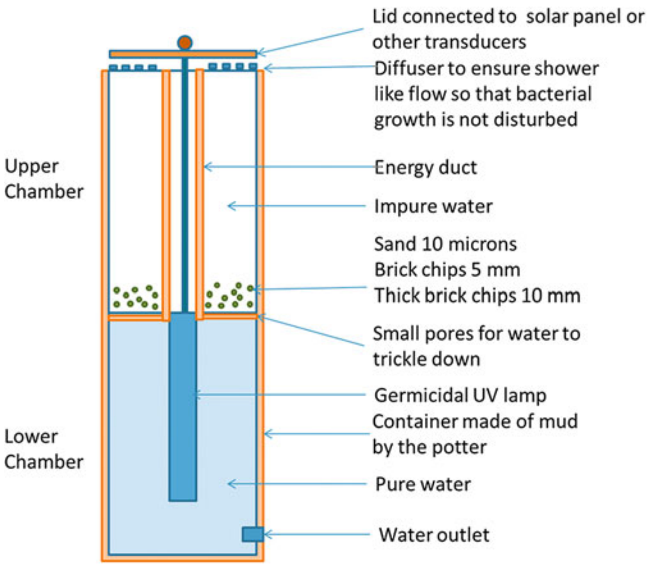


Fig. 9 Earthenware water filter

Element	Approximate cost (In rupees)
Mud Chambers	50
Battery	80
Solar panel	80
Germicidal UV lamps	80
Total	290

Fig. 10 Approximate cost of the proposed water filter

The approximate cost of production for the water filter will be 290 Rs (Fig. 10). The cost per litre for the buyer would come to very low as 0.0004 RS/L of water at the rate of 20 L production per day.

$$\begin{aligned}\text{Cost/litre} &= \text{total annual cost/total annual litres of water produced.}\\ &= 0.00047\,\text{RS/L.}\end{aligned}$$

4.1 Sustainability Parameters

Low-fire clay needing a heating temperature of around 1–4 cones accounting to 1,120 C. There are no new skills for the potter to be learnt. As compared to a polycarbonate body of state of the art filters or the stainless steel bodies of yesteryear filters, the clay body consumes lot less energy to make [9]. Midrange clay is to be used, since, if they are not recycled, the easily disintegrate into natural elements.

4.1.1 Potter's Perspective

The average income of a successful potter family is around 1,500 Rs/month [6]. They have peak sales during festivals and runs close to dry on other months. The damages that are caused to his inventory during storage as well as transport are also borne by them. The new cost of the filter could be around 350 Rs.

$$\begin{aligned}\text{Revenue for the potter from one sale} &= \text{cost of filter} - \text{cost of production}\\ &= 60\,\text{Rs.}\end{aligned}$$

60 Rs/filter are a sizeable amount that a potter could make as compared to the old revenues they get from selling a pot.

The loss of chambers during storage and transport could be lessened by adapting a hexagonal cross section for the chambers (Fig. 11). This helps in packing them like a honey comb which ensures better shock resistance.

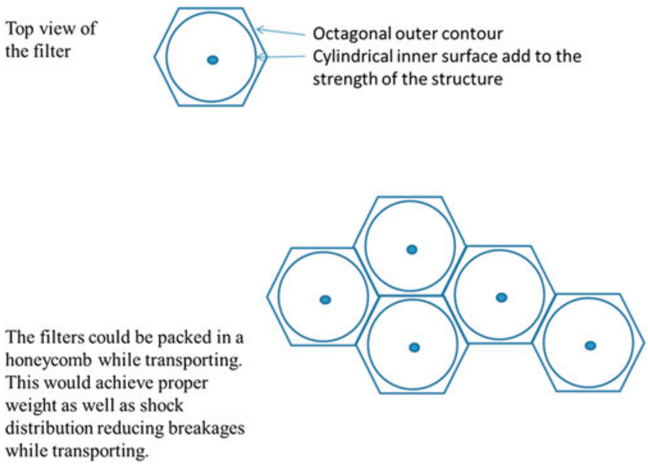


Fig. 11 Earthenware water filter—top view

4.1.2 Designer's Perspective

Such practises are achievable through participatory design process where in addition to user study to identify the needs, the process of manufacturing needs to be keenly noted to stem any inadvertent process related losses. The same model and learning could be exported to other systems. When working with a community, designers should be able to identify all the other peripheral activities as well. Many of them could be made to come under the sustainability dragnet easily. Designers should also pay attention to the importance of localisation, for example, the filter substrate could be tweaked or altered based on the impurities that are present locally.

5 Conclusion

A complete supply chain perspective for water filter design is presented here which will help identifying a sustainable ecosystem benefiting both the producer and the consumer very effectively. Traditional practises have been mastered over generations and their outcomes are all that we may need as solutions for complex problems of today, whether it is health, education or food. The task of the designer is to identify these pockets of important practises and tradition and find ways of retrofitting them with the current challenges to achieve equanimity and sustainability.

References

1. The situation of Child in India—A profile: UNICEF May 2011
2. National health profile India (2011) Central bureau of health investigation, Ministry of health and family welfare, India
3. Maternal and child mortality and total fertility rates (2011) SRS, Office of the registrar general, India
4. Delivering safety: Corporate reports, Business India, June 14, 2009
5. Technical notes on drinking water, sanitation and hygiene in emergencies: WHO
6. Rajiv Gandhi national drinking water mission. National rural drinking water programme: Framework for implementation Ministry of rural health and development, Government of India (http://www.indiawaterportal.org/sites/indiawaterportal.org/files/National%20Rural%20Drinking%20Water%20Programme_MoRD_2010.pdf)
7. Barkin D and Barón L (2005) Constructing alternatives to globalization: strengthening tradition through innovation. Development Pract 15(2):175–185 (Published by: Taylor & Francis, Ltd. on behalf of Oxfam GB Stable URL: http://www.jstor.org/stable/4030078)
8. Suresh LB Rural artisans—Indigenous technology: an empirical study on village potters in Warangal, Department of Economics, Kakatiya University, Warangal (http://community.eldis.org/lalbsuresh/.59e05148/.59e8c693)
9. Project Bravo (2006) Field study in Haiti, a summary of results, June 2006. Centre for affordable water and sanitation technology (www.cawst.org)
10. Thomas A (2006) Design, poverty, and sustainable development. Des Issues 22(4):54–65 (Published by: The MIT Press Stable URL: http://www.jstor.org/stable/25224076) (Autumn, 2006)
11. WHO (2012) Born too Soon: The global action report on preterm birth

Designer's Capability to Design and its Impact on User's Capabilities

Pramod Ratnakar Khadilkar and Monto Mani

Abstract Extending the dictionary meaning of 'capability' as individual skills or abilities, the current paper adopts a Capability Approach (CA) based definition. Accordingly *capabilities* are effective (operational) options available to an individual to be and do as aspired, in leading a life of value upon reflection. This concept primarily evolved in development economics, and has remained confined to the Bottom/Base of the Pyramid, wherein the *capabilities* of the poor are envisaged to be leveraged upon in alleviating poverty. Design for the BoP aims at designing appropriate products to serve as means to realize or augment the *capabilities* of the poor. However, the designer's role as an individual with *capabilities* is taken for granted. *capabilities* to design are the effective options/resources available for the designer to design effectively. The current paper extends the concept of CA to the designer, and evaluates the related *capabilities* for its impact on designing products aimed at the BOP to alleviate poverty.

Keywords Design · BoP · Capability approach · Capability space

1 Introduction

The definition of Design as used in this paper is, *'activities that actually generate and develop a product from a need, product idea or technology to the full documentation needed to realize the product and to fulfill the perceived needs of the*

P. R. Khadilkar · M. Mani (✉)
Center for Product Design and Manufacturing, Indian Institute of Science, Bangalore, India
e-mail: monto@astra.iisc.ernet.in

P. R. Khadilkar
e-mail: pramod@cpdm.iisc.ernet.in

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4_115, © Springer India 2013

user and other stakeholders' [1]. Throughout the design process a designer (as a design team or firm) requires access to extensive information starting from the end user/beneficiary needs and peculiarities, affordability and pricing, market size, and product life-cycle, viz., material and manufacturing data, service life and disposal. A successful product essentially is determined by the market response, and in the case of the poor, in terms of the products ability to serve as a means in alleviating poverty. Besides customers, various stakeholders are involved, viz., designer, manufacturer, transport, sales-network, service and disposal. Product design essentially connects the designer to the consumer, with the role of each stakeholder being characteristic in determining product success, i.e. gratified beneficiary with a profitable product [2].

To reiterate, the definition of *capabilities (italicized henceforth)* in CA are the options available to an individual to be and do, as aspired, in leading a life of value [3]. *Functionings* are realized *capabilities*, e.g., for an individual aspiring to become literate, going to a tutor or self-learning using Tablet-PC's are *capabilities.* Eventually opting for a Tablet-PC would become a functioning in the individual's aspiration to become literate. A designers role in designing a tablet-PC conducive to self-learning is determined by the *capability* options available during the design process, viz., conversancy in touch-screen technology, dynamic team, freedom to innovate, etc. In the case of products designed for the Bottom of the Pyramid (BOP), Capability Approach essentially values the *capabilities* of an impoverished individual, which through product means, can provide opportunities to come out of poverty. However, in designing for the BOP, the CA perspective has only been applied to the beneficiary. However, it is crucial to understand that CA applies to an individual, and every stakeholder comprises individuals, whose attitude essentially determines its role and effectiveness [4]. Thus extending the CA to evaluate the *capabilities* of other stakeholders would be more appropriate in determining the success of a product. Since Designers and Users (BOP) are the two critical stakeholders, the current study focuses on evaluating CA through the *capabilities* of the individuals characterizing these two stakeholders (see Table 1 for the Tablet-PC example).

The following section illustrates the distinctive features of CA. The designers *capabilities* (to design) is discussed in detail in Sect. 3, followed by an appreciation of how the users capabilities are impacted by that of the designers' capabilities (embodied in the designed product) in Sect. 4.

1.1 Research Motive, Questions and Contributions

Prahalad [2] in his influential work proposed that businesses (products and services), targeted at the BOP can infuse development amongst the poor while ensuring profit in business, i.e. eradicating poverty through profits. However, the impact of this approach remained inert as it lacked clarity on what *development for the poor* really meant. Products/services can potentially leverage on the existing

Table 1 Designer’s capability to design and its effects on capabilities of users/beneficiaries through appropriate product design

Stakeholders		Users/beneficiary (poor/BOP)		Designer (formally trained)		Manufacturer (OEM), others, ...
Aspirations		• To be literate • To enhance social stature, ...		• To design trendsetting products • To improve sales/profit, ...		...
Configuration of available Capabilities	Internal abilities	• Go for tuitions, or • Buy a Tablet-PC and self-learn	• Basic visual ability • Conversancy with electronic gadgets/PCs	• Company value position to design & allocate resources for the BOP	• Ability to sketch, visualize • Creativity, ...	...
	External resources /means	• Income or affordability	• Tablet PC • Self-teaching apps • Electricity, Antivirus, ...		• CAD and prototyping support • Collaboration with GUI team	...
Functioning		• Being literate by self-learning using a Tablet PC,		• Design of simple user-friendly Tablet PC to promote literacy for the BOP		...

skills and strengths of the poor in supporting them to achieve what they want to do and be in life. Understanding the needs of poor is a challenge, as a product acceptance (by the poor) depends on factors more than a product’s functionality alone. It deals with complex socio-cultural value judgments that the poor perceive, and does not vibe with simple ‘return on investment logic’ [5].Well intended products designed for the poor have failed due to inadequate understanding of the users’ needs, inadequate infrastructural setup [2, 20] and for being too product/ technology focused [6] clearly traceable to inadequacies in the analysis phase of product design. The analysis phase is attributable to the designers *capabilities*, wherein the authors strongly believe can be addressed through the CA normative framework. This would require the designer to understand ‘why’ a product is designed beyond product functionality and ‘what’ product is to be designed keeping in mind the beneficiaries aspirations and *capabilities*. CA provides a lens to appreciate an individual’s value judgments in terms of capabilities, i.e. effective options to ‘be’ and ‘do’ something of value. Embodying a product with functionalities attributed to users’ (beneficiary) *capabilities* provides a broader perspective for the designer to accommodate and respond to. The objective of the current study is to provide a CA based design methodology (for designers’ *capabilities*) to effectively design for the poor. This would place the designers’ *capabilities* to be mapped from the conventional requirements of design-experience, sketch-ability, creativity [7] to mechanisms to permit interaction with remote BOP users [8]. To evaluate a successful design (product) intervention it would be useful for the designer to foresee the likely impact on the lives and *capabilities* of the poor. A model to permit this assessment would provide crucial foresight *capability* to the designer. The current paper is an attempt in this direction towards developing a '*capability* space for design' based model that would permit the delineation of various stakeholder (Design for BOP) *capability* spaces.

2 Capability Approach

2.1 Introduction to Capability Approach

Capability Approach was proposed by Nobel Laureate Amartya Sen as a normative framework to broadly evaluate individual wellbeing and social arrangements. It fundamentally relies on the freedom of individuals operating at two levels, viz., firstly in the effective individual freedom to decide what to be and do, i.e. *capabilities*, based on ones perception of a valuable life, and secondly in the freedom to achieve and/or realize from the list of capabilities, referred as *functionings*. Sen [9] articulates '*functioning'* as achievements and 'capability' as the options to achieve. As discussed earlier, an appropriately designed product can potentially expand the *capabilities* of the user/beneficiary. Thus, a design process converts a want/need into user *capabilities*. The effective adoption of a product is an achieved functioning (see example in Table 1).

2.2 Distinctive Features of CA

Understanding CA requires an appreciation of its distinctive features. Three distinctive features [10] include (1) Distinction between means and ends—instruments, such as mobile-phones, can be perceived as means to facilitate a sense of individual achievement as in 'improved social stature', or for 'business networking', etc. This distinction is important, as (intrinsically) just owning a mobile-phone can be mistakenly evaluated as an end. (2) Distinction between means and capabilities—means are distinct from *capabilities* in that just access/possession to a means does not translate to *capability*. Further means would require other essential means for its effectiveness, e.g., For the *capability* of business networking, an individual should be conversant with using the means of a mobile phone, the successful operation of which depends on other essential means such as mobile connectivity, power, etc. (3) Importance in understanding relation among means—multiple interdependent means, such as with mobile phones, connectivity, talk-value, etc., can be in '*and'* or '*or'* dependency. *And* dependency indicated concurrent availability, e.g., Owning a mobile phone *and* available connectivity *and* talk-value would support the *capability* of business networking. *Or* on the other hand, a person could be engaged for business networking. While this and/or relation between means might seem trivial, it is in reality fundamental [11, 12] to how a product can succeed in a market, for e.g., access and availability of basic infrastructure was mistakenly taken for granted in initial ICT projects in developing countries, resulting in failures [13]. A fourth distinction of CA [11] is in its qualitative vs quantitative dimension, for e.g., an achieved functioning of adequate food (to satisfy hunger for wellbeing and productivity), must include adequate quantity *and* adequate quality (nutrition value). Though this might seem apparently obvious or trivial, it has not been explicitly dealt with regards *capabilities* and carries the risk of being overlooked.

3 Capability to Design

3.1 A Capability Approach Perspective

According to CA, a designers' (as an individual and/or a design firm) capability are the available (internal and external) effective options/resources to design (a product) as intended. This would include, besides intuitive and trained ability to design, available design tools, Computer Aided Design (CAD), prototyping facilities, set design-values (guidelines), information support, etc. However, dictionary based meaning of capability would imply an individual's 'quality of being capable—physically, intellectually or legally' [14] to design in the current context. The discussions in this paper are targeted at products designed for mass consumption in free market, as in Sen [3].

3.1.1 Capability to Design: Distinction Between Means and Ends

A design statement specifies the exact motives and requirements of the product/service being designed. However, generally this statement fails to permeate to the level of questioning the fundamental purpose 'why' of designing (a design individual and/or a firm/organization). Designing can be a means of achieving something intrinsically important, for e.g., *designing* for purpose of profit would differ from *designing* for a more nobler cause such as charity/service, and both would vary in terms of *ends* achieved. Further, companies running for profit, could also base their design on other intrinsic values such as sustainability, abolishing child-labor, abolishing poached product-use, etc. A company's mission statement would reveal the underlying values guiding the means of *design*. Design is responsible for the resources consumed throughout the lifecycle of the product. Thus for the same design statement (challenge), firms with different underlying values would differ both in the means adopted and ends achieved. Design firms working with strong sustainability values will adopt appropriate capabilities to design appropriate products (ends). For e.g., 3M a global company known for its

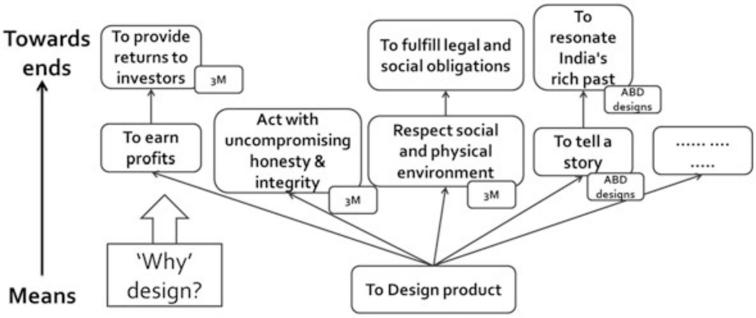


Fig. 1 Distinction between means and ends

innovative products states the values that defines (see Fig. 1) the ends of what they do, such as [15]:

> Act with uncompromising honesty and integrity in everything we do
> Satisfy our customers with innovative technology and superior quality, value and service
> Provide our investors an attractive return through sustainable, global growth.
> Respect our social and physical environment around the world
> Value and develop our employees' diverse talents, initiative and leadership
> Earn the admiration of all those associated with 3M worldwide

An Indian design firm, Studio ABD, a recipient of Red dot award 2010 states: '*At Studio ABD we design from our heart. Emotion underlines our products, giving them poetic and inspired meaning. They connect deeply with the user by* ***telling vivid stories****, by overlaying the familiar with the new and surprising ….. propelled by humor, craft, rituals, people, situations and Indian heritage, we create products that speak a unique language—an Indian design vocabulary.*'[16]

3.1.2 Capability to Design: Distinction Between Means and Capabilities

Designers need skills linked with imagination to help them in generating (innovative) artifacts that are yet non-existent. Understanding design methodology, basic engineering knowledge, ergonomics, rendering skills and CAD tools are some core skills linked with the design. The designer's experience plays a critical role. Further, there is convincing proof in the design literature [17, 18] and in practice that design requires significant external support. Top management support positively impacts design quality/effectiveness [19]. Designs targeting BOP customers pose different demands, a different methodological approach [20].

Thus, the list of resources required to support the designer is quite varied and difficult to comprehend without a tool/aid. Kleine [21] provides a 'choice framework' to aid the listing of resources (interchangeably referred as 'means' in the

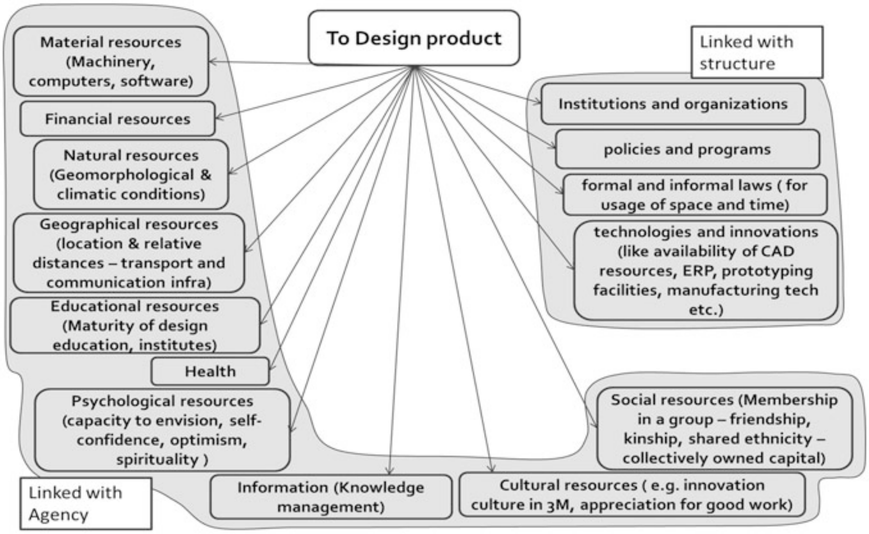


Fig. 2 Distinction between means and capabilities. *Source* Adapted based on choice framework [21]

current paper) required to fulfill a given *capability*. Figure 2 illustrates the list for the paper's current theme 'to design a product'. This framework differentiates *agency* linked resources (resources that directly interface with an individual to help in taking charge of their destiny) from *structural* resources available to an individual.

3.1.3 Capability to Design: Importance Given to Understanding Relation Among Means

Relation ('*and*'/'*or*') between resources would depend on the case being considered and requires to be discerned explicitly with regards *capability* to design. The design firm's policies, cultural and social resources, which significantly influence the psychological resources of an individual, could be considered as being in '*and'* relation working as a set. Absence of any one of the resources (in '*and*' relation) would make the set ineffective. Natural resources in realizing a product (e.g., biodegradable fabric), could be in 'or' relation, viz., cotton '*or*' jute.

3.1.4 Quality and Quantity Dimension of Capability to Design

The mere availability of resources as illustrated in Fig. 2 in adequate *quantity* would not ensure a fulfilled *capability* to design for the designer (individual/firm).

The *quality* of material resources is as important as *quantity* and are in *'and'* relation as inadequacy in either would result in a design inadequacy. *Quality* reinforced through design-firm's policy, influences the *capability* to design. If the *quality* of a PC's hardware-software configuration is unsuited for a desired function then its physical presence (*quantity*) is ineffective.

4 Effects of Design on User's *Capabilities*

4.1 Capability Space

Technologies/products, appropriately designed, can serve as the potential means for *capability* expansion [22]. An intention is definitely in-built the product attributed with the purposeful nature of the design [23]. Each product is designed to satisfy customer's needs. That satisfied need could be considered in terms of CA as the achieved beings and doings (*capabilities)*, thus *functionings* of the user. A given product may work as instrument to achieve some high level need, which in turn will fulfill other higher level need, till the intrinsic end is achieved (refer Sect. 3.1.1), for e.g., with access to a sewing machine, a beneficiary's health and ability to use the machine effectively translates as a *capability* to sew. This, through proper market mechanisms, provides a vocation to earn income (level 1) which beyond providing adequate nutrition (alleviating hunger) can support the education of children (level 2) through which there's a perceived improvement in social stature. The beneficiaries, as parents, can now achieve an intrinsic end of being proud parents (an achieved functioning). Thus a single product like a sewing machine, along with maze of other products/services/resources, renders an individual with different *capabilities*. Thus many products can converge to serve a single purpose. Likewise, in a market, a product can satisfy multiple purposes, e.g., a mobile phone can serve for business communication as well as for esteem/stature.

The concept of *capability* space is illustrated through Fig. 3 to discern the effect of design on *capabilities*. *Capability 1* is possible by adopting either or a combination of Products A, B and C. The space bound by these three products and linked resources can be outlined as Capability 1 space (thick black line in Fig. 3). The three product alternatives may vary in terms of linked resource needs, e.g., a solar LED lantern vs. a rechargeable CFL lantern vs. a user-replaced battery light have varying resource requirements. The first permits self-reliance; the second requires a charging-point, while the third requires periodic battery replacement. The choice of either of these would determine the linked *capabilities* (and profit), e.g., for a poor street-vendor requiring illumination to better his sales to make a living. Some resources might be shared amongst product alternatives while some could be unique.

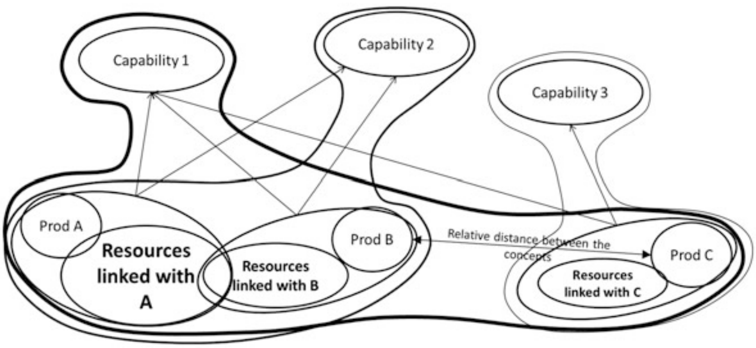


Fig. 3 Capability space

4.2 Effects of Design on Capabilities

Design affects the capabilities of the users/beneficiaries in following three ways:

4.2.1 Design Operating in a for-Profit Market Results in a Restrained Capability Space

Products 'for' profit tend to monopolize to maximize market share (volume of sales). The designer has to ensure that the products meet functional requirements, is appealing and still meets production cost targets to maintain competitive edge. With more than one product, with varying quality (and pricing) to serve the same purpose, increases the potential *capability* space for the user. However, for a company, aiming to monopolize sales, maintaining many products for the same purpose may not be profitable, whereby they tend to retain only few such products. Consequently customers' *capability* space and available options are restricted. Development by definition can be number of options available to people to lead life [3]. A variety of traditional hand-made toys are vanishing (along with the associated skills and local material use) from the market with the dominance of standard mass-produced products using cheap (and often toxic) plastics. Thus, design for profit may not necessarily be amenable to sustainability of *capabilities*.

4.2.2 Design Decisions Directly Affect the Capability Space

Product design determines effectiveness of achieving product functionality. Besides material resources for manufacturing, design dictates the resources (energy, accessories, training, etc.) required for its successful usage by the user/ beneficiary. A product designed to utilize resources commonly available to people (consumers) further increases their *capability* space, e.g., water cans (to fetch drinking water) that can be fitted on bicycles that are ubiquitous.

Variety in design is crucial, and is defined as the distance of a product concept from the center of the concept space [24]. A product design that is farther away from the center can potentially expand the users' *capability* space (see Fig. 3). For e.g., for communication and socializing, video conference provides an opportunity which is far varied from actual face to face meeting and significantly expands the *capability* space, such as in tele-medicine where the deprived and impoverished from Africa and Asia have access to the best of medical diagnosis. However, disruptive innovations can bring in too much variety that can kill existing products, and severely constrict the *capability* space. In some cases certain section of society may not have the new resources required to benefit from the new product, and old products are no longer available. This usually leaves a void of helplessness in the *capability* space. Products designed and developed with the prime motive of profit can cause such voids amongst the lower economic strata or BOP. The prevalent evidence of the BOP having little or no access to basic healthcare contrasted with thriving multispecialty hospitals within the same landscape is one example [25]. Software's developed for a particular Operating System is a good example. Emergence of microfinance is an example of filling such a void in the *capability* space amongst the poor's *capability* to access capital [26]. As discussed in the earlier section, the product/service quality dimension is crucial as access to inferior quality products would represent fulfilled capabilities, but with limitations.

4.2.3 Design by Virtue Cannot Shy Away from Being Paternalistic

Emphasis on freedom of choice (for the BOP) places enormous importance to participatory design to include customers' preferences and aspirations. This infuses customer's voice in Capability Approach integrated design. Though designers' tend to give due respect to customer aspirations (social, cultural, esteemed, etc.), they often are compelled to take unilateral decisions in interest of the beneficiary. Given the number of stakeholders and the consequent plurality of the considerations involved (as discussed in earlier sections), the designer's role becomes inadvertently paternalistic. The designer is thus the architect of the users/ beneficiaries' *capability* space. This is valid even if the design has been approved by the users, as the designer takes a paternalistic stand from the instance he proposes a set of design/product alternatives for the users/beneficiaries' to choose from. As in the case of disruptive innovations, users might not be able to fully comprehend the entire benefits resulting from the envisaged product [27].

5 Summary

This paper provides an overview of Capability Approach and its critical role in designing for the BOP. It moves beyond conventional definition of capability, to include effective (operational) options available to an individual to be and do as aspired, in leading a life of value upon reflection. The paper views various stakeholders involved in a successful design (product/service) as individuals with *capabilities*. The current paper evaluates the *capabilities* of the designer (individual or a firm) for its impact on designing products aimed at the BOP. A concept of *capability* space has been adopted to provide a vantage for the designer to evaluate the effect of design on the *capabilities* of users (beneficiaries). Such studies would permit the evaluation of successes and/or failures associated with products/services aimed at expanding/fulfilling *capabilities* of the users. Mapping the *capability* space before and after introduction of a product can help in further discerning the multi-stakeholder system and underlying influences.

Acknowledgments This research has been made possible with a research grant from the Netherlands Organization for Scientific Research (NWO) for the project 'Technology and Human Development—A Capability Approach'

References

1. Blessing L, Chakrabarti A (2009) DRM, a design research methodology. Springer, London
2. Prahalad CK (2005) The fortune at the bottom of the pyramid: eradicating poverty through profits. Wharton School Publishing, Singapore
3. Sen A (2000) Development as freedom. Oxford University Press, New York
4. Mani M, Ganesh LS, Varghese K (2005) Sustainability and human settlements. Sage Publications, New Delhi
5. Banerjee A, Duflo E (2011) Poor economics. Randon house publishers, Noida
6. Margolin V, Margolin S (2002) A "social model" of design: issues of practice and research. Des Issues 18(4):24–30, MIT, Cambridge
7. Ahmed S, Blessing L, Wallace K (1999) The relationships between data, information and knowledge based on a preliminary study of engineering designers. ASME design theory and methodology, DETC/DTM-8754, Lag Vegas, Nevada
8. Diehl JC (2009) The first learning experiences of design for the BoP. In: Kandachar P, Jongh I, Diehl JC (eds) Designing for emerging markets: design of products and services. Delft University of Technology, Delft
9. Sen A (1983) Economics and the family. Asian Dev Rev I
10. Robeyns I (2005) The capability approach: a theoretical survey. J Hum Dev 6(1):93–114
11. Khadilkar P, Monto M (2012a) A methodological framework to investigate the connect between capability approach and livelihood enhancement using ICT. In: Dahmani A, Ledjou J-M (eds) The information and communication technologies (ICTs) in southern countries: from promises to the socio-economic reality. Karthala Publications, Paris
12. Khadilkar P, Monto M (2012b) Assessment of technology in the view of sustainability and capability approach. In: Mukhopadhyay C, Akhilesh KB, Srinivasan R, Gurtoo A, Ramachandran P, Iyer PP, Mathirajan M, BalaSubrahmanya MH (eds) Driving the

economy through innovation and entrepreneurship: emerging agenda for technology management Springer, India
13. Gigler B (2004) Including the excluded—can ICTs empower poor communities? Towards an alternative evaluation framework based on the capability approach, international conference on the capability approach, University of Pavia, Italy
14. Word web software (2010) Version 6.3. Princeton University. Accessed in April 2012
15. 3M India official website. http://solutions.3mindia.co.in/wps/portal/3M/en_IN/About3/3M/. Accessed in July 2012
16. Studio ABD official website. http://www.studioabd.in/about.html. Accessed in July 2012
17. Cross N (2000) Engineering design methods strategies for product design. Wiley, West Sussex
18. Ulrich KT, Eppinger SD (2004) Product design and development. Tata McGraw-Hill, New Delhi
19. Swink M (2000) Technological innovativeness as a moderator of new product design integration and top management support. J Prod Innov Manag 17:208–220 Elsevier
20. Ramani SV (2011) On the diffusion of toilets as bottom of the pyramid innovation: lessons from sanitation entrepreneurs. Tech Forecasting Soc Change. Elsevier Inc 79(2012):676–687
21. Kleine D (2010) Ict4what?—using the choice framework to operationalise the capability approach to development. J Int Dev 22:674–692
22. Oosterlaken I (2009) Design for development: a capability approach. Des Issues 25(4):91–102. MIT, Cambridge
23. Simon H (1982) The sciences of the artificial. MIT Press, Cambridge
24. Shah J, Vargas-Hernandez N (2003) Metrics for measuring ideation effectiveness. Des Stud 24:111–134 Elsevier
25. UN (2012) The millennium development goals report 2012. New York
26. Yunus M (2007) Banker to the poor. Penguin books, New Delhi
27. Leonard D, Rayport J (1997) Spark innovation through empathic design. Harvard Bus Rev. Harvard business school publishing, 102–113

Author Index

A
Abdulrahman, Aisha, 1177
Abhishek, Pravimal, 1077
Ahmed, Saleem S., 859
AL-Ameri, Aysha, 1177
ALDousari, Shaikha, 1177
Allen, Janet K., 745, 759
ALShamsi, Abeer, 1177
Amaral, Fernando Gonçalves, 873, 885
Anand, Vivek P., 593
Athavankar, Ameya, 605
Athavankar, Uday, 605
Attias, Danielle, 721
Avidan, Yonni, 1139

B
Babu, Ram K., 965
Babu, S., 1015
Balasubramanian, N., 529
Balu, A. S., 543
Banerjee, Sharmishta, 605
Bapat, V. P., 249
Behncke, Florian, 237
Bergendahl, Margareta Norell, 187
Bertoluci, Gwenola, 677
Bhat, Soumitra, 721
Biswas, Swati Pal, 387
Blessing, Luciënne, 447
Bolton, Simon, 85
Bordegoni, Monica, 435, 939
Bosch-Mauchand, Magali, 913
Bricogne, Matthieu, 913
Brissaud, Daniel, 569
Brodbeck, Felix, 643

C
Chakrabarti, Amaresh, 211, 491, 557, 785
Chakraborty, Shujoy, 317
Chakravarty, Arnab, 691
Chakravarthy, B. K., 175, 477, 605
Chatterjee, Jayanta, 593
Childs, Peter R. N., 137
Chinneck, Camille, 845
Chithajalu, Kiran Sagar, 1063
Chowdhury, Anirban, 411
Clarkson, John P., 809
Cláudia de Souza Libânio, 873, 885
Coatanéa, Eric, 1005
Colombo, Giorgio, 423
Corney, Jonathan, 773
Cugini, Umberto, 435
Culley, Steve J., 151

D
Datt, Sachin, 283
Dekoninck, Elies A., 151
Deshmukh, Bhagyesh, 271
Devadula, Suman, 491

E
Eisenbart, Boris, 85
Eynard, Benoît, 913

F
Farel, Anirban Majumdar Romain, 617
Farzaneh, Helena Hashemi, 1151
Ferrise, Francesco, 939

A. Chakrabarti and R. V. Prakash (eds.), *ICoRD'13*, Lecture Notes in Mechanical Engineering, DOI: 10.1007/978-81-322-1050-4, © Springer India 2013

F (*cont.*)
Frenning, Lars, 1117
Frey, Daniel D., 41
Fritzell, Ingrid, 821
Furtado, Guilherme Phillips, 939

G
Gautham, B. P., 745
George, Dani, 199
Gericke, Kilian, 85
Gero, John S., 73, 631
Gheorghe, Florin, 679
Goldschmidt, Gabriela, 3, 26, 1139
Gomathinayagam, A., 195
Göransson, Gustav, 82
Goswami, Suparna, 643
Goyal, Sharad, 759
Graziosi, Serena, 939
Grobman, Yasha Jacob, 951, 1051
Gustafsson, Göran, 821, 1117

H
Habeeb K. Mohamed Rasik, 1015
Hansen, André, 977
Harinarayana, Kota, 125
Harivardhini, S., 557
Helten, Katharina, 897
Herrmann, Marnina, 29
Holstein, Manuel, 187
Howard, Thomas J., 977
Hussain, Romana, 973

I
Ihsan, Muhammad, 223

J
Jagtap, Santosh, 581
Jiang, Hao, 763
Jowers, Iestyn, 163
Junaidy, Deny W., 223

K
Kain, Andreas, 163
Kaiser, Maria Katharina, 1151
Kalmbach, Hansjörg, 187
Karmakar, Sougata, 411
KATO, Takeo, 61
Kernschmidt, Konstantin, 643
Kirner, Katharina G. M., 797, 809
Kohn, Andreas, 643
Kota, Srinivas, 569
Kothari, Samiksha, 691
Krcmar, Helmut, 643
Krishnan, S. S., 529
Krishnapillai, Shankar, 1023
Krus, Petter, 101
Kulkarni, Gajanan P., 859
Kulkarni, M. S., 735
Kulkarni, Nagesh, 745
Kumar, Madhan M. K., 1089
Kumar, Manoj, 125
Kumar, Prabhash, 759

L
Landel, Eric, 1005
Larsson, Andreas, 581
Lindemann, Udo, 163, 187, 211, 303, 643, 797, 809, 897, 1151
Lindow, Kai, 517
Linsey, Julie, 113
Lorenzini, Giana Carli, 885

M
Machiel Van der Loos, H. F., 679
Magee, Christopher L., 41
Maisenbacher, Sebastian, 707
Malhotra, Anisha, 1215
Mandal, Soumava, 347
Manivannan, M., 365, 377, 991
Mark O'Brien, 261, 1129
Mathew, Mary, 859
MATSUOKA, Yoshiyuki, 61
Mauler, Stefan, 187
Maurer, Maik, 643, 707
Mbang, Sama, 187
Messaadia, Mourad, 913
Metzler, Torsten, 163, 303, 1151
Mihoc, Ariana, 1031
Minel, Stéphanie, 505
Mishra, Vishwajit, 1201
Mistree, Farrokh, 745, 759

Mistry, Roohshad, 271
Moorthy, Srinivasa S. A., 833
Moreno, Diana, 41
Mosch, Michael, 303
Mocko, Gregory, 119
Murthy, Narasimha H. N., 1063

N
Nagai, Yukari, 223
Neelakantan, P. K., 293

O
Onkar, Prasad S., 655
Orhun, Simge Esin
Oswal, Sonam, 271

P
Panchal, Jitesh H., 745, 759
Parker, Indrani De, 1165
Patil, B. A., 735
Patsute, Rajendra, 447
Picon, Lucile, 505
Poovaiah, Ravi, 283, 1215
Prakash, Raghu V., 965
Prasad, Raghu M. S., 365, 377
Purswani, Sunny, 365, 377

Q
Qureshi, Ahmed, 85

R
Raghuvarman, B., 1015
Ramadas, Rithvik, 411
Ramanna, Rahul, 125
Rana, Nirdosh, 447
Rao, B. N., 543
Rao, P. V. M., 735
Ray, Gaur, 447
Reddi, Sarath, 463
Reddy, K. S., 1077
Regazzoni, Daniele, 423
Reif, Julia, 643
Renu, Rahul, 199
Ritzén, Sofia, 667
Rizzi, Caterina, 423
Roy, Rajkumar, 773
Roy, Satyaki, 593
Rucks, Camila, 885

S
Sathikh, Peer M., 1105
Sekhar, A. S., 1077
Sen, Dibakar, 463, 655
Shaja, A. S., 15
Sharma, Anshuman, 399
Sharma, Susmita Y., 477
Shinde, Chirayu S., 331
Shivraj, B. W., 1063
Singh, Amarendra K., 759
Singh, Amitoj, 347
Singh, Gurpreet, 991
Singh, Vishal, 631
Sinha, Sharmila, 175
Sirin, Göknur, 1005
Sivaloganathan, Sangarappillai, 1177
Sivasubramanian, T. N., 1023
Siyam, Ghadir I., 809
Snider, Chris M., 151
Sridhar, Naren, 261
Srinivasan, V., 211
Stark, Rainer, 517
Ström, Mikael, 821
Sudhakar, K., 125
Sunder, Shyam P., 529
Szigeti, Hadrien, 913

T
Tasa, Umut Burcu
Thomas, Tony, 1031

V
Vallet, Emilie, 721
Vasantha, Gokula, 773
Vasantha, Gokula Annamalai, 785
Vecchi, Giordano De, 423
Venkatesh, V., 529
Vergeest, Joris S. M., 927
Vieira, Sonia Da Silva, 73

V (*cont.*)
Viswanathan, Vimal, 113
Vogel-Heuser, Birgit, 643
Vyas, Parag K., 237, 249

W
Walters, Andrew, 1039
Wang, Zhihua, 137
Wiegers, Tjamme, 927
Wolfenstetter, Thomas, 643
Woll, Robert, 517
Wood, Kristin L., 41
Wynn, David C., 809

Y
Yammiyavar, Pradeep, 1201
Yannou, Bernard, 505, 617, 721, 1005
Yekutiel, Tatyana Pankratov, 1051

Z
Zagade, Pramod R., 745
Zwolinski, Peggy, 569