Smart Innovation, Systems and Technologies 65

Amaresh Chakrabarti
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Research into Design for Communities, Volume 1

Proceedings of ICoRD 2017

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Preface

Design is ubiquitous; 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 have transcended time, most designs are in a perpetual process of being evolved. Research into design and the emergence of a research community in this area have been relatively new, its development influenced by the multiple facets of design (human, artefact, process, organisation, ecology, micro- and macro-economy by which design is shaped and which it shapes in turn) and the associated diversification of the community into those focusing on various aspects of these 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 two book volumes constitutes the Proceedings of the Sixth International Conference on Research into Design (ICoRD'17) held at the Indian Institute of Technology Guwahati, Guwahati, India during 9–11 January 2017. ICoRD'17 is the sixth 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 goals are 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 global and local challenges by forming and realising the collective vision. The conference is intended for all stakeholders of design, and in particular for its practitioners, researchers, teachers and students.

348 abstracts was submitted to ICoRD'17 and selected for full paper submission. 223 full papers were submitted, which were reviewed by experts from the ICoRD'17 International Programme Committee comprising 241 members from over 151 institutions or organisations from 32 countries spanning five continents. Finally, 177 full papers, authored by 356 researchers (356 unique authors, actually 502 author entries in 177 papers) from 117 institutions and organisations from 19 countries spanning six continents, were selected for presentation at the conference and for publication as chapters in this book. ICoRD has steadily grown over

the last five editions, from a humble beginning in 2006 with 30 papers and 60 participants, through 75 papers and 100 participants in ICoRD'09, 100 papers and 150 participants in ICoRD'11, 114 papers and 170 participants in ICoRD'13, to 118 papers and 200 participants in ICoRD'15.

ICoRD'17 had 129 podium papers, and 48 papers with brief podium presentations followed by poster display and discussion. It had keynotes from prominent researchers and practitioners from around the world such as: Tetsuo Tomiyama from Cranfield University, UK, Jinan KB from Reimagining School, India, Cees de Bont from Hong Kong Polytechnic University, Hong Kong, Nitin Gupta from sickle Innovations, India, Monica Bordegoni from Politecnico di Milano, Italy, Pradeep G. Yammiyavar, IIT Guwahati, India, and Arun Garg, University of Wisconsin-Milwaukee, USA. It had one panel discussion on "Practice of Design", and four workshops, on Decision-Making in Design, Emotional Engineering, Publishing Papers, and Asia Design. From 2015, ICoRD started giving ICON^3 awards (acronym for **I**CoRD **O**utstanding **C**ontribution to desig**N** scie**N**ce and educatio**N**) to outstanding contributors to design education and research. Prof. Sudhakar Nadkarni from Welingkar Institute of Management, India, and Prof. John Gero from George Mason University, USA were selected as ICON^3 awardees for 2015, for their outstanding contributions to design education and design research respectively. Prof. Tetsuo Tomiyama of Cranfield University, UK and Professor Cees de Bont from Hong Kong Polytechnic University, Hong Kong, have been selected as the ICON^3 awardees for 2017.

The chapters in the two book volumes 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 later 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 of the book volumes. 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 so on.

The theme of ICoRD'17 has been "Design for Communities". While Design traditionally focused on the development of products for the individual, the emerging consensus on working towards a more sustainable world demands greater attention to designing for and with communities, so as to promote their sustenance and harmony—within each community and across communities. ICoRD'17 has been hosted at the foothills of the Himalayas in the north-east of India, which is home to myriad linguistic and cultural communities with their own traditions, heritage and aspirations. It was only appropriate that the theme for ICoRD'17 aligned with this ambiance.

This volume, 'ICoRD'17—Design for Communities, Volume 1' focuses on the topics of Design Theory, Research Methodology, Human Factors Design for X, Enabling Technologies, Design Management and Applications in Practice.

On behalf of the Steering Committee, Advisory Committee, Organising Committee and Co-Chairs, we thank all the authors, delegates, institutions and organisations that participated in the conference. We also thank members of the International Programme Committee for their support in reviewing the papers for ICoRD'17, which is essential for maintaining the quality of the conference, and for their support in putting this book together.

We are thankful to the Design Society and Design Research Society for their kind endorsement of ICoRD'17. We thank Indian Institute of Technology (IIT), Guwahati and its Department of Design, and Indian Institute of Science (IISc), Bangalore and its Centre for Product Design and Manufacturing, for their support of this event. We also wish to place on record and acknowledge the enormous support provided by Ms. Kumari M.C., Mr. Ranjan B.S.C., and Ms. Nishath Salma of IISc in managing the review process, and in preparation of the conference programme and this book, and the large and dedicated group of student-volunteers of IIT Guwahati and IISc Bangalore in the organisation of the conference. A special thanks goes to Dr. Prasad Bokil of IIT Guwahati for his relentless, day-to-day organisational support and leadership to make ICoRD'17 a success. Finally, we thank Springer, especially Senior Editor Swati Meherishi and Editorial Assistant Aparajita Singh, for the wonderful support extended in the publication of this book and in sponsoring books and book coupons for ICoRD'17 Distinguished Paper Awards and ICON^3 Awards.

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About the Conference

Design is ubiquitous; it pervades all spheres of life, and has been around as long as life has taken up the task of purposefully changing the world around it. Research into design and the emergence of a research community in this area has been relatively new. Its development has been influenced by the multiple facets of design (human, artefact, process, organisation, the micro- and macro-economy and the ecology by which design is shaped) and the associated diversification of the community depending on the facets of focus or that of their applications. Design is complex, balancing the needs of multiple stakeholders, and requiring a multitude of areas of knowledge to be utilised, and resources spread across space and time.

ICoRD'17 is the sixth in a series of conferences intended to be held every 2 years in India to bring together the international community from diverse areas of design practice, education and research. It aims to showcase cutting-edge research about design to the stakeholders; aid the ongoing process of developing and extending the 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 take up the challenges to realise the vision. The conference is intended for all stakeholders of design, and in particular for its practitioners, researchers, pupils and educators.

The theme of ICoRD'17 is "Design for communities". While Design traditionally focused on the development of products for the individual, the emerging consensus on working towards a more sustainable world demands greater attention to designing for and with communities, so as to promote their sustenance and harmony—within each community and across communities. ICoRD'17 is hosted at the foothills of the Himalayas in the north-east of India, which is home to myriad linguistic and cultural communities with their own traditions, heritage and aspiration. It is only appropriate that the theme for ICoRD'17 aligns with this ambiance. The conference contained:

- Invited/keynote presentations from eminent international experts and practitioners;

- Panel discussion and presentations of refereed papers as podium and poster presentations;
- Presentation of ICoNNN Awards and Keynotes;
- Networking Sessions for Young researchers;
- Workshops on dedicated topics.

Contents

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Part I
Design Theory and Research Methodology

Different Rationalities of Creative Design—A Comparative Case Study

Christoph Richter and Heidrun Allert

Abstract Starting from the premise that a deeper understanding of creative design requires closer attention to the practitioners' own accounts of what they are doing, a case study was aimed to trace and compare the way creative design is conceived and enacted by different design teams. Episodic interviews on past design projects were carried out with practitioners from two professional design teams and one educational institution. The case based analysis indicates locally coherent models of creative design, the cross-case comparison reveals fundamental differences in the way the local design processes and the underlying rationalities are construed.

Keywords Creative design · Rationalities · Case study · Practice theory

1 Introduction

Despite considerable amount of research on creativity and design, there is no consensus on whether creative design can be understood as a generic form of activity and how the differences in the way design is practiced are to be explained [6]. Design research has brought forward a range of alternative accounts on what design essentially is and how it is carried out. While it is suggested that these accounts provide different research perspectives on design [2, 9], the designers' own theories and epistemologies have largely been ignored so far. Following [12], we believe that we cannot understand design as an activity unless we understand the designers' accounts of what they are doing and how these accounts are evolving. The objective of the present case study is to corroborate the idea that creative design cannot be subsumed under a single epistemic model, but builds on different, locally

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situated, rationalities. Adopting a practice-oriented perspective, the study traces the way the design process is conceived and enacted by different design teams. The intent of our analysis is not to unravel general principles of creative design, but to shed light on the differences in the meshwork of design practices enacted in different settings. To elicit practitioners' conceptions of the local design practices, episodic interviews were carried out with 3–5 practitioners from two professional design teams and one educational institution. Based on the interviewees' narrative accounts, locally shared models of the design process and the underlying rationalities were reconstructed.

2 Rationalities of the Design Process

Research on creative design has primarily been concerned with the generic features of the underlying cognitive activities as well as the characteristics of the design situation that account for the different ways in which creative design is enacted (e.g. [11]). However, respective accounts assume the creative design process to be essentially shaped by a set of external factors, putting aside the question of how respective endeavors come into existence and how they relate to the designers' own conceptions of the design activity [6]. The question of whether creative design can be subsumed under a single epistemic model or methodology cannot be answered with recourse to any design theoretical position, but requires a broader conceptual framework capable to account for the emergence of heterogeneous epistemologies.

A Practice-Oriented Perspective: Drawing on the work of [4, 8], we take practices as the central unit of analysis for the present study. Social practices, according to this perspective, are those patterns and styles of action that emerge from an individual's or group's repeated interaction with the world, allowing the participants to form shared expectations on how to act in a certain situation (cf. [4]). Social practices hence can be understood as the conventions and arrangements enacted by a certain group of people at a certain point in time. As practices cannot be separated from the concrete doings and sayings of the practitioners and the material assemblages in which these take place, particular practices are necessarily local and historical. Yet, as situations are usually open to different interpretations, they require an active framing of those engaged in them, and therefore not only practical knowledge on how to act but also overarching schemes that allow actors to interpret and define the situation they find themselves in (cf. [4]). These overarching schemes can be understood as those rationalities that "reflect what constitutes a good design and good designing" ([10], p. 85). They provide an epistemic framework on which the designer's assessment of the situation is based and from which reasons for the appropriate way of acting are derived. In this sense, the designer's rationalities identify "the ways of knowing, of deciding what is worth knowing, and of adding to the collective body of knowledge and understanding of a community of practice" ([7], p. 223). To elicit, synthesize, and compare the design rationalities enacted in different settings we drew on the frameworks for the comparison of design paradigms [1, 9, 10] and devised an integrative analytic model. According to this model, a design rationale provides an account of (a) the role of the designer in relation to the designer and the product, (b) the relation between the user and the product, (c) the designer and the users, as well as (d) the micro- and macro-dynamics of the design process.

3 Case Study Design and Methods

The comparative case study was carried out in three organizations that took part in an R&D project focused on ICT support for collaborative design teams.[1] Case 1 exemplifies an independent design company who carefully chooses the clients they want to work with, Case 2 represents a work unit within a global enterprise devoted to generate new concepts to advance and innovate the company's product portfolio. Case 3 is an academy educating prospective designers, providing a place of particular experimentation and realization. While the three cases differ regarding size, product portfolios, primary target groups, level of autonomy and closeness to market, they all have (a) a strong background in product and/or industrial design, (b) are aimed to actively drive innovation and (c) have a considerable track record and reputation in their fields of operation. Even though the selection of cases is by no means representative, all three cases are exemplary in that they represent teams recognized for successful creative design, while at the same time covering different types of design work. To elicit the practitioners' conceptions of the local design practices, episodic interviews [3] were carried out with 3–5 practitioners in the three organizations, including 4 master-level students and 1 instructor in Case 3. Interviews were carried out by trained interviewers, familiar to the field of creative design. In the episodic interviews participants were asked to report on two different design projects they had been actively involved in with the respective organization. The narrative accounts of the interviewees' (lasting 40–90 min) were then used to probe into the interviewees (iwees) understanding of the local practices. All interviews were audio-recorded, transcribed and anonymized. The subsequent analysis entailed three main steps. 1st step: the interviews were analyzed individually. The transcribed interviews were paraphrased, thematically coded by an individual analyst who then produced an initial synopsis. The initial coding list was derived from existing proposals for the comparison of design paradigms [1, 9, 10] as well as generic accounting schemes for qualitative research [5]. The coding lists and procedures for individual analysis were tested and attuned based on a initial analyzed by all subsequent coders. The coded interview and synopsis was then cross-checked by a second analyst and a consensual interpretation sought. 2nd step: the individual accounts were compared and integrated into a case-based account. The case-based accounts are based on the commonalities evident in the individual

[1]See Idea-Garden.org for more information on the project and its deliverables.

accounts. The case-based accounts were also cross-checked collaboratively by the research team. In case of conflict the individual accounts and interviews were consulted. 3rd step: the case-based accounts were juxtaposed and searched for similarities and differences by the research team.

4 Results: Case 1—Design Company

Strong background in object and interior design, holds more than a dozen mechanical patents, has been awarded more than 60 international awards for their products.

Model of the Designer in Relation to the Product. With its focus on furniture and object design for well-known clients in the upper market segment, there is an evident commercial intention in the design efforts. While considerations for technical feasibility and economic viability have been mentioned as crucial dimensions of a product's success, the primary intent, as articulated by the interviewees, is to create innovative and meaningful everyday objects that promote an understanding of a certain design culture. This aspect is evident both in the characterization of the company's clients who are supposed to "have an understanding of design culture and cherish the designers and their work", as well as in the team's concern for the cultural connotation the products have. In this sense the company's products can be understood as an expression of a particular designerly identity and attitude. The team does not only aim to find novel technical solutions but also to open new perspectives on everyday objects and their utilization.

Model of the Relation between the User and the Product. The majority of products are everyday objects such as chairs, tables, kitchens, lamps or bathtubs. While these objects are seen as pragmatic and assistive devices, characterized in terms of their usability, utility and ergonomic properties, they are also understood as carriers of meaning and cultural responses by the interviewees. The products can also be seen as objects of distinction for an economic or cultural elite who is capable to purchase and/or appraise the qualities of these objects. The focus of all three iwees has been very much on the products and their built-in qualities, which are supposed to reveal themselves or be conveyed to the user. The design objects primarily appear as significant enablers in the everyday life of its users, even though the particular qualities of the products, such the nuances of the formal design, material, and overall impression might remain unnoticed by the layperson.

Model of the Designer in Relation to the User. The designers characterized themselves as problem-solvers who devise meaningful products that provide innovative functionalities and experiences to those who purchase or use them. In collaboration with the client/manufacturer, it is the designers' task to identify user needs and to translate these into manufacturable objects. Seeing themselves as drivers of an otherwise settled and less innovative market, the design process is described as free and unrestricted by outside control. While potential users are seen as an important point of reference for the assessment of the functionality and suitability of products for daily use, the users are construed as essentially similar to the designers and their experiences. Accordingly, there appears to be no particular need for the direct involvement and participation of the envisioned end-users in the design process, as commonsensical understanding is assumed to be sufficient.

Process—Macro- and Micro-Level Dynamics. The design process is driven by a guiding "idea", which provides the overall direction for the conceptual and detailed design. The identification of the guiding ideas marks an essential moment in the creative process. While the employees are actively involved in the initial research phase, the three partners play a strong role in the development of the guiding idea, which is then handed down to the employees in order to produce more and more detailed design models in collaboration. While in the initial stages different ideas are explored, the conceptual design process as such is aimed to narrow down presumably interesting design directions and to translate the guiding idea into an objective form. As indicated in the interviews, the main challenge for the employed designers is to develop solutions for the detailed design that correspond to and strengthen the overall conceptual design. This process however also requires exploration and experimentation in order to devise convincing solutions. The iwees described the extensive creation and use of design models/artifacts and prototypes as a unique feature of their work. The respective micro-level process dynamics can be understood as iterative cycles of focused speculation, prototypical realization and collaborative assessment. The iterative cycles entail a form of guided experimentation to find a solution that best translates the pre-established design concept into a product. These micro-level processes of iterative refinement and modeling are however embedded into the macro-level process dynamics that are focused on the advancement and faithful realization of the guiding idea.

4.1 Case 2—Work Unit Within a Global Enterprise

The work unit is one of the frontend innovation departments of the global enterprise. Within this context the work unit's focus is on long-term innovation, aimed to identify opportunities to deliver more radical products.

Model of the Designer in Relation to the Product. The designers in the work unit introduced themselves as "diplomatic rebels" within the company, in that they try to bend the rules and explore how far ideas can be advanced under the company's label and within its value system. Due to its experimental nature, the design endeavor turns into a learning process in which the team capitalizes not only on what works but also on what does not work. Besides the experimental focus of the work unit, the iwees stressed the commercial dimension of their efforts: there aim is not just to produce innovative ideas, but to also ensure that these ideas are technically feasible, marketable, and attractive to kids. Adopting this perspective, the designers do not see themselves primarily as open-ended explorers or inventors, but as those, who respond to a strategic challenge defined be the company.

Model of the Relation between the User and the Product. The primary value of the products, from a user's perspective, has been attributed to the play experiences the toys promote. The iwees depicted the primary user group, i.e. children, as active protagonists, who build on and appropriate the designers' ideas. The play experiences the children create with a particular product are not understood as something inscribed into the product, but as emergent from the active utilization of the toy. One of the designers stressed this indeterminacy when pointing out that: "We don't know what people will do with it". As a consequence, the design products are primarily conceived as a vehicle to spur the children's creativity, providing constructive props for creative expression and play. A core quality of the products hence is their openness for different usage scenarios and play experiences, which is continuously extended and enriched by the children themselves.

Model of the Designer in Relation to the User. The conception of the user as an active and autonomous protagonist is also mirrored in the users' direct and indirect involvement in the design process. In characterizing the user group, the iwees in the work unit stressed the differences between their own ideas and perspectives and those of the children and even between different groups of children. While the team members bring in their particular expertise and skills in different fields of design, marketing and research, the users are approached as indispensable authorities when it comes to the understanding of playful and enjoyable usage scenarios and experiences as well as the assessment of respective product ideas.

Process—Macro- and Micro-Level Dynamics. Similar to the general company, the design process within the work unit builds on a stage gate system in which the emerging design concepts are regularly evaluated against strategic objectives and insights. The design process starts with an open and explorative design brief, which provides the overall assignment for the design team. The design process then is structured by a series of consecutive gate meetings throughout which the design concepts are refined and narrowed down until a decision is made on whether the concepts are worth further pursuing or not. The process in between the gate meetings is highly agile, unpredictable and even messy, aimed to develop and iteratively test a range of alternative ideas. The design process is made up of a sequence of divergent and convergent phases, which results into more and more refined concepts and ideas from the initial brief to the delivery of the final design. Moving beyond the overall structure of the design process, the iwees stressed the importance of explorative prototyping and testing the emerging ideas throughout all stages of the design process. Both prototypes and tests are attuned to the maturity of the concept, ranging from co-creation, focus group tests with mockups and concept sketches to systematic trials with prototypes. The micro-level process dynamics described by the iwees can be understood as iterative cycles of speculating, prototyping, and collection of users' responses, which result into a constant accumulation of insights. These micro-level process dynamics are embedded in the macro-level dynamics of the collection of insights and trends, the staged design and production process, and follow up studies on the uptake of the products.

4.2 Case 3—Academy of Fine Arts and Design

The academy offers a Bachelor's and Master's study program in the field of Industrial Design. It is based on a project-based curriculum in which students work through a series of complex design projects individually or in small groups.

Model of the Designer in Relation to the Product. In the interviews the students mentioned two alternative approaches to design that they labeled as the "classical" and the "experimental" one. In line with these approaches they also suggested two different models of the relation between the designer and the product. According to the students' accounts, the classical approach is associated with the creation of meaningful and well-thought-through products, aimed to address a societal issue, be it in direct response to a societal challenge, the provision of support for underserved groups and/or attempts to foster forms of sustainable production and consumptions. In contrast, the experimental approach was described as more prone to a form artistic or thought-provoking expression, capitalizing on subjective experiences and reflection, aimed to push the boundaries with respect to the public and disciplinary understanding of interaction design. Independent of this the students framed their projects as integral to their own learning and development process emphasizing personal aspiration over immediate utility and marketability.

Model of the Relation between the User and the Product. The designs created by the students cover a broad spectrum of product categories, ranging from mobile organizers, over medical devices to interactive installations of a more artistic nature. Due to this diversity, there are fundamental differences in the way respective products are generally approached and utilized and the relation between the user and the product is construed. While the products developed under the "classical" approach are primarily supposed to be of practical utility to the users and advance their scope of action, products and installations developed within the "experimental" strand are typically geared towards an immediate and radical experience. Despite the differences students' projects were all geared to support quite specific usage scenarios in which the intended users appear as operators rather than as agents that have an active role in the design and utilization of the products.

Model of the Designer in Relation to the User. While the students expressed some uncertainty regarding their personal role as prospective designers, they all emphasized the agency of the designer and the need for a professional designer to develop a personal stance. They highlighted the designer's ability to identify relevant issues, to devise innovative solutions and to make deliberate design decisions in support of an intended user group. While understanding the users and the situations they are facing is deemed essential, representatives of the user group are approached as informants on pertinent needs in the "classical" approach or enrolled to test prototypes and provide feedback in the "experimental" approach.

Process—Macro- and Micro-Level Dynamics. The students' design process is shaped by the educational context, including constraints due to the timing of terms and the lack of a subsequent engineering or implementation phase. The design process usually starts with a briefing provided by the teaching staff, and has the form of a generic theme, rather than a specific problem. Even though the iwees made reference to a generic model of the design process, dividing the overall process into subsequent phases of the ideation, conceptual design, detailed design and prototypical realization, the iwees pointed towards the existence of at least two concurrent approaches, the "classical" and the "experimental". The "classical approach conceived as a rather structured procedure that starts from an idea that is fixed rather early on in the process and is then incrementally translated into a more and more refined design, while the quality of the solution is primarily assessed by the extent the design provides a proper realization of the initial idea. The "experimental" approach was described as open, explorative and research oriented, a process in which the idea takes shape only in the very course of the design project, which usually materializes in a series of prototypes. The two approaches realize different micro-level process dynamics. While in the first the process dynamics are aimed to continuously narrow down the design space by consecutive cycles of specification, incremental translation and corrective assessment, the dynamics in the second approach are rather open ended, actuated by cycles of speculation, experimental prototyping and exploratory assessment. While both approaches allow the students to respond to an open-ended design brief and produce a conceptually and aesthetically sound design solution without being constrained by pressure for immediate applicability or marketability, they draw on different rationales.

5 Discussion

Comparing the iwees' accounts across the settings, there are some basic commonalities: (a) the start from a generic and open-ended briefing or assignment, which needs to be interpreted and concretized in the design process; (b) the understanding of creative design as a non-trivial and highly unpredictable endeavor; (c) a conceptual demarcation between the design and the subsequent engineering or implementation process. Despite these commonalities, the interviews also reveal remarkable differences in the way creative design is construed by the practitioners. The *model of creative design in Case 1* is heavily based on the upfront establishment of a guiding idea, which addresses functional, aesthetic, and cultural desires. The product is not supposed to be yet another everyday item but an object that promotes an understanding of design culture. The designers themselves are given an active role in defining and articulating the design agenda. As the innovativeness of a product is not primarily assessed in terms of its utility but in its capability to enrich daily life and challenge preexistent conceptions of how objects ought to be, there is no immediate need for direct user involvement or feedback. In contrast, the *model of creative design in Case 2* is reliant on user feedback and the empirical validation of design ideas. As the product is seen as an open-ended prompt to be actively finalized and appropriated by the users themselves, there is a constant need to understand and learn how users conceive design ideas and what they are actually doing with the products. Thus, the users are actively involved throughout the design process. The reports from students *in Case 3 in turn, pointed towards two alternative models* they had enacted in their projects at the academy, a fact also mirrored in the professor's account. They described a more structured procedure as the "classical" approach, in which the design problems are understood as more or less objectively given and as identified by careful observation and analysis. The primary aim of the design process is to devise products that effectively address the problems identified. While potential users are involved as informants, the designer is seen as the main driver to put forward ideas and solve the problem. On the other hand, the students also described an "experimental" approach to creative design. The procedure here is more explorative than solution oriented. Instead of aiming at meaningful products the focus is on artistic or thought-provoking expressions that enable certain experiences or foster reflection. Again the designer is assigned a strong role in the definition of the design agenda while users are primarily involved as recipients and testers. The *differences in the models of creative design as entertained in the three cases appear* to be significant as they point towards different rationalities and epistemologies, which are not directly reconcilable with each other. Differences are evident in the construal of the knowledge base as well as the epistemic strategies and resources deemed relevant. E.g., the knowledge base is alternatively understood as objectively given, emergent, culturally shaped or based on personal insight. Also the epistemic strategies differ and range from forms of cultural analysis, over phenomenological oriented approaches to experimental interventions and observations. Hence there are substantial differences in the type of knowledge deemed relevant and the procedures to make use of and add to this knowledge. While being internally consistent, the rationalities cannot simply be exchanged or mixed. E.g., the direct involvement of users is of little use and might even be contra-productive in Case 1 as it might blur or subvert the cultural statements and ambitions entailed in the products. On the other hand, personal insights and cultural considerations are of little help for the design of toys, if these are assessed as "no fun" by the kids, they are intended for. It appears that there are substantially different and practically incommensurable ways, in which creative design is conceived and practiced in the different settings.

6 Conclusions

The findings of this comparative case-study challenge the idea that creative design could be subsumed under a single (epistemic) model (e.g. [11]), but is in line with those who suggested that design can be based on different rationalities and enacted in qualitatively different and even practically incommensurable ways (e.g. [10]). While this comparative case study has been focused on three settings only, the findings indicate that the relation between designer/design-object, design-object/user as well as designer/user can be construed in quite different ways, each depicting a different way in which design is and can be practiced successfully. The aim of this study has not been to provide a catalogue or typology of potential design rationalities, but to point out the fact, that a thorough understanding of creative design cannot be achieved without taking into account the practitioners' construals of the way they act and why they are doing so. If we want to be serious of the social dimension of design, we need to go beyond models that conceive the social as contextual factor. To understand the impact of design on community and to get a hold on the interplay of community and design, it appears more productive to inquire into the rationalities and models enacted by the practitioners in a particular setting rather than to develop and stipulate generic models of design. The findings raise the question of how and where the different rationalities emerge from. While authors such as a [11] suggested that differences in the way design is practiced emerge in response to different contextual conditions and external factors, others argued that they are an effect of the actors' personal stance towards design (e.g. [10]). Adopting a practice-oriented perspective instead, we argue that these rationalities actually emerge out of the recurrent engagement with design projects in a particular environment. While some of the differences we found, might indeed be attributed to external factors such as the size of the core design group and overall structure of the organization, it is hard to see how the differences in process dynamics, as well as the designers conception of their role, the product and the user could be attributed to external factors straightforwardly. Practitioners in all three cases argued that their local practices are different from what their competitors are doing and that design is and can be practiced differently by design teams working in the same domain. It appears implausible that the different conceptions of creative design are simply the result of personal preferences as they are shared within the teams and must provide viable framings to ensure the teams' success in competitive markets. Against this background it seems more realistic to assume that the rationalities and models of design are itself situated in and emerge out of local practices. The success of a design team then would not depend on the adoption and application of a preconceived rationality and methodology, but on the team's ability to develop a viable niche in interaction with its environment and the communities they intend to serve.

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Design Space Configuration Trough Analytical Parametrization

Petter Krus

Abstract In design, proper parametrization is an important activity. A straightforward parametrization using e.g. geometric dimensions directly seldom achieves models that can be easily modified to respond different functional requirements. A good parametrization contains some implicit information about the design space, and automatically excludes invalid solutions by minimizing the region of a design space that is unfeasible, e.g. by introducing parameters based on dimensionless numbers. In this way, waste of design space is minimized, and it can be quantified using design information entropy, so that different parametrizations can be compared. This is particularly useful in design optimization, but it is equally important in manual design. This is related to the independence axiom in Axiomatic Design, where ideally each functional requirement (FR) should be depending on only one design parameter (DP), but it is much more general, since it does not implicitly assume that the functional requirements are independent, but instead allows for correlation between them.

Keywords Design space · Singular value decomposition · SVD · Performance estimation · Design information entropy

1 Introduction

In computer aided design parametrization is an extremely important activity. It is, however, a mostly overlooked area and parametrization is mostly done on an ad hoc basis. It is important when a flexible model is to be created that can be used in conceptual design, where different dimensions and other parameters can be explored. In [1] parametrization in aircraft design is thoroughly discussed and the importance to separate size from function is emphasized. Furthermore, to have

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concise, flexible and robust parametrization is also underlined. This is also discussed in [2]. This corresponds to minimizing the design entropy as discussed in [3] by having the smallest design space that includes as much as possible of the viable design space, while avoiding constraints. This was also applied to the configuration problem in [4]. In [6] axiomatic design is presented as a way to make a design that not is so coupled, the same can be applied also to the parametrization.

In this paper singular value composition (SVD), see [5], is introduced for analytical parametrization of design, since the resulting parameters can be automatically aligned around the feasible region of design. To do this a dataset with example design points within the feasible design are used. This gives a parametrization with a minimum number of parameters that can define a design within the design space.

It is, however, not always that the SVD parameters are intuitive from a user point of view. The first parameter can usually be considered as a size or scaling parameter but the other are not so clear. It can, however, also be used to test a given parametrization by studying the correlation with the ideal SVD parameter set. This is important since it is sometimes useful to have a parametrization that have a clearer interpretation than the synthetic SVD parameter set can provide. Interestingly, it is also possible to derive the number of driving requirement in a product category by studying a number of instances of a particular kind of product. This can be useful in order to understand a market.

Singular Value Decomposition (SVD) is a technique that is related to principle component analysis. It is a method to achieve this that involves an elegant mathematical method to obtain a model that is aligned with the main axis of the data set. Consider the data set X which is a matrix. Then there exist a decomposition of the form.

$$\mathrm{X} = \mathrm{U} \times \mathrm{W} \times \mathrm{V}^{\mathrm{T}} \tag{1}$$

where W is diagonal. This is the Singular Value Decomposition, SVD. This can look like this:

$$\begin{pmatrix} x_{11} & x_{12} & x_{11} \\ x_{21} & x_{22} & x_{23} \\ x_{31} & x_{32} & x_{33} \\ x_{41} & x_{42} & x_{43} \end{pmatrix} = \begin{pmatrix} u_{11} & u_{12} & u_{11} \\ u_{21} & u_{22} & u_{23} \\ u_{31} & u_{32} & u_{33} \\ u_{41} & u_{42} & u_{43} \end{pmatrix} \times \begin{pmatrix} w_1 & 0 & 0 \\ 0 & w_2 & 0 \\ 0 & 0 & w_3 \end{pmatrix} \times \begin{pmatrix} v_{11} & v_{12} & v_{13} \\ v_{21} & v_{22} & v_{23} \\ v_{31} & v_{32} & v_{33} \end{pmatrix}^T \tag{2}$$

The consequence of this operation is that if each row in the X and U matrix represents a data set of the entity that should be modelled, any point in U is mapped onto X trough the matrix product. In this example there are therefore four data sets, each represented by three parameters. Usually the resulting matrices are arranged in such a way that the diagonal elements of the W-matrix are in descending order. Hence the influence of the u variables is in descending order in each row, which means that the last ones can be omitted in order to get a simpler model without too

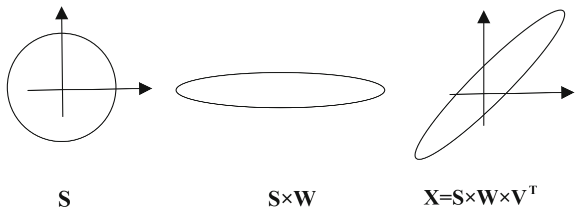

Fig. 1 The transformation from the SVD parameters to the X parameters

much loss in accuracy. However, for this to be valid the dataset should first be centered around the mean value. This can be done by subtracting the average of each column in the x-vector from the values of each column. An interesting property of the U matrix is then that the sum of the variance of each column is one. That is:

$$\sum_{i=1}^{n} u_{ij}^2 = 1 \tag{3}$$

This means that all columns (that is parameters) have the same deviation $\sigma = 1/\sqrt{n}$. The W matrix is then a weight matrix with only diagonal elements, and V^T is a matrix that rotates the coordinate system from the main axis into X (Fig. 1).

To estimate parameters and properties the following equation is used:

$$X = S \times W \times V^T \tag{4}$$

Here the X and S are now vectors. S is the input vector with *SVD-parameters* that are orthogonal and X is the estimated values of parameters and properties. This can look like this:

$$\begin{pmatrix} x_1 & x_2 & x_3 \end{pmatrix} = \begin{pmatrix} s_1 & s_2 & s_3 \end{pmatrix} \times \left(\begin{pmatrix} w_1 & 0 & 0 \\ 0 & w_2 & 0 \\ 0 & 0 & w_3 \end{pmatrix} \times \begin{pmatrix} v_{11} & v_{12} & v_{13} \\ v_{21} & v_{22} & v_{23} \\ v_{31} & v_{32} & v_{33} \end{pmatrix}^{T} \right) \tag{5}$$

With

$$K^T = W \times V^T \tag{6}$$

$$\begin{pmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ k_{31} & k_{32} & k_{33} \end{pmatrix}^{T} = \begin{pmatrix} w_1 & 0 & 0 \\ 0 & w_2 & 0 \\ 0 & 0 & w_3 \end{pmatrix} \times \begin{pmatrix} v_{11} & v_{12} & v_{13} \\ v_{21} & v_{22} & v_{23} \\ v_{31} & v_{32} & v_{33} \end{pmatrix}^{T} \tag{7}$$

This can be written as

$$\begin{pmatrix} x_1 & x_2 & x_3 \end{pmatrix} = \begin{pmatrix} s_1 & s_2 & s_3 \end{pmatrix} \times \begin{pmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ k_{31} & k_{32} & k_{33} \end{pmatrix}^{T} \tag{8}$$

or

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ k_{31} & k_{32} & k_{33} \end{pmatrix} \times \begin{pmatrix} s_1 \\ s_2 \\ s_3 \end{pmatrix} \tag{9}$$

Note that since the orthogonal parameters are sorted in ascending order it is often sufficient to use only a few input parameters. If it is reduced to just two parameters, in this example, the system gets reduced to:

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} k_{11} & k_{12} \\ k_{21} & k_{22} \\ k_{31} & k_{32} \end{pmatrix} \times \begin{pmatrix} s_1 \\ s_2 \end{pmatrix} \tag{10}$$

The individual element in the k matrix is the same as before. The same result is therefore achieved by just setting the last element in the input vector in Eq. (9) to zero. The error introduced in this way are such that the square errors are minimized.

One issue with this model is that the elements variance of the S-vector is dependent on the number of data set, and hence also the K-matrix. Therefore, it can be suitable to normalize the S-vector so that the variance of the elements is one. This is simply done by dividing each element with the deviation and then consequently multiplying the elements in the K-matrix with the same value.

$$\begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = \begin{pmatrix} k_{0,11} & k_{0,12} \\ k_{0,21} & k_{0,22} \\ k_{0,31} & k_{0,32} \end{pmatrix} \times \begin{pmatrix} s_{0,1} \\ s_{0,2} \end{pmatrix} \tag{11}$$

where

$$s_{0,j} = \frac{s_j}{\sigma_S} = s_j\sqrt{n} \tag{12}$$

And consequently

$$k_{0,ij} = \sigma_S k_{ij} = \frac{k_{ij}}{\sqrt{n}} \tag{13}$$

1.1 Design Space for Parameterization

The following example of parametrization of an aircraft wing planform was discussed in [3]. It is a well-known parameterization of aircraft wing used in literature e.g. in [7]. The planform for a wing can be defined with three parameters (disregarding wing sweep). These are wing span, b, root cord, c_r, and tip cord, c_r as

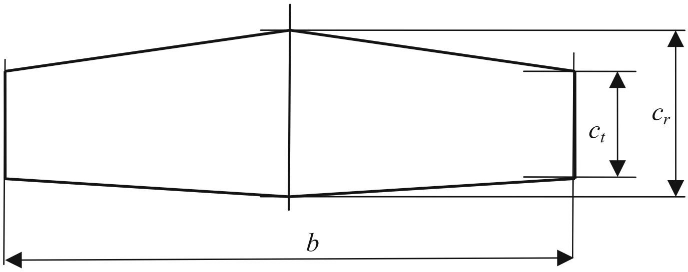

Fig. 2 Wing parameters

defined in Fig. 2. These are here referred to as the primary parameter set. In general, however, it is common to use wing area, S, aspect ratio, AR, and tapering, λ, as parameters instead. See e.g. [7]. These are here referred to as the secondary parameter set. The relationships between these are:

$$\begin{aligned} S &= \tfrac{b}{2}(c_r + c_t) \\ AR &= \tfrac{b^2}{S} \\ c_t &= c_r\lambda \end{aligned} \tag{14}$$

To study the design space a data set of existing aircraft are shown in Table 1.

Plotting the region spanned by the extreme values in the secondary parameter set, in the coordinates of the primary parameter set gives Fig. 3.

In order to be able to deal with large variation of parameter values it is convenient to use the logarithm of the parameters instead.

This is justified by the fact that it is more relevant to define parameter tolerance in relative terms of the nominal parameter value. In the left part of Fig. 4. The

Table 1 Parameter values for existing aircraft

	b	cr	ct	S	AR	λ
AN225	88.4	16.5122	3.96293	905	8.63487	0.24
A380	79.75	17.6594	3.53187	845	7.5267	0.2
A320	34.09	5.99394	1.19879	122.6	9.47902	0.2
Gulfstream IV	23.7	5.73191	1.71957	88.3	6.36116	0.3
U2	32	4.83333	0.966667	92.8	11.0345	0.2
F-16	9.96	4.47711	1.11928	27.87	3.55944	0.25
Mirage 2000	9.13	8.5537	0.427685	41	2.0331	0.05
Cessna 172	11	1.59214	1.35332	16.2	7.46914	0.85
Max value	88.4	17.6594	3.96293	905	11.0345	0.85
Min value	9.13	1.59214	0.427685	16.2	2.0331	0.05

Data is from open literature such as Wikipedia and might be inexact, but are just used as an illustrative example

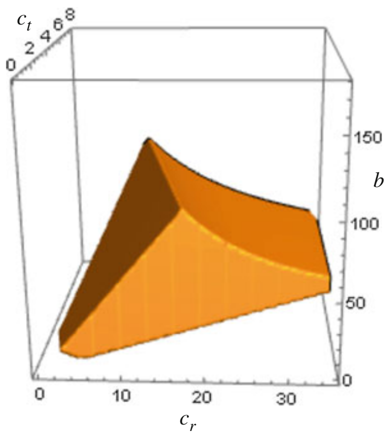

Fig. 3 Design space using the secondary parameter set

design space defined by the logarithm of the secondary parameters is shown as the slanted block. The parameters of all the studied aircraft are fitted inside this box. To the right, the outer box represents the design space defined by the primary parameters. As can be seen there is some part of the design space of the secondary parameters that is outside. This represents an empty part of the design space, which can be regarded as a sort of "waste" of design space. Using the primary parameter set all of the volume outside the slanted block in the right in Fig. 4 is also wasted design space.

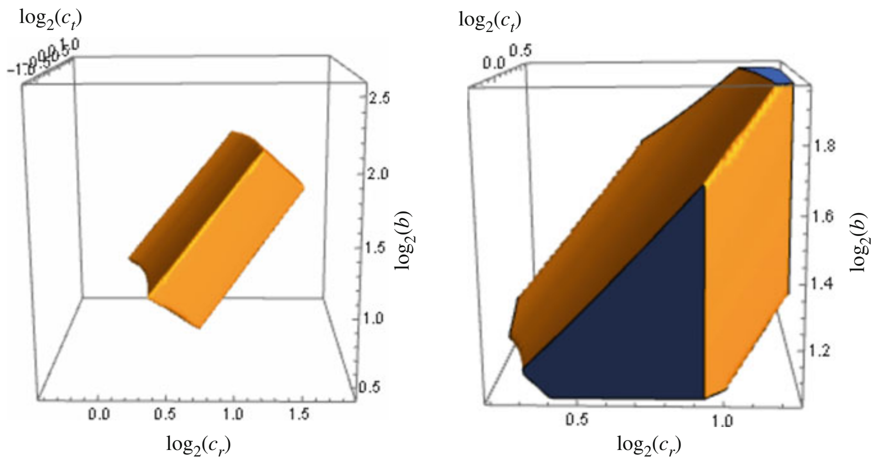

Fig. 4 Design space defined by the logarithms of the secondary parameter set, displayed in the logarithms of the primary parameter set. To the *right* the outer box represents limitations on primary parameters

1.2 Analytical Parametrization of Wing

If the primary parameters are used and used to formulate an SVD parametrization the following model is obtained.

	Offset	s1	s2	s3
b	1.41	1.002	0.225	0.092
cr	0.81	0.725	−0.115	−0.498
ct	0.16	0.700	−0.203	0.384

It can be seen that the all the primary parameters are strongly dependent on the first SVD parameter. This is natural since the first SVD parameter is related to size.

If the secondary parameters are used to formulate an SVD parametrization the following model is obtained.

	Offset	s1	s2	s3
S	2.02	0.598	−0.003	−0.024
AR	0.80	0.105	0.176	0.103
λ	−0.65	−0.055	0.303	−0.061

Here it can be seen that the first SVD variable have a strong influence on S which is the dimensional parameter. The influence on the dimensionless number has only small influence on the first SVD variable but much higher in the second (AR) and third (λ).

The design space is considerably smaller than for the other parametrizations. The result from calculating the volumes of the design spaces yields the results in the Tables 1, 2 and Fig. 5.

Apparently the analytical parametrization using SVD has the smallest volume, while still including all the samples. It is not surprising since this is the design space most aligned with the samples. This means that in order to be able to have a design space that can reach all designs, the SVD parametrization generates the smallest one. It can be interpreted such as information about the design is imprinted already in the design space, since some of the unviable solutions are removed already from the design space, and less information is needed to reach a specific part of the design space.

Table 2 Design space volumes of the different parameter sets

Parameter set	Design space volume
b, cr, ct	0.914
S, AR, λ	0.877
SVD	0.25

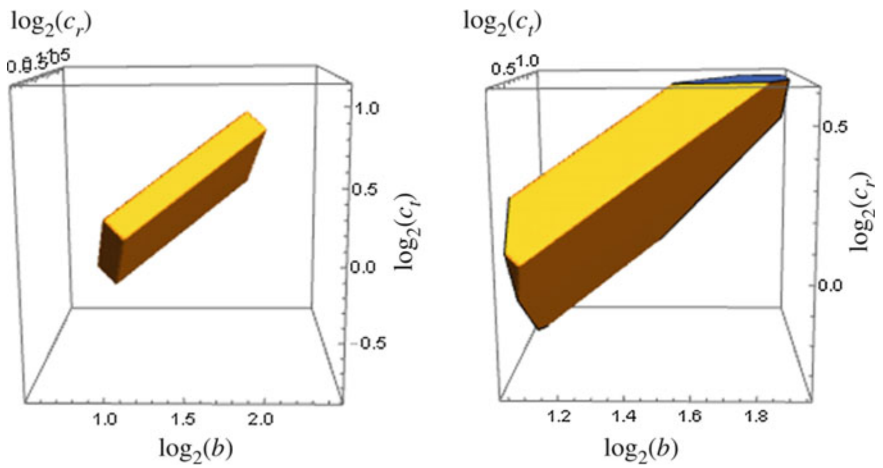

Fig. 5 Design space defined by the logarithms of the SVD parameter set, displayed in the logarithms of the primary parameter set. To the *right* the outer box represents limitations on primary parameters

It also means that using the primary parameter set would waste design entropy according to [3] the difference in design information entropy needed to define a design within a certain tolerance s, for these two different design spaces is simply:

$$H_w = H_1 - H_2 = \log_2 \frac{S_1/s}{S_2/s} = \log_2 \frac{S_1}{S_2} = \log_2 \frac{0.914}{0.25} = 1.87\text{bits} \tag{15}$$

Hence if optimization is used to define the design, less effort is needed to arrive at the optimal design. Even though this is not to significant in this case with three parameters, it can significantly reduce the effort for large problems. Furthermore, this can also be used to reduce the number of parameters for optimization. E.g. the thirds SVD variable have a rather small impact on any of the parameters and could be considered to be dropped to further speed up optimization.

1.3 *Singular Value Decomposition for Estimation of System Characteristics*

If also other attributes such as functional characteristics, are added to the data set, they can also be mapped onto the design space, and an estimate of system characteristics can be obtained directly. As an example a parameter set of 400 jet engines where used.

The result is a model that can predict the relation between geometrical dimension, diameter and length, bypass ratio, mass, and thrust and specific fuel consumption (Figs. 6 and 7).

	Estimate	Adjusted	Result	Average	k-matrix						SVD variables	w-diagonal
Bpr+1	6.10	0.79	0.12	0.67	0.106	-0.208	0.011	-0.028	0.011	0.001	1.11	16.17
T [kn]	305.15	2.48	0.54	1.94	0.483	0.025	-0.025	-0.008	0.000	-0.029	0.02	5.38
Sfc [1/hr]	0.40	-0.40	-0.06	-0.34	-0.074	0.101	-0.011	-0.056	0.000	0.008	-0.32	1.81
w [kg]	5636.89	3.75	0.51	3.24	0.463	0.042	0.004	0.008	0.023	0.026	-0.33	1.41
d [m]	2.72	0.43	0.25	0.18	0.213	-0.042	-0.016	0.000	-0.046	0.016	-0.15	1.20
l [m]	4.14	0.62	0.15	0.46	0.158	0.042	0.074	-0.007	-0.013	-0.007	0.16	0.96

Fig. 6 SVD-model for aero engines. Showing values for the Pratt & Whitney PW2040 for reference

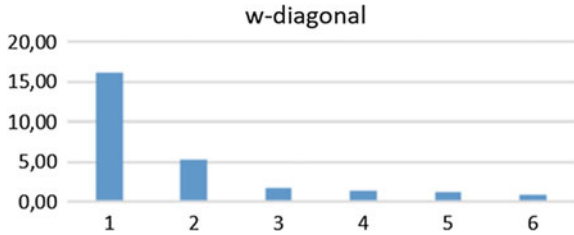

Fig. 7 Influence of the SVD parameters

Since the two first parameters are dominant a reduced model base on this is:

$$\begin{aligned}
&\text{Bpr}{=}10^{0.67+0.106s_1-0.208s_2} = 4.68 \times 10^{s_1 0.106} 10^{s_2(-0.208)} = 4.68 \times S_1^{0.106} S_2^{-0.208}\\
&T = 87.1 \times 10^{s_1 0.483} 10^{s_2 0.025} = 87.1 S_1^{0.483} S_2^{0.025}\\
&\text{Sfc} = 0.457 S_1^{-0.074} S_2^{0.101}\\
&m = 1737 S_1^{0.463} S_2^{0.042}\\
&d = 1.77 S_1^{0.213} S_2^{-0.042}\\
&l = 1.41 S_1^{0.158} S_2^{0.042}
\end{aligned} \tag{16}$$

Here we have also introduced $S_i = 10^{s_i}$. Varying s between -1 and 1 means that S would vary between 0.1 and 10, to stay within the standard deviation of the dataset. Note that setting both S to one means that the average engine is obtained.

The error when using just two parameters instead of the full set of six parameters is small, although for one or two characteristics that can be up to 30% for some of the engines. It can also be interpreted such that some engines are slightly outside the design space created. Even so, this must be considered a good fit since the engines are so diverse, and it gives an indication of what typical engine characteristics that are reasonable when different concepts are studied in early aircraft design, where typically only desired thrust is known and one more degree of freedom is useful to get the proper balance between weight (m), specific fuel consumption (SFC) and size (l, d).

This type of model can be used in e.g. conceptual design stage to quickly get estimates of component characteristics in a system. Models can be used for any kinds of components such as electric motors, hydraulic, pumps and motors etc. It is possible to use e.g. one more parameter to get an additional degree of freedom and optimize an engine also for e.g. low weight. This will produce a plausible engine that is likely to be produced with modern technology since some of the engines in the dataset are quite old and will bias the dataset towards to an engine of average age, and not the most modern one.

2 Conclusions

In this paper it has been shown how analytical parametrization of a design using sample designs to span the design space. The resulting parametrization will have a minimum of parameters, and still be able to reach the sample designs, and also to interpolate in between. In some sense it can be regarded as the ideal parameter set. However, these parameters are seldom intuitive except one that the first can be interpreted as a measure of size or scale. Therefore, other parameter sets are often formulated. These can, however, be compared to the analytical parameter set. Singular value decomposition of sets of products or components can also be used to create very simple fast models of components that can be used in initial stages of design to get quick estimates of component characteristics.

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People, Chair, and Value(S): A Qualitative Inquiry into the Material Lives

Saurabh Tewari and Kumar Ravi Priya

Abstract The objective of this paper is to explore the different value(s) that are prioritized and delegated by their users in a thing under their possession. The seating furniture at home was taken as the subject to study where users see it as an extension of their being. Using a method pivoting around Grounded Theory and Observation, it gathers meaningful data, process it through coding and memo writing and achieves a range of categories after a theoretical saturation. The paper attempts to borrow the classical rigour of Grounded Theory to come up with a Design Research Methodology for studying Design and its consumption.

Keywords Design research methodology · Qualitative research · Consumption

1 Introduction

> We touch chairs not just with our hands but with our whole bodies. Yet despite their intimate place in our lives, we know little about them and their effects on us, physically and mentally. … We design them; but once they built, they shape us. [1]

A chair is more than itself as it encompasses a range of functions, meanings and associations. It is ubiquitous. When we travel, in a car, on a bike or in a bus, we sit on a chair, though of different shapes and forms. When we reach at a particular place, we look to sit somewhere, most preferably on a comfortable chair. Cognitively, a chair attempts to invite its user to sit over it. In politics, it becomes a subject of power tussle between multiple politicians. In indigenous language, it adopts another level of meanings. As *aasana* it literally portrays its form. As *takht, sinhaasan* and *kursi* it portrays power. Through its material and outer form, it

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conveys a taste of its user. As visible as the product signatures, for architects and designers it has been a love interest in the last century. As if, they want to portray all their skills in one piece of object that engages with a human being in various modes and moods.

2 Research Question

The field of Design Studies is largely divided into two domains—Production and Consumption [2]. The first end, Production, has been glorified in the many variants including the Design Research and Art History, as lot of studies have been presented through the visions of designers. The study here is situated in this domain of consumption where adoption, domestication, usage and afterlife form the various stages of their continuous negotiation with its users. The idea is to see the relationship between a designed non-living thing (chair) and the living being (user). The larger aim of the authors; research is to understand the value(s) embedded in design by its users. However, the aim of this paper is to understand; what are the different value(s) that are prioritized and delegated by their users in a thing under their possession? In this case, a piece of furniture, the chair.

3 Methodology

3.1 Formulating Inquiry

Khambete and Athavankar [3] suggest that the "qualitative methods may be suitable if the intent is to discover which contextual issues and details of user's interaction with the product lead to such perceptions." They further highlight on the context of the inquiry. The ontological inquiry, particularly here, can be diverged further on three major 'structuralist' categories borrowed from architectural studies; Form, Function and Meaning [4]. These categories were expanded into various aspects to develop a semi-structured questionnaire (Table 1).

After a quick pilot interview with a contextual user, it was realised that the abovementioned categories are not of colloquial nature. So, participants may not be able to give detailed answers its specificity and purpose. The difference between the terms used by designers and 'not-so-designerly' users can also be its reason. Believing in the idea that data is not given, the data has to be discovered and

Table 1 Further aspects within the three categories of form, function and meaning

Form	Function	Meaning
Style	Use	Nostalgia/story
Layout	Comfort	Communication
	Flexibility	Symbol

excavated, the authors decided to explore examples of Grounded Theory [5, 6] and Constructivist approach [7]. With a decision to organically embed the points during the interview, the authors decided to drop the pre-decided formally written questions.

3.2 Sampling and Research Setting

Authors opted the selective sampling [8] where the identification of population is made before the data collection commences. As the larger dimension of first author's research deals with the emergence of economic liberalization in India, the year 1991 was the year of large-scale disinvestment and liberalization policies [9]. Authors were looking for the participants who have experienced the emergence of Indian economy from it's restricted past and have lived in both economic landscapes: pre-liberal and post-liberal India, along with the exposure to their ideas of design through their 'designed' objects. With this, participants should have had experience of or witnessed this emergence in their early youth, where they start becoming an independent self. So, mathematically, the people born between 1970 and 77 became one of the prime sampling conditions.

A chair as seating furniture is placed in various spots in a home, so the drawing room was chosen as the focus, which is often the public interface. The woman in the home became primary research participant, as her role of in deciding, decorating and designing a drawing room is important. Through the academic scope, the project is set at the campus of the university. Pragmatically, the authors chose spouses of faculty members whom they had an easy access, comparatively. Through the job qualification and profile, most of them have similar houses in quantity and quality with a range of furniture pieces and other items. Since, the general configuration of a residence unit illustrated the presence of a drawing room, the authors thought it would be accessible to study and set any interaction with the participants in this public interface. With some commonalities, the authors also wanted to have differences. Fortunately, the participants represented the different geographical and ethnic identities, varying professional affiliations and their spouses' academic affiliations too were varying. All the commonalities and differences are illustrated in the Table 2.

Table 2 Commonalities and differences in theoretical sampling

Commonalities	Differences
– Born between 1970 and 77 – Women – Married and Wives of Faculty at Campus – Residents of Campus – Similar houses [Quantitatively] – Interviews set in their drawing rooms	– Ethno cultural Origins from East, North and West of India – Spouses represent range of departments: Engineering, Humanities and Social Sciences and Interdisciplinary Studies

3.3 Conducting Interviews and Data Gathering

One to one interviews were to be conducted with the participants at their homes and in their drawing room at the Campus faculty residences. So, one of the known female faculty member from the Fine Arts division of the university became the crucial key to unlock further interactions with the prospective participants. Participants residing in the campus but being working individuals, it was not easy get their first appointment. One of them was really hesitant to meet in person and was keen to fill up a survey form where would have described and asked questions with clarity. In introspection, the authors realised that the intent of asking 'personal' questions was the hindrance. So, it was immediately corrected as 'questions regarding objects around'. It took some time to convey the purpose and scope of this research, as the medium remained the Fine Arts faculty. Probably, her being a woman and knowing them through previous social interactions was vital in introducing the authors to the participants and building a basic trust. Participants only agreed to give a half to an hour from their busy schedules. In ethnography traditions, this much time is never enough. However, Donald Norman's concept of 'Rapid Ethnography' [10] used in Design Thinking approaches provided the motivation required to accept this condition as a challenge. Data can also be extracted by various other mediums. We understand that the study may shift away from the practised constructivist grounded theory methods [11] but a possible triangulation internally will verify emerged data from multiples sources. These multiple sources have been illustrated and elaborated further.

Architect Ludwig Mies van der Rohe said, "God lies in details". The same spirit the authors wanted to induce in the researcher-self. However, with the utopian expectations of having more and more time to observe things, and late realizing the constraint of limited interaction, author realised that he might have to settle for little less. Authors were able to contact and conduct interviews with three participants: P1, P2 and P3. Each of the participants gave their comfortable time to conduct interview. For a consistency in analysis, authors wanted each of these interviews to be set in these participants' home and preferably in their drawing room. But, in the case of P2, it did not happen at first. Initially, author could only meet her at her office. However, P2 invited author for a second round of interview and to see her house and record the experience in form of visual mediums. The author attempted building a dialogic relationship with the participants by propelling clues on 'design' in conversation and accepting the details of use and meaning participants wanted to focus upon.

3.4 Process of Analysis

To further analysis and before coming to a judgement while generating and excavating the data, the authors chose to locate and view through multiple points and methods analysis. So, each of the case, the study involved:

a. Interview and Ethnographic observation
b. Transcription
c. Coding: Open and Focused Coding (see Table 3)
d. Independent Observation on the transcript (see Table 4)
e. Writing Memo on Ethnographic observation (see Table 5)
f. Visual Records with two line comments (see Table 6)
g. Derived categories from the abovementioned steps (see Table 7)

The data is processed through a constant comparison between the focused codes and the given data. To bring in a triangulation in the process, and to optimise the influence of the pre-illustrated categories (in Table 1), author asked a third person to summarise them as short notes. The constant comparison with all the data (c, d, e and f) is carried forward with continuous juggling of categories and sub-categories helped in deriving categories (g). One case is illustrated in Tables 3, 4, 5, 6 and 7.

Table 3 Illustration of Initial and Focussed coding on P1's data with an intermediate regrouping introduced by author

P1 initial codes (as per order in interview)	P1 focused codes
− Curiosity towards things − Understand cultural differences visually − Stress on comfort − Likes traditional and ethnic − Doesn't like Godrej type modern furniture − Material identification and uniqueness − Expectations for more things to add − Empathic towards the craftsperson − Open towards change − Love visual harmony − Stress on lightweight and flexibility − A bit of brand conscious and a bit of money minded	• Admire harmony and rich details • Likes things which are dark, traditional and ethnic • Furniture has to be comfortable, lightweight and flexible • Open curiosity towards change but not necessarily modernity • Appreciates Craft and Craftsperson • Like unique material

Table 4 Independent observation on the transcript: this external person, a mathematics teacher, reads the interviews and produced short notes contributing to initial codes

– Likes traditional furniture and handicraft
– Gets emotionally attached to things
– Comfort is important consideration
– Material matters to her
– Doesn't like bulkiness
– Believe in low cost high quality

Table 5 Memo on ethnographic observation

P1 looked little apprehensive towards the modern furniture (like Godrej) where she compared them with furniture at restaurants. For her, the furniture at home should convey her taste of ethnic and traditional. She even pointed a folk-styles painting at her wall, which was painted by her artist friend from Shantiniketan. Her framing of the same represents the worth of this particular art. She was particular about having dark colored furniture, which she compared with her choices in clothing also. This colour, ethnic and traditional choice is very much visible as a whole also

3.5 Extant Theories

The subject, the chair or the furniture for seating, was understood through Cranz [1] who thoroughly covers its existence, form and ergonomics. However, it was not applied directly as the initial premise of the categorization, Form, Function and Meaning, was based on a theory from architectural and design studies of Capon [4] which gave a spectacle to not just questions to be asked but also in the focussed coding. Further, Yarwood-Ross and Jack's [12] account and explication of three different models gave the confidence to interpret and further apply Grounded Theory.

3.6 Nature and Scope

The nature, scope and timeline of this project were limited to three participants. The opportunity of going back to the field as what Charmaz [12] suggests was not possible. However, the independent observer concreted the focused coding. Authors understand that making this researcher wider would have brought in more and richer 'subjectivities'. However, covering the different geographical and ethnic identities, varying professional affiliations and their spouses' academic affiliations attempts to cover the diversity spectrum. The idea of this research is not to look for democratic values of majority, rather it again stresses on the qualitative part to be unearthed in the consumption of designed objects by participants.

4 Results

A convergence of all the derived categories with three participants is illustrated in the Table 8. The categories are placed in two groups: common and unique. All the categories are then reflected briefly in its occurrence in phenomenon. These final categories, which represent the preference values of participants, are different from the 'structuralist' categories and subcategories mentioned in Table 1.

Table 6 Visual records with two-line comments

	
Image 1: P1 in her drawing room P1 can be seen here in her drawing room sitting on her sofa. Her liking of dark colors is visible on her clothes, sofa clothing, sofa wood and the background wall. The harmonic looking setting conveys her ethnic and traditional taste	*Image 2: P1's daughter in the drawing room* The other side of the drawing conveys a contrast to the otherwise dark theme of the room. Perhaps, it is the bright light from the other side that accentuates the warmth of reds, browns and blacks of the space

Image Source Saurabh Tewari

Table 7 Derived categories

• Harmony
• Rich craft
• Traditional and ethnic
• Comfort
• Flexibility with layout
• Material uniqueness

Table 8 Final categories

Themes	P1	P2	P3
Common	Comfort	Comfort	Comfort
	Flexible with layout	Flexible with Layout	Flexible with layout
	Rich craft	*Ornamented* craft	Craft
Unique	Association	Spatial identity and hierarchy	Transient and ascetic
	Harmony	Limited life	
	Traditional and ethnic		

4.1 Comfort

Out of all the categories emerged, comfort is the most discussed and accepted criteria for a user-object relationship. Comfort in this context is the ergonomic ease of using the furniture, a chair. All three participants stressed on this quality not necessarily as an answer to a question, but as a description and elaboration. Like pointing to a piece of furniture, P1 says, "Now it is becoming very popular. It is comfortable. Heavy weight people like us can also sit on this easily. Very comfortable." P2 mentioned comfort as priority and P3 did most technical elaboration through a reflection. So, whether practical or technical, comfort remains the priority for the participants.

4.2 Flexible with Layout

The other common quality was the flexibility of furniture with respect to layout. During the discussion, P1 mentioned the heaviness of the piece. P3 says pointing to the utilitarian aspect of her small sitting table and her likings towards the open spaces, "I have a very small thing which I can move here and there, like jigsaw puzzle we keep on moving things. So tomorrow even… my curtains are very light."

4.3 Craft

Each of the participants had their own admiring views about craft and craftsperson.

Craft as a category reflect the human intervention towards detailing through ornaments or just a humane touch. Like P1 appreciated a known carpenter's craftwork and other craft clusters in the country. For P2 craft just meant ornamentation. P3 critically appreciated craft and the love and labour associated with it.

4.4 Association

P1 stressed on association through a personal story of Kashmiri table gifted by her grandfather.

4.5 Harmony

For P1, it was important to have all new furniture to be harmonious with existing; "I have every intention of making my dining table black. So that it comes under a harmony. I have told GJ (carpenter) about keeping it similar."

4.6 Ethnic and Traditional

These qualities reflect the sense of place in the object as belongingness and cultural continuity. On asking about buying new furniture, P1 replied, "My taste is bit traditional. I don't like modern furniture. I'd never buy Steel furniture like Godrej has come up with. I think they suit places like hotel. For me it has to be ethnic."

4.7 Spatial Identity and Hierarchy

P2 was clear with placement of furniture in public and private realms. Each piece of furniture was placed according to its hierarchy of spaces.

4.8 Limited Life

Each of the objects has its own life as the object in use, which is limited. This life can also be psychological, and not necessarily always material. This was realised with P2.

4.9 Transient and Ascetic

A sense of ascetic and transient relationship with possession was seen in P3. She narrated a story to support her argument; here it goes, "Once there was a sage. Who just had a mat, as a belonging? He lived quite peacefully. A foreign tourist visits him and asks, "Where are your things?" Sadhu asked him back "Where are your things?" Visitor said, "I am just a traveller, why do I need things", Sadhu replied, "Same goes for me, why do I require things?" She questions, "So that kind of philosophy we really believe in. We are travellers and we don't want to accumulate many things." The minimal number of furniture and visible open planes at P3's home somehow supported this story and her subscription to this ascetic philosophy.

5 Discussion on Implementation

> Design activity is immersive, aimed at insights and solution based on the designer's individualistic understanding if the problem and the context. Therefore, designers and design researchers alike might have natural affinity towards qualitative methods, several of which have a post-positivist underpinning that questions the idea of shared single reality. … qualitative methods may be suitable if the intent is to discover which contextual issues and the details of user's interactions with the product lead to such perceptions. [3]

Along with the adaptability of qualitative method, as pointed above this study offers many points to ponder in practices and the larger domains of Design Research and Design Studies. Design Theorist Ken Friedman [13] too has identified the issues within the practice and theorization as, "One of the deep problems in design research is the failure to engage in grounded theory, developing theory out of practice. Instead, designers often confuse practice with research." This paper describes a qualitative method to understand the consumption of a 'designed' thing. It will empathize the producers and designers towards the priorities of its users. Like in this study, the designers and manufacturers can see that how a user never compromise on 'comfort', which emerged as the common category. In this case, the chair may embody many other symbolic roles, but its utilitarian value for participants may remain prime.

Associated fields like Design History studies have traditionally been Euro-centric and tilted towards designer's visions [14], the study may contribute towards the Indian and consumption side. Though Architectural and Interior Design

Studies involve space as its prime subject, it would be beneficial for these disciplines to think through object-user relationship, which often operate within their concern of 'space'. It would be a bottom-up approach for both the architects and the designers, who often surrender to the set 'standard' dimensions of practicing design.

6 Conclusion

Boradkar [15] explains that how value is a fluid aggregate relation which is continuously under flux through process of production, consumption and distribution. He quotes German sociologist Georg Simmel who says that value transcends object and subject into a third form known as demand. Boradkar further says that things gain and lose value through their existence. As the idea was to explore the relationship between a designed non-living thing (chair) and the living being (user), this study will has limited temporal and contextual value. All these philosophical arguments over the value of things are points to ponder.

The study was able to come up with the emerged categories of priorities, as the aim of this paper was to understand the different value(s) prioritized and delegated by their users in a thing under their possession. The study was challenging, as common users do not share the academic vocabulary of design-researchers. The elaboration and expression of a user, like participants in this study, is colloquial. The words they would choose are often informally metaphorical and allegorical. This study gives a qualitative view of 'value(s) of things' through a set of people (theoretical sample). Further work can be done over these points in different contexts. With this and similar qualitative methods, one can extract richer data in the field of design studies.

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Design Dialogue at Design Tree

K. Anil Kumar and P.S. Chani

Abstract The paper aims at sensitizing designers towards the voices of every stakeholder involved in designing a product that influences through the product's life cycle, in a comprehensible way with an objective to facilitate designer towards a better design. This paper discusses the basic purpose and nature of design in the context of judging the aptness of a dialogue among the stakeholders including product in itself. It also discusses designers stand towards other stakeholder's ideas in the design process for making the conversation dialogical or arguing in nature. The paper proposes 'Design Tree' as a structure, for creating distinct platforms for dialogue to happen at all stages of design evolution for design dialogue to be comprehensible.

Keywords Design dialogue · Design tree · Design judgment · Design process

1 Introduction

> If you think of Brick, you say to Brick, 'What do you want, Brick?' And Brick says to you, 'I like an Arch.' and if you say to Brick, 'Look, arches are expensive, and I can use a concrete lintel over you. What do you think of that, Brick?' Brick says, 'I like an Arch.' and it's important, you see, that you honor the material that you use. (..) You can only do it if you honor the brick and glorify the brick instead of short-changing it. [4]

Louis I Kahn in his lecture was explaining the importance of honoring building material. The designer is at a junction and he has to choose a path. He has to decide between economy and honor of material. The decision, that designer takes, is case specific and depends on various other factors as the case might be.

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The decision of whether to go logical or intuitive is discussed by many authors and designers in many ways, some supporting logical or rational views and others intuitive or art based. Kahn's quote mentioned above emphasizes on intuitive decision (as an honor towards the material) over logical way (which is the economy). Christopher Alexander in his book 'Notes on the Synthesis of Form' discusses whether design is logical or intuitive in the introduction chapter of 'the Need for Rationality' emphasizing the logical way. The list of people supporting either of the views is long, but for any specific case, designer chooses something over the other which influences the most in that context. Thus, interactions among the stakeholders that influences the decision is a concern.

Related to any product/building, there can be interactions happening in-between three groups, one, that of designer (maker), secondly of the product and the environment in which it is placed and thirdly the user's. Interactions generally happen between these three groups and within themselves, each raising voices that suit the better for it. In these three groups, the makers (designers) and users are mostly humans. The second group, 'the product and its environment' is the group that the makers try to mold to meet the necessities of the users. There can be a fourth group which is not covered in any of the above three mentioned groups and they are outside all these and they are observers and critic's. Dialogue happens between these four groups in the life cycle of a product.

In today's world the issues of sustainability, being true to materials, design chaos, misfits, etc., are issues that arise due to lack of designer's sensitivity or ignorance towards voices of the second group i.e., Product and its environment. On the other hand, there is a necessity to suffice clients and designer's aspirations for they are the cause and doers of the building activity. Thus, it is absolutely necessary for a designer to be able to comprehend all voices together to be able to design better.

Current paper aims to bring out the voices of everyone and everything that interacts with the product either directly or indirectly through its life cycle in a comprehensible way with an objective to facilitate designer towards a better design.

In doing so, this paper attempts to discuss around

- Understanding dialogue
- Necessity of a dialogue in the process of designing
- Judging criteria for design dialogue
- Dialogue versus Argument as a stand by designer
- Analog of design processing in mind
- A method for comprehending all voices to facilitate designers

2 The Dialogue

For the purpose of the paper, every element though living or non-living, has a voice and is able to express something about it. These expressions or voices put forward are the issues that we need to be sensitized to, which are like the character, suitability and properties of the material.

A dialogue is a conversation between two or more entities regarding a particular topic for a purpose. As mentioned earlier, there are four groups which can be associated with that of a product among whom the dialogue happens.

In the context of Architectural Hermeneutics, Snodgrass and Coyne discusses conditions for a dialogue to happen taking the reference definition of German philosopher Hans-Georg Gadamer [7]. The conditions are

- Open minded nature of participants
- Participants have their own opinion and can be distinct from others
- Participants should accept others point as worthy consideration
- The dialogue is regarding a particular topic and for a purpose

Examples of these dialogues are described below

Example 1 of a dialogue: A potter wants to mold the clay in a certain way. He thinks of an image and tries to craft it from the clay with his hands. But the clay is stubborn, it has a nature of its own. It may not always accept the form the potter is trying to give to it. Clay continuously tries to communicate to potter by virtue of the shape it takes and sends signals to potter through his hands. Potter responds to it and continues to evolve the design of the pot by manipulating the amount and direction of pressure he is applying in the making. Thus, both the ***designer and product have their own voices in a peculiar way and dialogue happens to form a final product***.

Example 2 of a dialogue: Below is set of three diagrams (Fig. 1). Each diagram has a major entity and below are the options depicting the possibilities of perceptions. The question is how is it being perceived?

Option A is additive in nature while Option B is subtractive in nature. Option A is formed as addition of two squares. Option B is formed by subtracting portions from a larger square. Even the product is once formed it is not always perceived in the same manner. In the above set of diagrams, the probability of the diagram being read as the option A increases while chances of being read as option B decreases as one moves from left to right. This is an example of the perception of the user towards finished design.

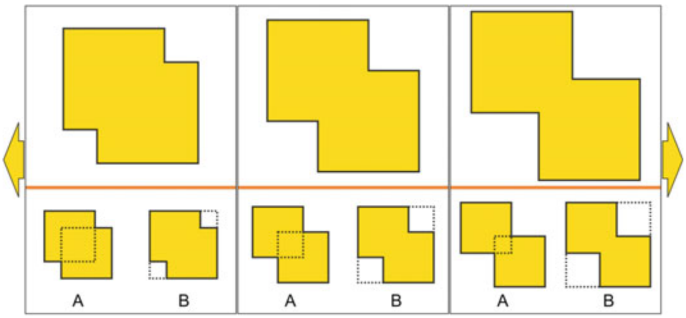


Fig. 1 Perception of two squares

3 Necessity of a Dialogue in the Process of Designing

"The impractical idealism of designers who want to redesign entire cities and whole processes of manufacture when they are asked to design simple objects" a quote from Christopher Alexander's 'Notes on the Synthesis of Form' [1].

Though these words were told in the realm of 'good fit' in the book, there is a conflict that can be seen in the quotes, the conflict between designer's aspirations and that of the brief given to the designer in the environment he needs to design. Thus, there will be a negotiated conversation to lead further between designer, the environment and client towards a product.

Approach to design—Lawson's studies on design behavior [6] have compared the problem—solving strategies in a designer's way to that of scientist's way, where the results show that designers try to analyze the problem by trying solution rather systematically solving the problem. The study also reveals that designers are strong in solution planning and not that strong in analyzing the problem structure. Thus, a dialogue with every stakeholder can help the designer to know the problem and conditions better.

Nature of the problem—The nature of the problem given to designers doesn't have a unique solution. If the solution to the problem was unique then there can be fewer chances for the dialogue to happen. The degree of freedom of solution is large in number. The number of degrees of freedom depends on

- How complex is the problem?
- Does the problem have a unique solution? (Degrees of freedom)
- How dynamic (constant changing nature) is a system with which designer is dealing?
- Context of the design (interaction between design and its environment)

The above mentioned 'conflict of aspirations', 'approaches to design' and 'nature of problem' are few scenarios where dialogue is necessary among the stakeholders. As there are no definite formulae for design, these subjective issues need to be addressed. As designers, one might not be able to answer all voices through design. Thus, a designer has to judge for a better design based on the dialogue among the stakeholders.

4 Judgment Criteria for Design Dialogue

The judgment criteria for design dialogue mostly are case specific. The complex problem along with the four groups (Designers, product and its environment, users and observers) speak out their voices in many varied directions. The purpose, of these voices, to be brought out is to be able to conceive all these voices on one platform. We as designers can't always give equal priority to every dialogue. As told by Christopher Alexander "designers do often develop one part of a functional program at the expense of another." [1]. The major challenge to a designer is to be able to prioritize these dialogues and be sensitive to decisions taken.

To judge a design dialogue and to be able to prioritize among dialogues, one needs to understand what design is all about.

Design Concerns: According to Nigel Cross the central concern of design is 'conception and realization of new things' [3]. It encompasses appreciation of the material culture and application of the art of planning, inventing, making and doing'. Nigel Cross also compares design with science and humanities and describes designing is about manmade world, achieved through modeling, pattern formation and synthesis of the product valuing practicality, ingenuity empathy and appropriateness.

Design Process: We rely on a lot of the unexpressed information that is contained in the statement of the task and take a great deal for granted [1]. This leads us to pre-assumptions that we take while understanding the problem and first steps towards solving. Schön speaks of design as a 'reflection-in-action', which is a reflective conversation with a situation. Snodgrass and Coyne extended this definition of design into the design process. In their book 'Interpretation in Architecture' they describe designing as a hermeneutical process [7]. Designers come with a presupposition and enter a design activity cycle of working in part to whole and whole to part.

The dialogical cycle questions designer about the preconceptions, prejudgments, pre-understandings values and attitudes the designer brings to the design situation. When the designer is continuously questioned, he is put into a vulnerable situation about his presuppositions. Then it is the stand that the designer takes, either to proceed in a one-sided manner, protecting his preconceptions and questioning the situation itself rather being questioned or evolve design with an open minded dialogical basis which is self-revelatory and self-discovered in nature. The first case of a one-sided approach is *argue-mental* while the second one is *dialogical*. An example of an argue-mental approach can be Niterói Contemporary Art Museum in Brazil by Oscar Niemeyer where the architect envisioned the museum to be like a UFO. Every other aspect of the museum building was fit within the main presupposed idea of a form. Similarly making of a pot as discussed earlier can be put as an example for a dialogical approach.

Thus, design can be argue-mental or dialogical based on the stand, designers take on the presupposition with which we enter the design dialogue.

5 Analog of Design—Processing in Mind

As the designing process is hermeneutical [7] the whole process is about how design scenario was understood and interpreted. This interpretation is based on metaphors that we choose to understand the particular phenomenon.

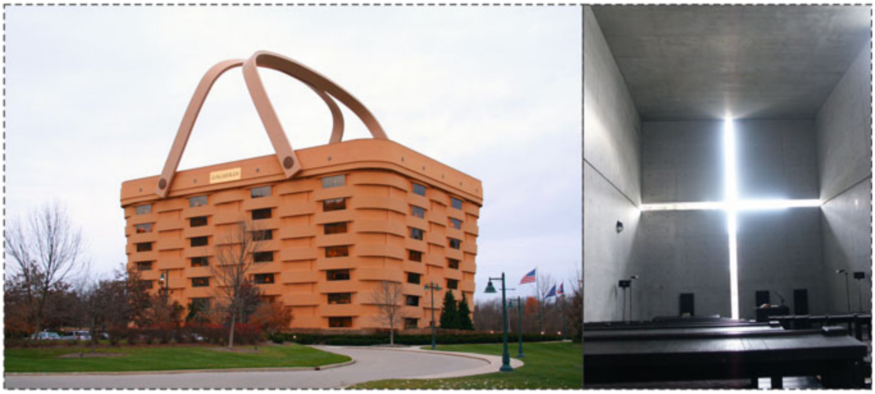


Fig. 2 Basket house and church of the light

5.1 *How Straight Is the Dialogue?*

There are two examples shown in the Fig. 2, one that of the basket house in Newark, Ohio, USA and the other is the Church of the Light by Tadao Ando in Ibaraki, Osaka, Japan. The basket house is a direct imitation of an inspirational object where the functions of the building are fitted in the form. In Church of the Light, Ando puts a notion of God being light in the darkness. The symbol of the cross being the light source in the dark defines the place as a church [5].

These two examples show the contrast in terms of design dialogue maturity. In the first case, the shape of metaphor (basket) is taken as presupposed by the designer which was a presupposition of client to enter into the dialogue. Every aspect has been questioned by the designer making the dialogue, a one sided argument. In the next case for the designer, the Church of Light is the architecture of duality—the dual nature of [co]existence—solid/void, light/dark, stark/serene [5], thus the depth of metaphor and its thought process.

5.2 *Dialogue with Metaphor*

If we take metaphor, not as a mere figure of thought, but as a structure, a ‘seeing as’ that is the seeing of a thing as something, then the hermeneutical circle is a play of metaphor [7].

When a designer discusses his work which is part of a design dialogue he takes the role of an interpreter. There are instances where a dialogue happens in the metaphor phase before entering the designing stage. The examples can be taken in Cubism and Biomimicry.

Fig. 3 Cubist painting and building

Example 1: Cubism: The act of dealing with the metaphor in a metaphor stage can be seen clearly in Cubism. In cubism, the inspiration object is broken to compose newer art form. In doing so, the original object is analyzed by looking it as something more to be fit in a greater context. The left half of the image in Fig. 3 is a painting by Jean Metzinger in 1912 depicting a landscape. Cubist way in architecture focused on juxtaposing simple geometric objects in three-dimensional forms. The right half of the image is of Heidi Weber Museum in Zurich by Le Corbusier. The museum has been designed as a composition of art-form. The museum materializes the spirit of his architectural theories, establishing a dialogue between art and architecture.

Example 2: Biomimicry: The three levels of Biomimicry as described by Janine M Benyus, are cases where a designer uses the organism, behavior and ecosystems in nature as metaphor and tries to have a dialogue with nature before mimicking in design [2].

5.3 Translation from Metaphor to Reality

Though the metaphor is **conceptualized**, the way, the dialogue with metaphor is translated into reality, is a major challenge to architects. In all the examples that are shown above like Basket house, Church of the Light and even styles like Cubism, procedures like Biomimicry have in them some sort of translation from metaphor to reality.

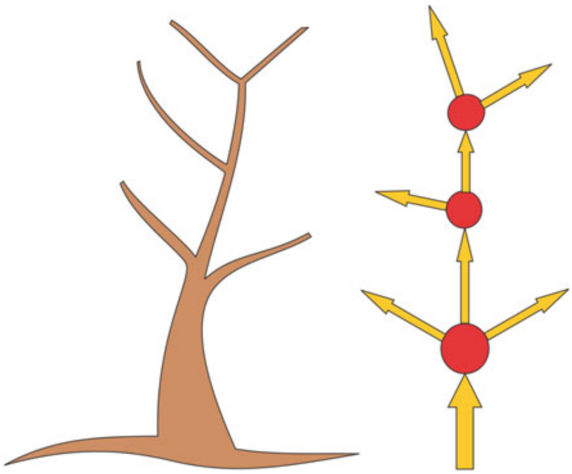
This translation of metaphor to reality leads to the first voices starting design dialogue. Every stakeholder joins the dialogue at some or the other stage of design development. Challenge to designer is to assimilate all the voices for a better design. There is no standard structure for following these for the design methods followed are varied. ‘Design tree’ proposed is an attempt to structure the process of designing adaptable to versatile scenarios.

6 Design Tree

To demonstrate the design dialogue there needs to be a live project where everything is documented. The exercise of building ‘design tree’ is part of the whole process, starting at the first action taken by a stakeholder and reaches its apex by final design proposal. The process of how one reaches the first idea or action is beyond the scope of design tree. Similarly dialogue continuous after the design proposal is finalized during the construction process and beyond, which is beyond the purview of the current exercise. This exercise plots the steps of design process on a tree system. The nodes are the design decisions and branches that offshoot being possible outcomes. Every design decision gives a range of possibilities which is represented in each branch. Each of the outcomes is verified individually to proceed further (Fig. 4). Thus to go up the design tree we choose one of the possible outcomes at every node. The criteria of evaluating which branch to take, is based on the dialogue with all the groups (designer, product and its environment, user and observer).

As the starting point of every design is different, the first step adopted in each process is different. Whatever so might be the first step taken, the action leads to some results and in evaluating these outcomes every stakeholder might have something to say. Thus, dialogue is initiated resulting in choosing a path from a range of solutions. Following is an example to demonstrate the ideology of design tree.

Fig. 4 Figurative structure of design tree



6.1 Example

Start point: Say there are two spaces, space A and space B. In the current example, both spaces are square in plan form and are of equal sizes and made to interact along its diagonal. Space A and space B can either react to each other or don't react and remain neutral to each other, further the reaction can be in positive or in negative terms.

As a next step, the extent of overlap along its diagonal is varied. The intensity of the reaction between two spaces on varying the extent of overlap is examined in the dialogue. Depending on the case in a real situation, the dialogue will happen.

Observations: Depending on the extent of overlap the resultant space is conceived differently. Larger the extent of overlap the reaction is stronger and similarly lesser the extent weaker is the reaction.

Stage (2): As a next stage the same spaces, space A and space B are made to interact along a diagonal in presence space C of third quality to form an overall square. The addition of spaces C is done without an overlap and is placed next to the combination of earlier two spaces. The result is space A, space B and reaction of A & B, along with space C. Thus resulting dialogue is between space A and space B in the presence of space C.

Observations: There is a difference between how space A and space B interact in the presence of space C from in absence of space C. Addition of space C to the dialogue makes the overall space a whole square which is a simple primary form in itself and is greater than its sum of parts.

Say from the stage 2 positive reaction is chosen for moving up the design tree.

Stage (3): In Stage three, one of the specific dialogues is reopened, but with a variation in the size of the squares and altering the relative positions.

Observations: Till stage 2 the dialogue and the form generated are symmetrical along both diagonal axes while in stage 3 the resultant dialogue is only symmetrical along one axis thereby more contextual.

By the end of stage 3, there are options for a way forward. Say the stakeholders of design decision chose function to decide the way forward.

Stage (4): In the example, the deciding factor in fixing the relative position is that of the kind of activity/function. Say design is of a dance stage with seating area around. The larger space being seating area and smaller space be stage support activity and the intersection being the stage.

As seen in illustration (Fig. 5), In the case of Tagore Theatre, Chandigarh, India or in a similar auditorium the kind of performance for which the stage was created is in a modern context where the stage has a front and back. In the case of Natya mandapa (Dance arena) in Ranganath Swamy temple in Mathura, India the context is traditional in nature. The mandapa is in the center of the foreground in the temple and people see the performance from all around the stage. Different extent of overlap, as iterated in the earlier stage, leads to each type of dance performance stages. Thus, the setting of the stage (function) in its context decides how the relation between the spaces should be.

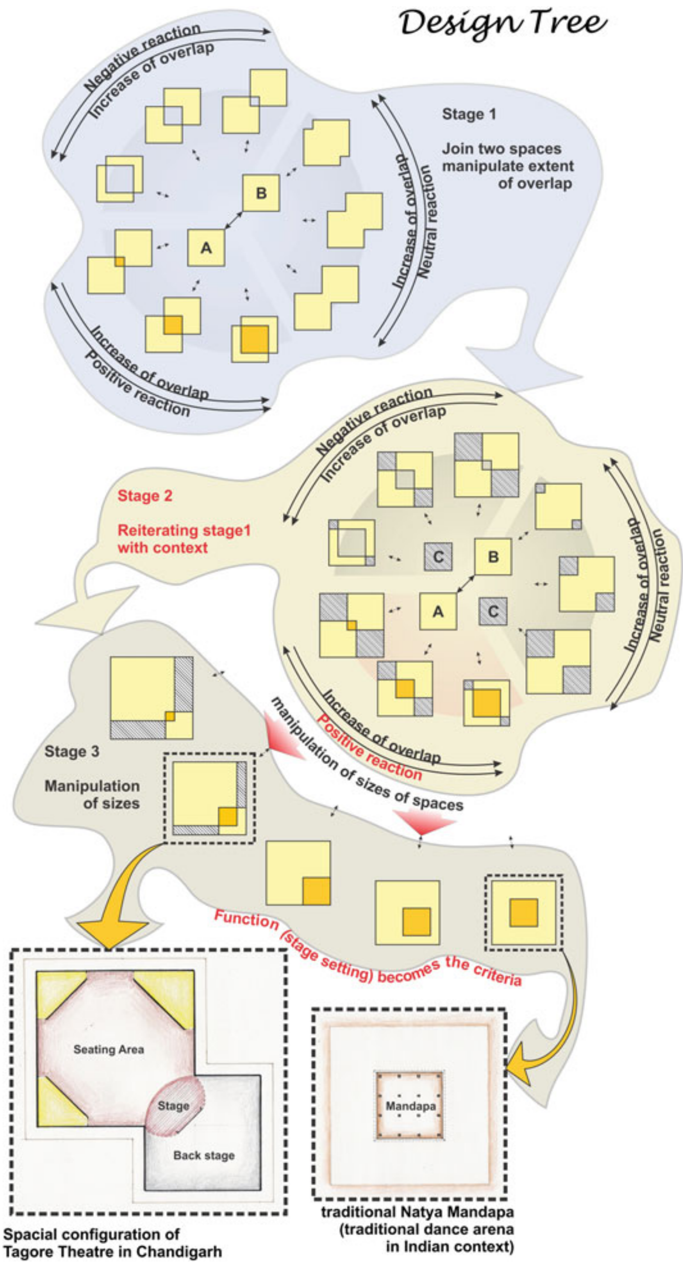


Fig. 5 Design tree illustrating the development of theatrical arena

Steps further: In further steps, the dialogue is taken to a level of elements from the basic diagram level. In the diagram shown above the additive nature of spaces are mitigated through level difference. Usage of elements in case of the mandapa makes its usage and visibility from all directions. In the case of modern theatre, fixed seating arrangement makes it direction oriented. This dialogue is extended further in detailing spaces, materials and construction details through its lifecycle.

6.2 Design Tree Potential

The exercise of design tree has a potential of developing a design language in complex situations. It gives distinct platforms for dialogue to happen at various stages of design. This approach to design gives a range of solutions which are shortlisted at every stage on a dialogical basis. This is also a good tool to analyze an existing design in varied environments to accommodate dynamic aspects of nature or the system.

7 Conclusion

The first part of knowing about dialogue reveals the mindset and conditions for a dialogue to happen. This section also brought the complexity of a design dialogue in terms of setting conditions and possible variety. This variety shows that designing is to be able to bring balance between all the voices.

In identifying necessity of a dialogue, the paper reveals the kind of conflicts, approaches to design and problems (design brief) that a designer face. To solve these conflicts the paper discusses the 'nature of design' and 'design processes' revealing that design is hermeneutical as well, opening gates of discussion to analog of the design processing in mind. This brought one new element/member (i.e. Metaphor and a dialogue at metaphorical level) to the dialogical stakeholders.

'Design Tree' proposed as a method of comprehending all voices has a potential to suffice its purpose by creating distinct platforms for design dialogue to happen at all stages of design evolution and linking them in a path similar to tree structures.

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Differences in Sketches and Mental Imagery in Ideation Stage of Novice Designers

Mia A. Tedjosaputro, Yi-Teng Shih, Chantelle Niblock and Patrick Pradel

Abstract Previous empirical studies in sketches and mental imagery showed that there is no significant difference in overall quality and possibility to use mental imagery as design tool. This preliminary study explores distinctions between two kinds of sessions in terms of how ideas are generated. Four design sessions of two novice designers are used to unveil differences. Based on preliminary results, physical properties of sketches underlie differences, also the availability of visual cues apart from the drawings itself. During interpretation stage, sketches provides an additional dialogue which is not available in mental imagery session. The use of mental imagery as design tool in novice designers vary and may not as effective as in experts. Pauses and gesture in both sessions are found to be fundamental designing aspects, including in environment when sketches are allowed. When crucial differences are no longer assumed, interplaying roles between the two can then be explored further.

Keywords Sketch · Mental imagery · Protocol analysis · Linkography

1 Introduction

Development of research in sketching and mental imagery in tandem, particularly in design studies for the last ten years can be considered sparse. In 2009, Christensen and Schunn posited that mentally modified and transformed objects serve as both help and hindrance between the perceived world and the imagined world [1]. After a series of seminal studies in expert architects [2–5], in 2008, Bilda and Gero's

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studies were rounded with an exploration that expert architects are able to develop ideas using imagery only. Previously, Athavankar argued that imagery can potentially be substituted for sketching [6, 7]. However, the question remains, what is the vital aspect designers do not have access to if they are not allowed to sketch when generating ideas?

This paper aims at gaining insights about differences of the two types of behaviour by conducting four design sessions of two novice designers and will be closely examined using a theory of visuo-spatial mental imagery. Limitations of the small sample study are foreseen without an attempt to make generalisations between expert and novice designers, but instead novices are used as a starting point to reveal potential when they have less design experience. It might entail less exposure of previously developed design solutions/events/design precedents; or smaller 'virtual images bank'. Previous findings will be mentioned, major theories of mental imagery will then be posited briefly, and how the preliminary study was conducted will be illustrated. Lastly preliminary results will be discussed.

2 Sketches and Mental Imagery

A summary of findings in relation with sketches and mental imagery in design studies is presented in Table 1. Due to the scope of investigation, the intertwining aspects between idea sketches (hand drawn) and mental imagery in early design stage; this study will focus on points number 1, 6 and 8.

In terms of the off-loading roles of sketches; if an operation cannot be handled using imagery only, producing external representations help to reduce the uncertainty. Although they are not the only external representation options, in this paper, the scope is limited to idea sketches only. Bilda and Gero suggest that limited visuo-spatial working memory capacity also affects designers' ability to retain

Table 1 Subset of findings of previous studies in external and internal representations

	Findings
1.	Sketches off-load or aid mental imagery processes [1, 3, 8]
2.	Expert designers can utilise mental imagery only to design [2–4]
3.	Expert designers' performance using sketches and mental imagery is comparable [4, 9]
4.	Spatial transformation connects internal and external representations [10]
5.	The use of mental imagery might relate to visuo-spatial aspects [5]
6.	Pros and cons related to both environments [6, 11–14]
7.	Expert designers have advantages over novice designers in terms of using imagery [15]
8.	Mental imagery is superior compared to the use of sketches [7, 9, 16]
9.	In the imagery context, hand gestures provide assistance [7]

Table 2 Differences of sketches and mental imagery

Sketches	Mental imagery
Relevant information is grouped spatially and it aids designers to see new relationship [19]	Ease and speed, rapid discovery [12, 23, 24]
Facilitating lateral transformations and preventing early fixations [20]	Modelling space and walkthrough [16, 17]
The chance to clarify existing ideas and develop a new one, 'reading off' a sketch [14]	Minimum effort compares to physical synthesis [7, 12]
Advantageous ambiguity [15, 21]	Facilitator on dealing with incomplete knowledge [18, 25, 26]
Handling different levels of abstract concurrently [22]	Evaluating ideas without the danger of real event, encourage fanciful play [7]
Capturing moment and store it [8, 23]	'*Combining*' process is achievable without sketches [8]
Supporting '*restructuring*' process when mental imagery is not sufficient [8]	Facilitating shape recognition and shape emergence [27]
Key to overcome limited short term memory and long term memory [3]	

mental images; therefore they need to be off-loaded [3]. Another plausible explanation is that designers decide that the operation is easier to do externally [8], which then suggests that given the choice, designers consciously make decisions about which mode is more effective.

Table 2 shows that physical elements of sketches underlie these differences. The ability to read-off turns into opportunities to engage with ambiguity, inspectable property of sketches, and the ability to perceive or interpret what has been drawn into creative discovery, facilitate lateral transformation and at the same time archiving new ideas. On the other end of the spectrum, mental imagery also provides better assistance to the idea generation process. For instance, the ease and speed of mental imagery facilitates rapid discovery. The chance to perform virtual design studio inside designers' head [16] also aided with volatile high resolution images [17] and walkthroughs [16] afford more simulation possibilities. In terms of dealing with absent objects and uncertainty, mental imagery enables retrieval of features and details which are not intentionally committed to memory [18].

Apart from the physical properties of depictions, what properties do sketches hold which are absent in using mental images only? What kind of feedback is missing if there is no conversational dialogue between internal and external representations? These questions will be explored by looking at a new theory of visuo-spatial mental imagery developed by Sima [28–30].

The *imagery debate* often refers to debate between proponents of the first two theories for the last forty years. The debate focuses on two means of representation, *depictive* and *propositional* representations. One key property of the depictive format, the Pictorial Theory [31], uses space in a representational medium to represent space in the world [32]. The second theory, the Descriptive Theory [33] rejects that underlying representations of mental imagery are purely propositional and humans use their tacit knowledge to simulate what it would be like to see something during tasks.

The third theory, the Enactive Theory [34] is not as comprehensively reviewed in literature in comparison to the others. Described by Thomas, it focuses on visual perception and visuo-spatial mental imagery. The theory argues that we have sets of inspection processes, seeing and imagining concepts, commonly called *schemata*. The fourth theory, PIT (Perceptual Instantiation Theory) is built upon the Enactive Theory. Taking the same understanding of visual perception, it is assumed that perception consists of several different specialised types of perceptual information which is selectively used in the process of retrieving information [30]. The formal framework is illustrated in Fig. 1.

The process of generating a mental image starts with retrieving mental concepts from C-LTM (Conceptual Long Term Memory), these mental concepts than are instantiated together with perceptual information through *select*-*execute*-*identify* processes [30]. Subsequently an interpretation of all identified mental concepts constitutes the mental image of the scene (ibid). This framework will be elaborated in terms of comparison between generating mental images with sketches and without sketches. It is hypothesised when the use of external representations is possible; during the interpretation phase where the most plausible subset is selected, it creates an additional conversational dialogue.

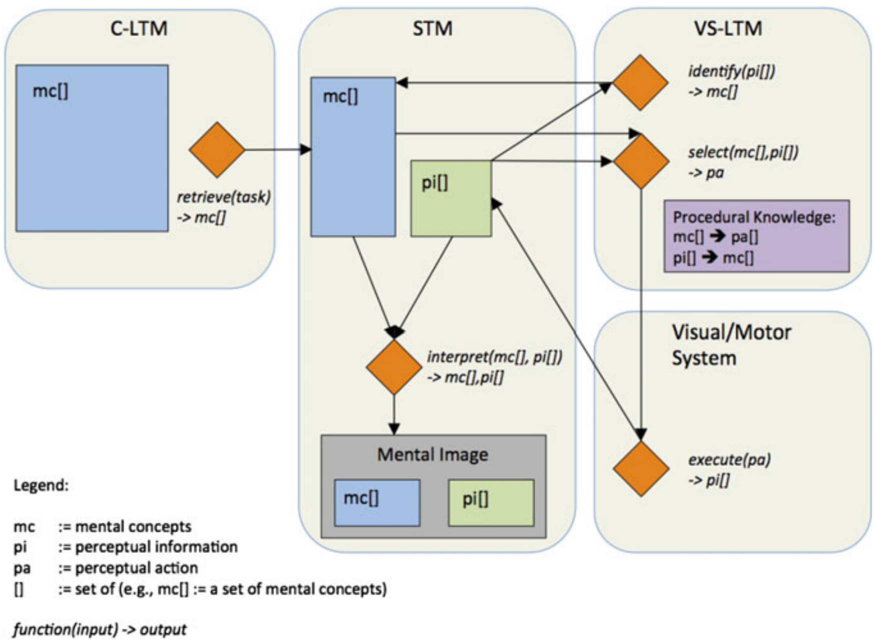

Fig. 1 Formal framework of perceptual instantiation theory. *Source* Sima [30]

Linkography [35] is utilised to illustrate and test the hypothesis. Developed by Goldschmidt, it is a notation system to analyse design moves and links among them. The graph is a directed graph, however arrows are not used due to the emphasis on the arrangements of the links in a network [35]. Design moves are presented as *vertices* in network studies, with links between moves depicted by *edges.* A Linkograph provides an access to the designer's thinking process at a certain point in time.

3 Methodology

Data was collected from two final year undergraduate design students of an overseas campus of a UK university with two different design backgrounds, architecture and product design. However, comparison between the two domains will not be explored in this paper. Sessions were conducted in English, consent was taken and research ethics approval was obtained prior to recruiting participants and contribution was voluntary.

Each design session lasted 45 min, and each participant did two sessions (mental imagery session-henceforth MI, and sketching session-henceforth SK). Differentiation of these two sessions is adapted from Bilda's study [23]. The time gap between the first and second session was one month to avoid fixations. Two participants are described as P1 and P2. There are four design sessions in total. Design tasks were: (1) FMS (Flexible Meeting Space) to design a convertible space for a creative industry company in an open plan office, less than 100 m^2 footprint and (2) HFS (Hybrid Furniture System), to design a hybrid system of sitting space and dining set-up for adults and toddlers with maximum footprint of 3 m × 3m.

Three to four audio/videos (front, top, side and a replayed pencast from a smartpen, capturing sketching process) in each session were used to compliment the segmentation process. Think-aloud method was used during design sessions and verbal data was transcribed, segmented, encoded based on intentions and was presented in the form of linkographs. The premise is that, if there is a link between two design moves, a line is drawn between the two resembling an edge in networks studies (Table 3).

Table 3 Detailed design sessions for each participant

Sessions		Duration (min)	Brief
Mental imagery (MI)	Session 1 part 1-Blindfolded (BF) session Session 1 part 2-Externalisation (Ext) session	35 10	FMS
Sketching	Session 2-Sketching (SK) session	45	HFS

4 Results

Figure 2 shows comparison of four linkographs of four design sessions. In MI sessions, more distributed design moves can be discerned in comparison with the SK sessions in which *chunks* (graphically distinct triangles) are more prominent. Particularly in the SK session of P2, these overlapped *chunks* dominate the linkograph. During Ext (externalisation) in the MI sessions, P1 and P2 recalled parts of mental images during a BF (blindfolded) session to draw, which can be seen from links generated for the BF session. During the Ext session, P1 did not refer to the first ideation phase (before move #40); but P2 recalled ideas from as early as move #3.

Numbers of generated moves in two environments echoed the notion that mental imagery has advantages in terms of ease and speed, and minimum effort compared to physical synthesis (refer to Table 4). It can be assumed that the greater the number, the more design activities occurred. P1 produced 25% more utterances in the MI session compared to the SK session, whilst P2 produced 46% more. Higher *link index* is a fast indication of higher linking activity and leads to insights into designer's efforts to achieve synthesis [35]. *A link index* is the ratio between numbers of links and utterances. Although it is not necessarily a hallmark of creative or good design, in general, link index value of P1 is contrary with P2. P1's *link index* in the MI session is higher than SK session, in contrary with P2's. Threshold of *critical moves* (CM) is not defined and Table 4 shows the maximum number of links to CM and they are all due to *forelinks*. Designers shift between *divergent* (ideation) and *convergent* (evaluation) modes of thought [35]. It might suggest that more links occur when designers used *divergent* thought indicated by the *forelinks*, when P1 and P2 generated ideas. In comparison between MI and SK's maximum number of links of CM of P1 and P2, in terms of idea generation, mental

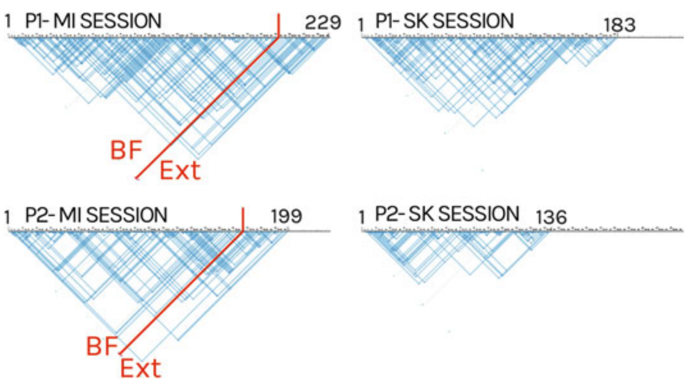

Fig. 2 Linkographs of four sessions

Table 4 Overall comparison of four sessions

	P1-MI	P1-SK	P2-MI	P2-SK
No of utterances	229	183	199	136
No of links	407	289	268	194
Link index	1.78	1.56	1.34	1.43
Max no of links to CM	13	10	9	8

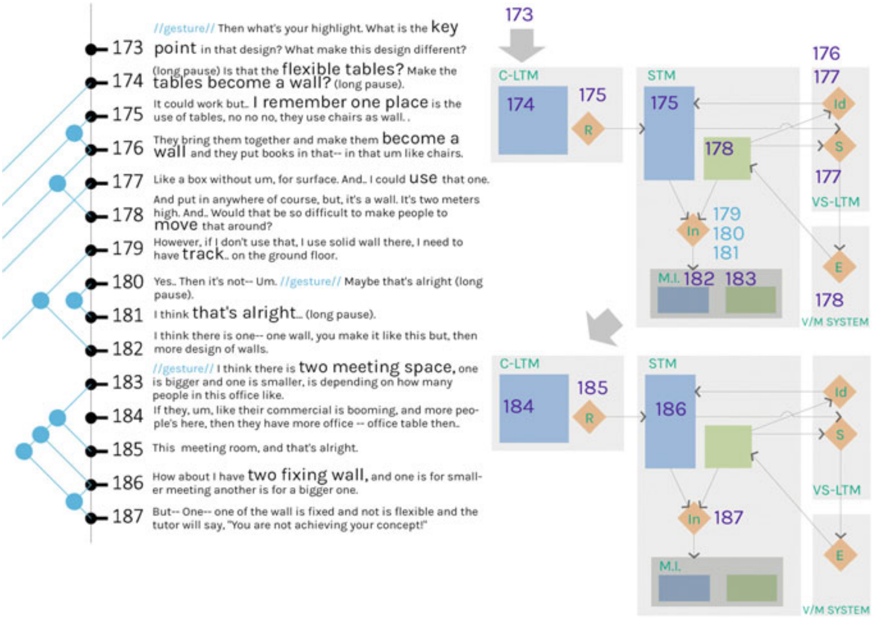

Fig. 3 P1's blindfolded of MI (mental imagery) session excerpt

imagery is more effective than sketches. In terms of idea evaluation, this is a separate research question.

With regards to posited questions and hypotheses, a partially zoomed in comparison between mental imagery and sketches are extracted. Excerpt from P1's sessions are used to illustrate. From left to right of the illustration in Fig. 3: partial linkograph-segmented transcription-mapped PIT framework (Fig. 1) are labelled according to segment number. Blue colour font in the transcription records prominent gestures.

The first part (Fig. 3) lasted three minutes towards the end of BF (blindfolded) session. In the middle of generating an idea, P1 retrieved a memory of a previously encountered event (#175) about 'flexible tables' which can be put away as walls. The first circle on the right shows how the idea of flexible walls went through the

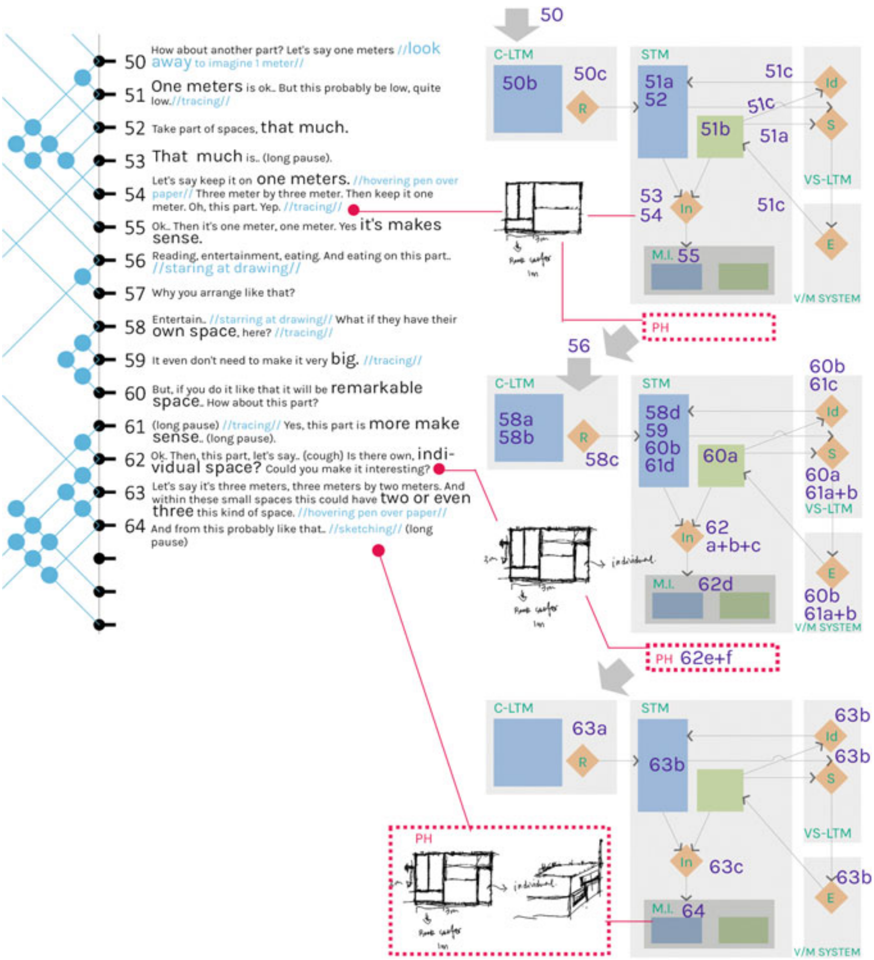

Fig. 4 P1's SK (sketching) session excerpt

process of select-execute-identify, rationaled (suggesting the use of 'track on the floor') and a final decision to be used in the next circle (#183).

The three minute SK session excerpt in Fig. 4 illustrates idea generation using sketches. There were a few instances where P1 did not engage in activities, only verbalising her thoughts (#54, #55, #56 or #63-hovering pen over paper) or just body movement (#50-looked away to imagine how big one meter is). In addition, she was engaged in drawing actions by tracing previously drawn lines (#51, #54, #58, #59 and #61).

5 Discussion

Mental imagery provides better assistance of rapid discovery in terms of ease and speed as can be seen from Fig. 3. Due to its lower effort when inspecting ideas (more economical in terms of the absence of externalisation), resulting in a higher number of segments in comparison with SK sessions, for both P1 and P2. This does not necessarily suggest a better design outcome (which is not in the scope of this paper). Another explanation is that in the SK session, with the act of sketching and thinking out loud concurrently, due to cognitive loads, participants might generate less verbal data. It can be illustrated in Fig. 4 where a single verbal segmented data may consist of more than one design moves (#51, #58, #60–#63) especially when gesture is involved. As mentioned in the previous section in Table 4, P2 MI session's link index is lower than the SK session. In contradiction with a previous study of expert architects where there was little deviation, BF link index values are higher. Early indication might suggest that novice designers do not have the same high capability when using mental imagery only. Due novice designers' lower design experience and smaller 'virtual images bank' derived from previous design experience and encountered events, the retrieval process might be different or limited. As far as the chance to deal with incomplete knowledge, transcript #175–#177 illustrate this, and without the danger of not being able to finish a part of sketches, partial incomplete information was used to inspect an idea. It is also noted that a prominent gesture (#173 and #183) might mark the beginning of a chunk of idea, although this needs to be studied in the larger context of the Linkograph and not in isolation.

During the sketching session (Fig. 4), due to the exposure to sketches and surroundings, more comprehensive activities are mapped. Rich dialogue between sketches and mental imagery is illustrated with the use of (partial) sketches as feedback to the MI process. During this kind of ideation process, hybrid mental imagery and drawing process occur. At the beginning of this excerpt, P1 looked away to imagine a distance of one meter. By doing this, P1 recalled a mental picture of one meter from what she saw in the room. The cycle of select-execute-identify is more identifiable, with the use of sketches and gesture. For instance, segment #51 which is comprised of 51a ("one meters.."), 51b ("but this…") and 51c (tracing); P1 selected the operation to explore about one meter and started to draw the division on the sketch and by tracing she identified the mental concept she then used in her next utterance. A PH (physical) object is added into the map suggesting that at the end of cycle, there are physical properties to be carried for the next cycle. Sometimes it is not the end product of one cycle (for instance, sketch in #54), in this case there was no drawing action in #55, or at the end of cycle (#62) when P1 annotated 'individual' space. The hypothesis of *interpreting* action in the PIT Framework, the use of sketches provides an additional dialogue in a way with available visual properties of sketches help to simulate important parts of design to be imagined. In all instances, the process started after a long pause. It is also noticed that the act of 'hovering pen over paper' and 'staring at drawing' occur during this process. In addition, with regards to the linkograph, the stage when interpretation happened, was when the idea links occurred.

6 Conclusion

The study has achieved considerations that the use of sketches and mental imagery, both are pertinent. For expert designers in previous studies, one can substitute another. Although mental imagery is not a commonly used in isolation to generate ideas, it can be highlighted that it can be used in design practice as a way to develop ideas. However, novice designers might utilise them differently. Reiterating the questions: (1) What properties do sketches hold which are absent in the use of mental imagery only? (2) What kind of feedback is missing? The physical properties of sketches are inarguably at the core of this. Preliminary study suggests that the availability of visual cues (not only from the drawing) but also the physical context of the designers might also assist the designing process. It is also found that for novice designers, the extent to which mental imagery only can be used as an effective design tool is limited. Mental imagery is an effective aid to generate ideas, however in terms of evaluating ideas it still remains unexplored. The hypothesis is that in the interpretation stage, the use of sketches creates an additional dialogue between parts to be selected. This gives a preliminary answer to the second question. It is also noticed that the role of pauses and gesture in mental imagery sessions, and interestingly in sketching sessions, is plausible. Perhaps in design education, the awareness of benefits and potentials of each way of designing should be introduced in early design education. In terms of digital design tools, the study is hoped to contribute to creation of more intuitive tools based on the interplay, or perhaps mental imagery in isolation which has been underestimated.

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Optimizing Operation Research Strategy for Design Intervention: A Framework for GOMS Selection Rule

Wricha Mishra, Anirban Chowdhury and Debayan Dhar

Abstract Designers often refer to task analysis for mapping user's activity while conceptualizing system design. Task analysis substantially optimizes task performance by addressing human error during system design. Goals, Operators, Methods, and Selection rule (GOMS) is widely used technique of task analysis to enhance usability, human performance and overall productivity of the system. Although widely used, a major constraint of GOMS is its inability to support designers to envisage the outcome of decision making for method selection while performing different operations to achieve the goal. This drawback of GOMS hinders efficiency of task analysis and thereby affects designers in optimizing design interventions for end users. The present study was conducted to address the issue of Decision making in GOMS. An integrated framework consisting of payoff matrix in GOMS has been proposed and validated. To evaluate the usability of proposed framework, five user experience experts were asked to evaluate two popular e commerce websites. The payoff matrix was evaluated using Laplace criterion of decision making under uncertainty rule of operation research strategy. The empirical evidence from the study indicated that selection rules for a method using human factors affects design decisions. The proposed framework reported here would support designers in their decision make process for an optimized design intervention.

Keywords Task analysis · Operation research · Decision making

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1 Introduction

Design researchers and practioners often advocate user centric systems to enable people to accomplish their task efficiently [14]. Efficient task accomplishment implies task performance with reduced human error in system design. Task Analysis (TA) is one of the prime methodologies in the evaluation of human error and their relative risk [18]. It covers task and element duration, task frequency, task allocation, task complexity, environmental conditions and other significant features essential for task performance [12]. The major objective is to predict possible human errors before it occurs so that possible prototypes can be made before launching in the market [4]. There are various methods of task analysis including Hierarchal Task analysis (HTA), Operator Action Event Trees (OAET) Cognitive Walk Analysis (CWA), Decision/action flow diagrams, Critical Action and Decision Evaluation Technique (CADET) Goals Operators Methods Selection (GOMS) etc. Among various techniques of task analysis Goals, Operators, Methods, and Selection rule (GOMS) is a well-recognized technique focusing on systems functionality and usability [3].

1.1 GOMS

GOMS implies Goals, Operators, Methods, and Selection rule. Goals are often divided into sub goals. Operators are actually the actions taken to achieve a goal and Methods are well-learned sequence of sub-goals. Whenever there is an alternative method to accomplish the same goal then selection rule comes in. Selection rules guides the users to select the appropriate method to achieve the goal. Compiling goals, operators, methods and selection rules conveys the knowledge of how to execute a specific task [8]. GOMS helps to forecast predictions on learning and performance for a given task. Thus, GOMS evaluates the physical, cognitive and perpetual actions of a task to enhance usability, human performance and overall productivity of the system [11]. GOMS is applicable for predicting usability. It is also useful for forecasting functionality coverage and functionality consistency. GOMS also generates operator sequence, execution time, error recovery while addressing practical design problems [8]. However, GOMS is not applicable to broader problems and also ignores contextual factor [8, 14].

There are various forms of GOMS model which have eventually developed. The designer while constructing a GOMS model envisages the possible actions of how users decompose the tasks into sub tasks and further steps followed for task accomplishment. Because the designers are unable to gather data and evaluate which alternative method is appropriate for accomplishment of task, hence, these decisions may be wrong. Therefore, by considering the judgment calls, designer may get an opportunity to explore the alternative methods associated for decomposing a task and also assessing if any serious consequence is related to decision made [11]. They are Keystroke-Level Model, first described by Card et al. [2], NGOMSL (Natural GOMS Language) by Kieras [10], CPM-GOMS Gray [5]. GOMS + PDL were developed to focus on uncertainty of decision making from user's perspective with human performance model [6]. However, none of the model was able to help and decide which method chosen would give best possible method. Moreover, there was paucity of studies showing modified GOMS method where decision making was quantitatively evaluated. Therefore, it can be said that GOMS does not envisage the outcome of decision making quantitatively for METHOD SELECTION while performing different OPERATIONS to achieve the GOAL.

1.2 Operation Research: Decision Making

The operation research is new decision making field which has been characterized by the use of scientific knowledge through interdisciplinary team effort for purpose of determining best utilization of limited resources [16]. According to OR, there can be three possible environments for decision making: decision making under certainty, decision making under uncertainty and decision making at risk. Decision at certainty reveals when there is no confusion in occurrence of outcomes. Decisions under certainty imply, a judgment call is taken logically which serves basis for taking appropriate decision. Decisions under uncertainty involve criteria based on the decision maker's attitude towards risk. It ranges criteria with different methods ranging from optimism to pessimism. For Decisions under uncertainty, decision maker has no ability to generate the probabilities with which various states of nature will occur. However, in the case of Decision at risk provides probabilities of the expected results of decision made with available states of nature.

Designers often have to come across many types of uncertainty which affect the design and operation of complex systems. These wide ranges of uncertainties and possible responses unified make the task performance difficult [4]. Therefore, the present study was conducted to integrate the Decision making rule of uncertainty of Operation Research into GOMS to capture wide range of uncertainty.

2 Methods

2.1 Approach

In, the present study, an integrated framework for GOMS with a payoff matrix of decision making under uncertainty in operation research was attempted to be integrated. A payoff matrix based on different possible outcomes, states the

Table 1 Representing general payoff matrix

	s_1	s_2	…	s_n
a_1	v (a_1, s_1)	v (a_1, s_2)	…	v (a_1, s_n)
a_2	v (a_2, s_1)	v (a_2, s_2)	…	v (a_2, s_n)
			…	
			…	
A_m	v (a_m, s_1)	v $(a_m\ s_1)$	…	v $(a_m s_n)$

probable value of different alternatives. The payoff matrix is composed of several available alternatives $(a_1 \ldots a_{m)}$ for an event to occur. The consequence is based on the chosen alternative on which event or set of events occurs $(s_1 \ldots s_n)$ (15). The general format for payoff matrix is under (Table 1).

*The element a_i represents action i and the element Sj represents state of nature j. The payoff or outcome associated with action OJ and state Sj is v(aj, Sj)′ [16].

The objective of the payoff matrix was to enhance the decision making at uncertainty while selecting alternative methods for selection rule. The payoff matrix was modified based on user experience perspective with certain factors described below.

One of the typical measures of efficiency is time [9]. Time taken to complete the task affects performance. Ease of use is important aspect of usability. Usability implies how particular class of users who are executing a task in specific environment accepts a system or product and how user friendly it is [1]. Users often prefer freedom and control of visiting website. In case of any mistake or forbidden steps taken by the user; the user the user wishes for emergency exit. In such scenario provision of previous, next, home button for user control is desired [13]. Accuracy is vital component as efficiency is measured by accuracy to complete the goal [7]. Reliability determines quality in use for an end user in particular context [1]. The aesthetic effects are responsible for content and the functional aspects. Therefore, the websites are said to have appealing aesthetics if navigation and interaction functions are user friendly [17]. For evaluating the payoff matrix Laplace criterion was selected.

Referring Table 2, consider a scenario when a user has to purchase a product from B2C website. In order to purchase a product he has to follow certain number

Table 2 Representing proposed payoff matrix for GOMS

Alternatives of tasks	States of nature			
Task	s_1	s_2	…	s_n
Operator 1				
Alternatives$_1$ $O_1(a_1)$	v (a_1, s_1)	v (a_1, s_2)	…	v (a_1, s_n)
Alternatives$_2$ $O_1(a_2,)$	v (a_2, s_1)	v (a_2, s_2)	…	v (a_2, s_n)
Operator 2				
Alternatives$_1$ $O_2(a_1)$	v (a_1, s_1)	v (a_1, s_2)	…	v (a_1, s_n)
Alternatives$_n$$(O_2 a_{2N})$	v (a_m, s_1)	v $(a_m\ s_1)$	…	v $(a_m s_n)$

of tasks like search a product, view and pay. To do each task (e.g. search) there may be certain alternatives (a_1 … A_m). The choice of better alternatives will be based on certain factors like time, ease of use, accuracy etc. The proposed payoff matrix may help the designers to contemplate user's action and decide the best possible alternative to execute that task based on some factors. The matrix may enhance the performance with reduced human error.

Table 2 represents alternative tasks in columns and states of nature in row. Alternative O_1 (a_1) implies first alternatives and s1 is state of nature. v (a_1, s_1) implies first alternatives first state of nature value.

2.2 Participants

In order to evaluate the proposed framework a case study was carried out. Two e commerce websites (Flipkart and Snapdeal) based on their popularity according to Alexa rating were chosen for the task analysis. The task was to purchase a wrist watch. The operators were search, view and pay. In Flipkart there were three alternative methods for search, two alternative methods for view and six alternative methods for payment. In Snapdeal there were two alternative methods for search, two alternative methods for view and six alternative methods for payment. The payoff matrix was evaluated for both the websites. Five user experience practioners for expert reviews were purposefully selected who had an experience of over five years in IT industry and in design of B2C application. The age group was 25–35 years with a minimum of five years of experience. The experts were asked to rank the human factors on a scale of 1–10 where 1 implied low and 10 implied high. The reviewers discussed and reached a consensus justifying the scores given to usability factors. Then the scores were evaluated using Laplace criterion.

The Laplace's criterion is based on the assumption that in case of absence of any information regarding probabilities of possible outcomes of decision making under uncertainty is available, then it is reasonable to assume that they are likely equally. Therefore, if there are n outcomes, the probability of each is 1/n. Laplace criterion assumes that all state of nature will occur with equal probabilities. Therefore this is computed by average payoff for each alternative by adding all the payoffs and dividing by states of nature.This approach allows the decision maker to compute the expected payoff for each alternative and chose he alternative with the largest value [15]. Laplace decision rule is followed:

1. Assign pj = P (Sj) = 1/n to each Sj in S, for j = 1, 2,…, n.…(i)
2. For each Ai (payoff matrix row), compute its expected value: E(Ai) = Σjpj (Rij) for i = 1, 2,…, m…(ii)
   Since pj is a constant in Laplace, E (Ai) = Σjpj (Rij) = pjΣjRij…(iii)
3. Select the action alternative with the best E(Ai) as the optimal decision [15].

3 Results

The results section comprises of Tables 3 and 4. Tables 3 and 4 are based on values of Table 2 with website and user interaction values. Amongst the search option it can be seen that on scale of 1–10 (1 denotes low and 10 denotes high) search bar is most preferable one.

As explained in Table 2 for each operator there are alternatives a1, a2, Am. States of nature are factors namely time, ease of use, user's control, accuracy, reliability and aesthetics. Table 3 is computed in same way on scale of 1–10. For example consider Task 1—search (operator 1) which has three alternatives search bar, search by category, go quickly. These are ranked on factors namely time, ease of use, user's control, accuracy, reliability and aesthetics a scale of 1–10. The final score were then evaluated by Laplace criterion. All the values from each row were added and divided by no of factors.

Therefore, values for search bar was = (7 + 9 + 8 + 8 + 9 + 8)/6 = 8.17…(iv)
Therefore, values for search by category was = (7 + 7 + 7 + 8 + 9 + 7)/6 = 7.50…(v)
Therefore, values for go quickly was = (8 + 7 + 4 + 8 + 8 + 7)/6 = 7.00…(vi)

Table 3 Payoff matrix for Flipkart

		Time	Ease of use	User's control	Accuracy	Reliability	Aesthetics	scores
T	**TASK 1 search**							
1	Search bar	7	9	8	8	9	8	8.17
2	Search by category	7	7	7	8	9	7	7.50
3	Go quickly	8	7	4	8	8	7	7.00
	TASK 2 view							
1	Quick view	9	8	7	8	8	7	7.83
2	Detailed view	9	9	9	7	9	9	8.67
	TASK 3 payment							
1	Credit card	9	8	8	8	8	7	8.00
2	Net banking	8	7	7	6	7	8	7.17
3	EMI	6	6	8	7	9	6	7.00
4	Debit card	8	8	8	8	8	7	7.83
5	Cash on Delivery (COD)	7	8	7	8	8	8	7.67
6	Gift card	6	5	8	7	6	6	6.33

Table 4 Payoff matrix for Snapdeal

		Time	Ease of use	User's control	Accuracy	Reliability	Aesthetics	Scores
	TASK 1 search							
1	Search bar	7	8	7	8	8	7	7.50
2	Search by category	5	4	6	7	8	6	6.00
3	Go quickly	–	–	–	–	–	–	–
	TASK 2 view							
1	Quick view	8	6	4	7	5	5	5.83
2	Detailed view	8	7	4	5	8	7	6.5
	TASK 3 payment							
1	Credit card	7	8	7	8	8	8	7.67
2	Net banking	6	7	7	5	7	9	6.83
3	EMI	5	7	7	7	7	7	6.67
4	Debit card	7	8	7	6	7	8	7.67
5	COD	8	7	8	8	8	6	7.50
6	Gift card	4	6	8	6	6	9	6.50

The best score is one which is higher in number. Therefore we can see search bar is the best possible alternative for search task.

Table 4 represents the payoff matrix for Flipkart. Amongst the search option it can be seen that on scale of 1–10 (1 denotes low and 10 denotes high) search bar is most preferable one. Between view options detailed view got higher score. Amongst the payment option the ranking follows in this order credit card, debit card, cod, net banking, EMI, gift card.

4 Discussion

There were several methods of task analysis which incorporated decision making approach. Decision/Action charts depicts the tasks involving decision making or complicated situations and contingencies There were studies which have showed how GOMS have evolved with newer approaches over the years. In this context, the present study assumes significance because the primary objective of investigation was to address decision making from the perspective of quantitative values and logical reasoning. The present study came up with integrated framework of payoff matrix with GOMS to quantitatively prove which method to select when multiple methods come in.

The (Table 3) results of payoff matrix showed that among the search methods search bar scored high followed by search by categories and go quickly. Search bar scored high (8.17) as its faster, shows popular products Search categories scored second (7.50) as it gives detailed systematic categorisation. Search quickly (7.00) was last in spite of fastest access as it does not display all categories. For view operation detailed view scored high (8.67) as it showed detailed features with purchase option. The last operation was payment where the scores in descending order were credit card (8.00), debit card (7.83), Cash on delivery (COD) (7.67), net banking (7.17), EMI (7.00) followed by gift card (6.33). Credit card and debit card got closer scores and were on higher side because after the first time payment the card details get saved for next time and make it easier for subsequent uses and give reward points which can be redeemed. Cash on delivery got next highest score as it is more reliable accurate and easier to use. The net banking got fourth highest score as the bank preferences are saved followed by EMI which gives option to make partial payment. Gift card scored lowest as it has many terms and conditions.

Similar results were obtained for Snapdeal (Table 4). Search bar scored high (7.50) as it is faster. Search categories scored second (6.00) as it gives detailed categorisation. But the scores were lower than Flipkart because it lacked the systematic categorisation and precision as compared to Flipkart. For view operation detailed view scored high (6.50) as it showed detailed features with purchase option. But again the scores were lower to Flipkart because it lacked features of viewing the products at different angles for all products, except few. It also lacked detailing as compared to Flipkart. The quick view alternative of Flipkart scored high than Snapdeal as the detailing features were more in Flipkart. The last operation was payment. The scores in descending order were credit card (7.67) and debit card (7.67), Cash on delivery (COD) (7.50), net banking (6.83), EMI (6.67) followed by gift card (6.50). Credit card and debit card got same and were on higher side. Because, it gives reward points which can be redeemed. But the scores were lower than Flipkart because there was no option to save the card details for subsequent uses. Cash on delivery got next highest score as it is more reliable accurate and easier to use. The net banking got fourth highest score but lower score than Flipkart because one needs to scroll down to check the names of bank in drop down menu unlike Flipkart where bank names are displaced on first view. Moreover popularly used bank names are also displayed separately on Flipkart.

Next is the EMI which gives option to make partial payment. The last one is gift card as it has many terms and conditions. But gift card scored high on Snapdeal as it has hide, unhide option for password which made it aesthetically appealing. Based on both the validating results of websites a matrix was proposed for designers which will allow to make decision for best possible methods.

Table 5 Validating Matrix

Tasks alternatives	Human factors				Scores	Interpretation
Task 1	f_1	f_2	…	f_n		
Operating feature 1 (OF_1)	R_1 (OF_1, f_1)	R_2 (OF_2, f_2)	…	R_n (OF_1, f_n)	1R	If $R_1 > R_2$, then 1R is best possible alternative to conduct the given task
Operating feature 1 (OF_1)	R_1 (OF_2, f_1)	R_2 (OF_2, f_2)	…	R_n (OF_2, f_n)	2R	
Task 2						
Alternatives $_1$ $O_2(a_1)$	R_1 (OF_1, f_1)	R_2 (OF_1, f_2)	…	R_n (OF_1, f_n)	1R	If $R_1 > R_2$, then 1R is best possible alternative to conduct the given task
Alternatives $_{n(}O_2a_{2N)}$	R_1 (OF_m, f_1)	R_2 (OF_m f_1)	…	R_n (OF_m f_n)	2R	

4.1 *Proposed Matrix After Validation*

After validating the integrated matrix the matrix is proposed in following way for designers. The matrix has essence of GOMS strategy with decision making for best possible alternatives to execute a task. To execute a alternatives of the available operating features are OF_1… OF_N (See Table 5). These operating features are ranked R_1…R n on basis of human factors f_1, f_2…$f_{n.}$ The scores are evaluated through Laplace criterion by adding the factors and dividing by number of factors. The higher the value better is the rank in terms of usability and design factors. Therefore, after computing 1R, 2R, etc., the highest score is the best possible score. In other words, this is the best possible alternative to execute a task.

Therefore, the study is unique in proposing an integrated framework for GOMS decision making for selection rule during alternative methods. Therefore, this will help designers to design the best alternative for a task for any interfaces. Moreover, by selecting the best alternatives human performance can be enhanced with reduced error.

5 Conclusion

The payoff matrix for integrated GOMS framework were made on six factors namely time, ease of use, user's control, accuracy, reliability and aesthetics. On evaluating the payoff matrix with Laplace criterion for two popular e commerce web sites, it was evident that the matrix helped in decision making for alternative methods. The study established the decision making for alternative methods quantitatively. It also proved which interface was better. However, the study needs to be carried out with other human factors and diverse interfaces.

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Application of Genetic Algorithm for the Optimization of Process Parameters in Keyway Milling

S.C. Mondal, P. Mandal and G. Ghosh

Abstract The aim of this work is to develop an integrated study of surface roughness for modeling and optimization of cutting parameters during end milling operation of C40 steel with HSS tools under wet condition. The experimentation is carried out using full factorial design (three factor depth of cut, feed and spindle speed and three level). Artificial neural network (ANN) based on Back-propagation (BP) learning algorithm is used to construct the surface roughness model and second-order response surface model for the surface roughness is developed using Response surface methodology. By analysis three different surface curves it can be concluded that the minimum surface roughness (2.1779 µm) will be achieved when spindle speed, feed and depth of cut are 486 rpm, 46 mm/min and 0.31 mm respectively. Optimum parameters are obtained using GA, is near about same as value of optimum parameters obtained using RSM so it is concluded that RSM method is verified by GA Optimization.

Keywords End milling · Surface roughness · Design of experiment · Artificial neural network · Response surface methodology · Genetic algorithm

1 Introduction

For any manufacturing company higher productivity as well as very good quality is primary concern. End milling, a machining process is commonly used in industry due to its ability to remove material faster giving reasonably good surface quality,

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high efficiency and the accuracy of the cutting surface. The end milling is used for the production of slots for keyway, pockets and dies, where quality is an important factor. The dimensional accuracy and surface roughness of products are always given to the primary attention by the industry. The quality of the manufactured parts not only depends on their geometries but also their surfaces textures such as roughness and waviness. Surface roughness affects friction, wear, fatigue, corrosion, and electrical and thermal conductivity [1].

The influence of cutting parameters (spindle speed, feed and depth of cut) on surface roughness is discussed in this study. The surface roughness depends on the various process parameters and machining condition. Due to its nonlinearity, the analytical approach for its modeling is very difficult. Different theoretical models have been proposed so far by the various researchers but these types of models are not accurate enough for wide range of cutting conditions. So, there is a need for a tool that can accurately predict the surface roughness of a product and also select optimum machining parameters. Mansour and Abdalla [2] developed surface roughness model using design of experiment of input process parameters (cutting speed, feed rate, and depth of cut) by response surface methodology (RSM). In this advanced and competitive market, the manufacturing system needed for more accurate and practical evaluation systems. The techniques of artificial intelligence, particularly artificial neural networks (ANNs), receive more attention in the industry and academia due its learning capability of experimental environment and produce good relationships between output responses and input process parameters. Oktem et al. [3] employed response surface methodology to develop a fourth order response surface model and optimized the cutting parameters for surface roughness of Al7075-T6 using genetic algorithm and reported that the surface roughness improved by 10%.

The present work involves the estimation of optimal values of the process parameters like spindle speed, feed and depth of cut, whereas surface roughness is taken as the output. Surface roughness model is developed by both artificial neural networks (ANN) and response surface methodology (RSM). ANN model based on back-propagation learning method was developed and tested to control the performance. A second order response surface model is developed for predicting surface roughness values in keyway milling. The performances of response surface and neural network models are compared. The results obtained show that ANN produces the better results compared to RS model. The developed Response Surface model is further coupled with a developed genetic algorithm (GA) to find the optimum cutting condition leading to the least surface roughness value. The predicted optimal cutting condition by GA is validated with a conformation test experimentally.

2 Literature Review

Oktem [4] has developed a model for surface roughness and found out optimum values cutting parameters for minimum surface roughness for end milling of AISI 1040 steel material with TiAlN solid carbide tools under wet condition. The surface roughness model is developed using artificial neural network (ANN). Genetic algorithm (GA) supported with the tested ANN is utilized to determine the best combinations of cutting parameters. Asilturk et al. [5] have measured surface roughness in turning operation at different cutting parameters such as speed, feed, and depth of cut. Full factorial experimental design is implemented to increase the confidence limit and reliability of the experimental data. Theja et al. [6] have developed a mathematical model using ANN. The present work involves the estimation of optimal values of the process variables like, speed, feed and depth of cut, whereas the metal removal rate (MRR) and tool wear resistance were taken as the output. Full factorial design was used to carry out the experimental design [7, 8]. Alauddin et al. [9] have presented an approach to develop mathematical models for tool life in the end milling of steel (190 BHN) by response surface methodology (RSM). Noordin et al. [10] have studied the performance of a multilayer tungsten carbide tool using response surface methodology (RSM) when turning AISI 1045 steel. Gowd et al. [11] have applied response surface methodology to predict the mathematical models of hard turning process of Inconel. It is found that speed; feed and depth of cut have significant effect on the feed force, thrust force, cutting force and surface finish. Palanisamy et al. [12] have developed a mathematical model based on both the material behavior and the machine dynamics to determine cutting force for milling operations. The system used for optimization is based on powerful artificial intelligence called genetic algorithms (GA). Zain et al. [13] have combined artificial neural network (ANN) and genetic algorithm (GA) techniques in order to search for a set of optimal cutting condition points that leads to the minimum value of machining performance. Three machining cutting conditions for end milling operation that were considered in this study are speed, feed and radial rake angle. Shunmugam et al. [14] have optimized the machining parameters such as number of passes, depth of cut in each pass, and speed and feed obtained using a genetic algorithm (GA), to yield minimum total production cost.

3 Experimentation

3.1 Workpiece Material

The component material was C40 mild steel rod (Fig. 1) of 100 mm diameter. Current experiment C40 mild steel used because this grade of steel offers better forming and bending quality. It is used for applications, where critical bending operations are required. C40 steel has very significant role in industry because it is used as shaft materials.

Fig. 1 Workpiece material

3.2 Data Collection for the End Milling Process

Keyway milling of C40 steel bar was conducted in Universal milling machine using HSS End milling cutter (Diameter10 mm). The machine is manufactured by Bharat Fritz Werner Ltd. (BFW), Type-UF-2 and Sl no. 443. The specification of universal milling machine are clamping area 1350×315 mm^2, longitudinal movement 800 mm, transverse movement 230 mm and spindle speed range 45–2000 rpm (Fig. 2).

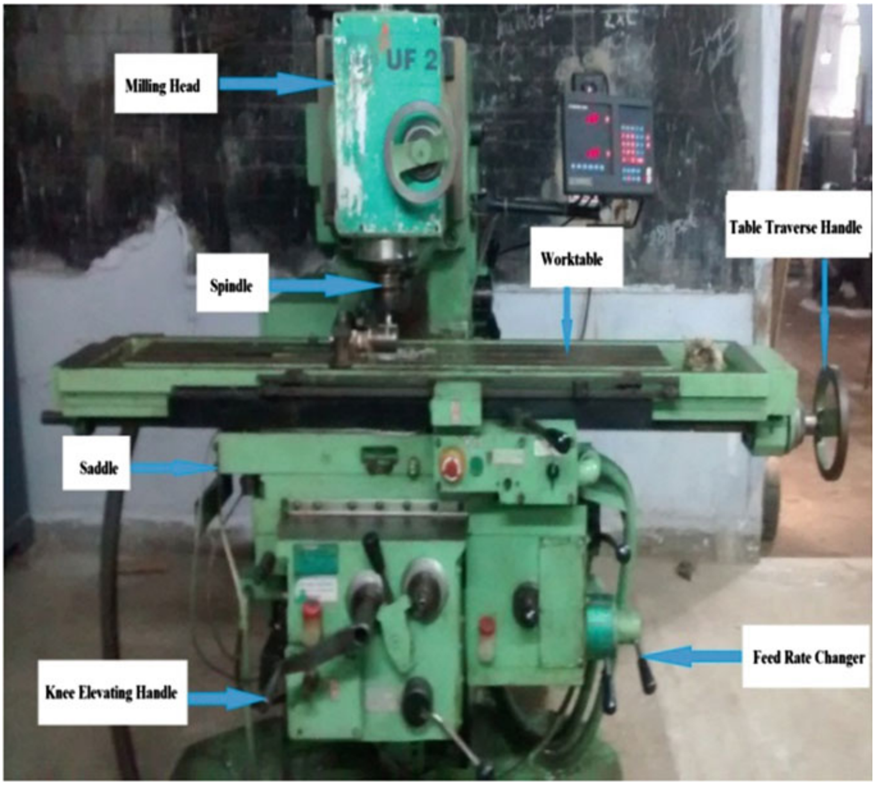

Fig. 2 Experimental set up for end milling operation

3.3 Design of Experiment

In order to determine the influence of control factors of end milling operation, three input parameters were selected depth of cut, feed rate and Spindle speed. For each factor three levels high, medium and low shown in Table 1 are considered Here three input parameter (P) and three level (L) so number of required runs for a full factorial analysis is $N = L^P = 3^3 = 27$.

Table 1 The input process parameters and their levels

Factors	Symbols	Low level	Medium level	High level
Spindle speed (rpm)	N	180	355	500
Feed (mm/min)	f	25	80	125
Depth of cut (mm)	d	0.2	0.6	1

Table 2 Experimental results

Ex. no.	N (rpm)	f (mm/min)	d (mm)	Ra (µm)
1	180	25	0.2	2.34
2	180	25	0.6	2.62
3	180	25	1	3.90
4	180	80	0.2	4.15
5	180	80	0.6	4.20
6	180	80	1	5.50
7	180	125	0.2	8.85
8	180	125	0.6	9.10
9	180	125	1	10.20
10	355	25	0.2	1.88
11	355	25	0.6	2.24
12	355	25	1	2.33
13	355	80	0.2	3.23
14	355	80	0.6	3.26
15	355	80	1	3.31
16	355	125	0.2	5.42
17	355	125	0.6	8.56
18	355	125	1	9.20
19	500	25	0.2	1.40
20	500	25	0.6	2.01
21	500	25	1	2.13
22	500	80	0.2	2.68
23	500	80	0.6	3.05
24	500	80	1	3.28
25	500	125	0.2	3.98
26	500	125	0.6	4.85
27	500	125	1	5.45

Total 27 experimentation were carried out according to full factorial design matrix and corresponding responses such that surface roughness were measured using stylus type surface texture-measuring instrument (Mitutoyo Surftest SJ-301 with cutoff length 2.5 mm). The experimental results were shown in Table 2.

4 Analysis and Results

4.1 Modeling Using Artificial Neural Network

Artificial Neural Network has been developed by inspiring of the biological structure of human brain. This is one of the most popular nonlinear mapping systems in artificial intelligence which is train with experimental knowledge to solve many problems including modeling, predicting of responses. There are many available training algorithms, but the most popular one is the back-propagation algorithm and it was used in this study. In back-propagation learning algorithm, there is a rule known as gradient descent method minimizing the mean square error between the desired output and the network output. The artificial neural network based on BP learning algorithm can be effectively created by utilizing the equations in the following [4]

$$NET_j = \sum_{j=0}^{n} W_{ij} X_i \tag{1}$$

In artificial neural network, the every neuron of hidden layer receives total input from all of the neuron in the input layer. The connection weight between ith input neuron and the jth hidden neuron is W_{ij}, X_i is the ith input, and n is the number of inputs to the jth hidden neuron. NET_j is the sum of the weighted outputs and transferred into the activation function (F) which gives the output (OUT_j) of the jth neuron in the next layers. Sigmoid function as activation function in Eq. 2 is chosen for the present study:

$$F(NET_j) = \frac{1}{1 + e^{(-NET_j)}} \tag{2}$$

$$\left(OUT_j\right) = F\left(NET_j\right) \tag{3}$$

In Back-Propagation learning algorithm the neural network is train by updating the connection weight until the mean square error (MSE) is converged to a minimum value. The network system mean square error:

$$MSE = \frac{1}{2}\sum_{m=1}^{M}\sum_{k=1}^{K}(DES_{mk} - OUT_{mk})^2 \tag{4}$$

The desired output denoted by DES_{mk} and network output denoted by OUT_{mk}, K is the number of output neuron and M is the overall number of data set. The connection weight is adjusted by the following Eq. (5):

$$\Delta W_{ij}(n) = -\eta * \frac{\delta E}{\delta W_{ij}} + \alpha * \Delta W_{ij}(n-1) \tag{5}$$

In above equation, η is the learning rate which controlling the stability, α is the momentum rate and n is the iteration. Determination numbers of neurons in the hidden layer(s), learning rate (η) and momentum coefficient (α) are the considerable task for find out the best network architecture A typical architecture of a neural network three input neurons corresponding to spindle speed, feed and depth of cut and one output neurons corresponding to surface roughness (Ra), is shown in Fig. 3.

The number of hidden layer, number of nodes in the hidden layer, learning rate (η), and momentum coefficient (α) are decided by trial and error. Table 3 shows that mean square error of training and testing for different network architecture, learning rate (η), and momentum coefficient (α). Different combinations of learning rate (η), and momentum coefficient (α) and number of hidden layer have been tried. Depending upon the mean square error, optimum network architecture has been arrived at. In the present case, from Table 3 for architecture 3-5-1 network with learning rate(η) = 0.2 and momentum co-efficient α = 0.9 mean square error (MSE) for training is 0.0041 and for mean square error (MSE) for testing is 0.0119 is minimum so it is found that optimum network is 3-5-1.

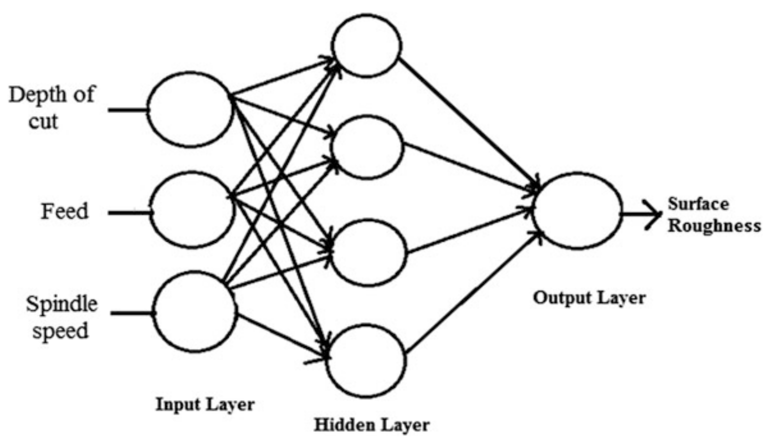

Fig. 3 Neural network with three input nodes and one output node

Table 3 MSE for different network architectures

Sl. no.	Architecture	Learning rate (η)	Momentum rate(α)	MSE (training)	MSE (testing)	Number of iterations
1	3-3-1	0.1	0.9	0.0623	0.1130	19
2	3-3-1	0.2	0.7	0.1640	0.5281	13
3	3-3-1	0.2	0.8	0.0841	0.1617	16
4	3-3-1	0.1	0.6	0.0648	0.0975	35
5	3-3-1	0.01	0.8	0.0579	0.0643	13
6	3-3-1	0.01	0.5	0.2211	0.3863	38
7	3-3-1	0.02	0.9	0.3301	0.2793	684
8	3-4-1	0.2	0.8	1.8513	1.7141	36
9	3-4-1	0.1	0.9	0.0250	0.0216	24
10	3-4-1	0.1	0.5	0.0259	0.4316	15
11	3-4-1	0.4	0.8	0.0620	0.0809	12
12	3-4-1	0.01	0.6	0.0966	0.1230	14
13	3-4-1	0.02	0.9	0.0337	0.0330	15
14	3-5-1	0.01	0.9	0.0067	0.1143	40
15	3-5-1	0.02	0.6	0.0146	0.0177	16
16	3-5-1	0.1	0.8	0.2565	0.2460	11
17	**3-5-1**	**0.2**	**0.9**	**0.0041**	**0.0119**	**35**
18	3-6-1	0.1	0.8	0.0432	0.0948	14
19	3-6-1	0.02	0.6	0.0179	2.3789	17
20	3-6-1	0.03	0.5	0.0459	0.0972	31

For validating the network is to create a regression plot which shows the relationship between the outputs of the network and the targets. This regression plot is analyzed for training, validation and testing pattern. Figure 4 shows experimental surface roughness value versus predicted surface roughness value for training, testing and validation and it is observed from the regression analysis that correlation coefficient (R) is for training is 0.99959 for correlation coefficient (R) is for validation is 0.99625 for testing correlation coefficient(R) is 0.99899 and overall R value is 0.9977 which implies moderate correlation between experimental and predicted responses.

Comparative study has done for experimental and network predicted surface roughness for test data. In bar chart (Fig. 5) Experiment No. are along with X-axis and Surface roughness (Ra) in μm are along with Y-axis. Black bar indicates experimental surface roughness value and adjacent white bar predicted surface roughness. Bar chart shows that experimental Ra value and predicted Ra value very close to each other so it can be said that for network architecture 3-5-1 will give very satisfactory result.

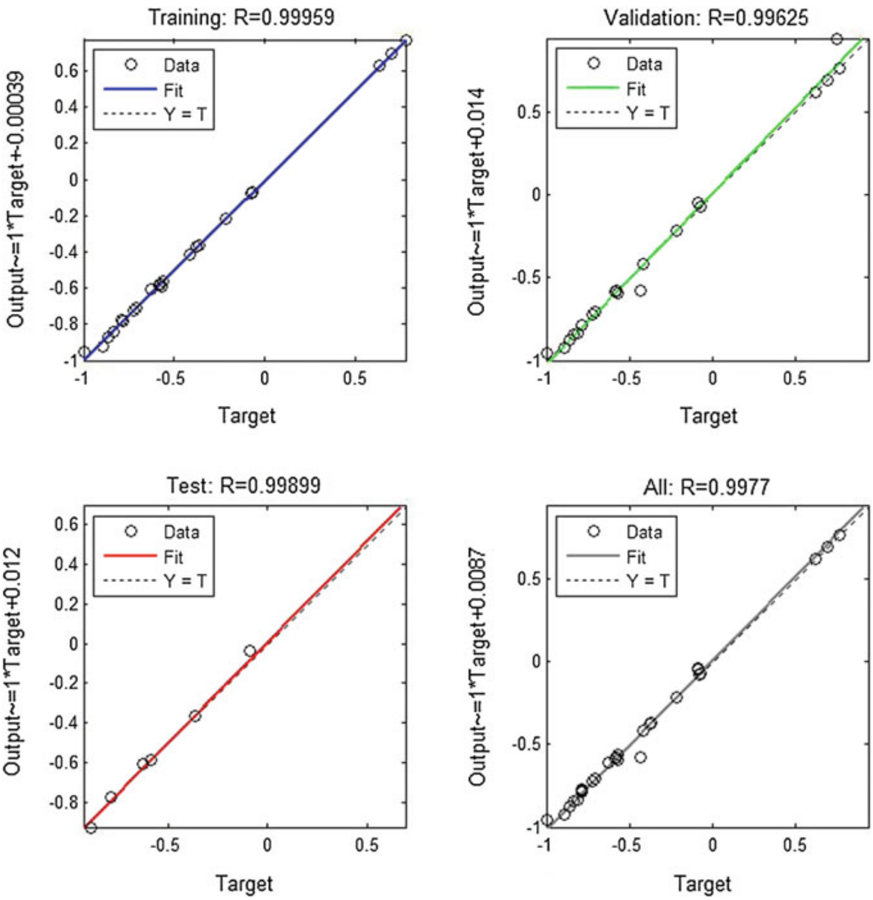

Fig. 4 Regression plot for training, validation, testing for 3-5-1 neural network

4.2 Modeling Using Response Surface Methodology (RSM)

Response Surface Methodology is mathematical and statistical techniques which are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response. The RSM is a dynamic and important tool of design of experiment (DOE) where the relationship between response(s) of a process with its input decision variables is mapped to achieve the objective of maximization or minimization of the response properties. Response Surface Methodology (RSM) is a combination of experimental and regression analysis and statistical inferences. The whole concept of

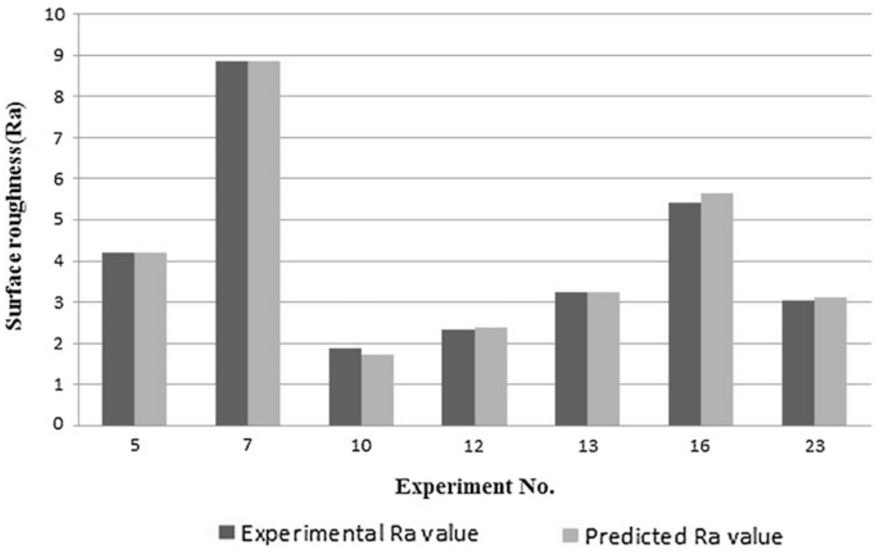

Fig. 5 Bar chart of experimental and ANN predicted Ra value testing data set for 3-5-1 neural network

response surface involves dependent variable Y also called the response variable and the several independent variable X_1, X_2, X_3, X_4, …, X_n. If it is assumed that all of these variables are measured, then response surface can be expressed as:

$$Y = f(X_1, X_2, X_3 \ldots X_n) + \varepsilon \tag{6}$$

Where ε is random error observed in the response Y. In most of cases, the response surface variables demonstrate some curvature in most of the cutting parameters. Therefore it is useful to consider the second order model in this study to evaluate the parametric effects on various response criteria.

$$Y_U = \beta_0 + \sum \mathrm{B}_i x_i + \sum \beta_{ii} X_i^2 + \sum \beta_{ij} X_i X_j + \varepsilon, (i = 1 \ldots k \,\&\, i < j) \tag{7}$$

The β parameters of the polynomials are estimated by the method of least squares. The second order model helps to understand the second order effect of each factor separately and the two–way interaction amongst these factors combined. In this work the second-order response surface representing the surface roughness (Ra in µm) is expressed as a function of keyway milling parameters such as spindle speed (N), feed (f) and depth of cut(d) where it is assumed as the data is normally and independently distributed with zero mean and variance unity. The regression analysis is performed to identify the significant process parameters participating in the response surface model. Using the experimental data for the surface roughness by MINITAB 17 software the second-order response function was determined below.

Table 4 Analysis of variance (ANOVA) for Ra

Source	DOF	Sum of squares	Mean square	F-value	P-value
Model	9	163.548	18.172	34.79	0.000
N	1	25.701	25.701	49.20	0.000
f	1	113.499	113.499	217.28	0.000
d	1	7.012	7.012	13.42	0.002
N^2	1	0.028	0.028	0.05	0.819
f^2	1	12.111	12.111	23.19	0.000
d^2	1	0.006	0.006	0.01	0.919
N*f	1	8.514	8.514	16.30	0.001
N*d	1	0.165	0.165	0.32	0.581
f*d	1	1.127	1.127	2.16	0.160
Error	17	8.880	0.522		
Total	26	172.428			

$$Ra = 1.80 + 0.00334\,N - 0.0095\,f + 1.27\,d - 0.000003\,N^2 + 0.000575\,f^2 - 0.19d^2 - 0.000105\,N * f - 0.00183N * d + 0.0153\,f * d \tag{8}$$

The P-values were used to estimate whether F was large enough to indicate statistical significance and used to check the significance of each coefficient. The P-values lower than 0.05 indicated that the model and model terms were statistically significant. In Table 4 most of P-values are lower than 0.05 means most of the co-efficient are significant. When regression coefficient (R^2) approaches to unity, it indicates a good correlation between the experimental and the predicted values. It is seen that values of R^2 and R^2 (Adjusted) are 94.85 and 92.12% respectively. So, that the proposed response surface model is adequate to express the real keyway milling process.

4.3 *Optimization Using Response Surface Methodology Plot*

The three dimensional surface plots for surface roughness are shown in Figs. 6, 7 and 8. In each of the plots, two cutting parameters are varied while the third one is held at its mid value. It is seen from these plots that there is significant amount of curvature indicating non-linearity in the variation.

By analyzing three different surface plots (6–8) it can be concluded that the minimum surface roughness will be achieved when spindle speed, feed and depth of cut are 486 rpm, 46 mm/min and 0.31 mm respectively. By using the values of the optimum cutting parameters surface roughness is found 2.1779 µm from the Eq. 8.

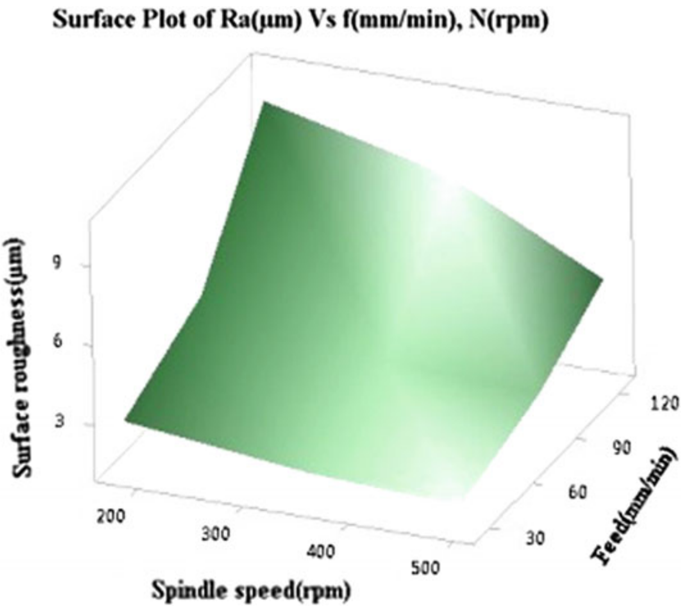

Fig. 6 Surface plot of Ra versus feed, spindle speed

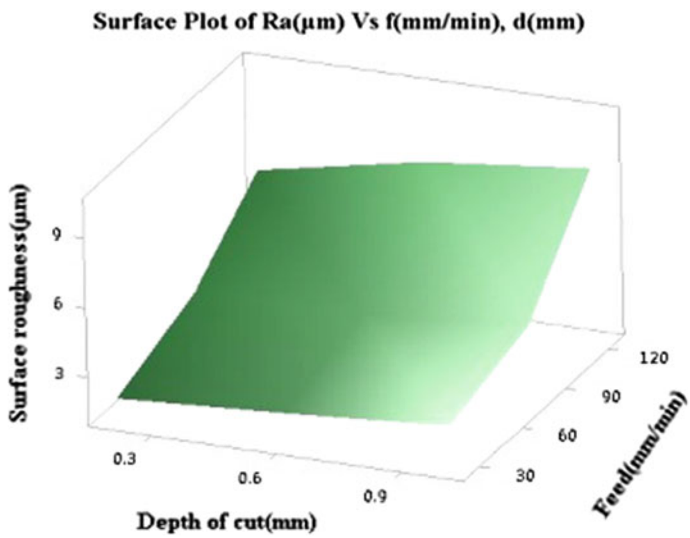

Fig. 7 Surface plot of Ra versus feed, depth of cut

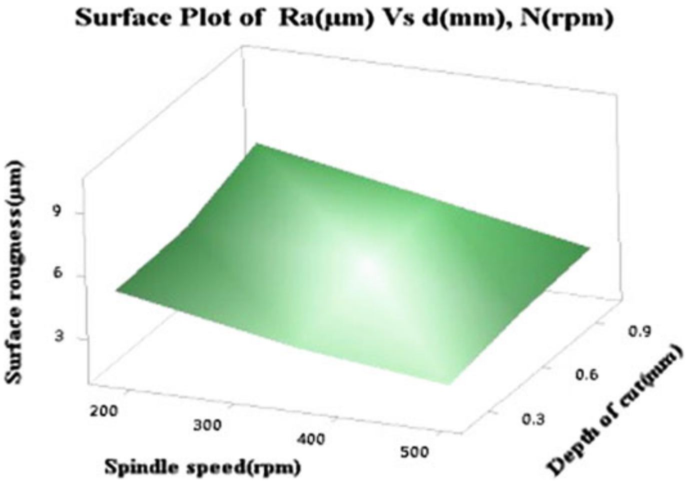

Fig. 8 Surface plot of Ra versus depth of cut, spindle speed

4.4 Optimization Using Genetic Algorithm

The complicated optimization problems in the engineering, mathematics, and the other fields can be solve using Genetic Algorithm, a powerful and robust optimization tool. Genetic Algorithm is developed in matlab environment for searching optimum process parameters based on Darwin's idea of "survival fittest" and "natural selection". These algorithms generate a population of solutions and make them evolve by encouraging the survival and the reproduction of the solutions which are the most likely to converge towards the optimum. The GA tried to converge on the better solution by beginning with a set of potential solution changing them through several iteration. The solution of an optimization problem with the GA algorithm begins with a set of potential solution that is known as chromosomes. The entire sets of these chromosomes comprise populations which are randomly selected. The entire set of these chromosomes evolve during several generations or iterations. New generations known as offspring are generated by utilizing the crossover and mutation techniques. Crossover involves the process of splitting two chromosomes and then combining one-half of each chromosome with the other pair. Mutation involves the process of flipping a chromosome. The genetic algorithm repeatedly modifies a population of individual solutions.

The objective of the optimization process in this study is to find out the optimal values of decision variables for which the minimum value of surface roughness is achieved. To formulate the optimization problem, the response surface model which is proposed in Eq. (8) is taken as the objective function (fitness function) of the optimization solution to minimize the surface roughness (Ra). The machining parameters are spindle speed (N), feed (f) and depth of cut (d).The minimization of the fitness function value of Eq. (8) is subjected to the boundaries (limitations) of

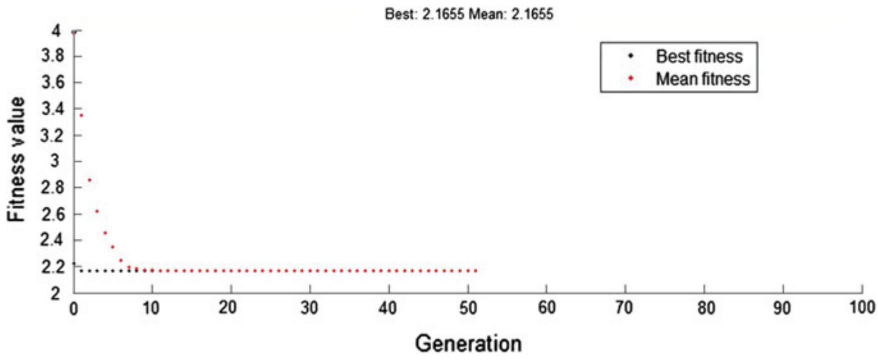

Fig. 9 Plot functions of the best fitness

cutting condition values. The range of values of experimental cutting conditions in Table 1 is selected to present the limitations of the optimization solution and is given as follows: 180 rpm ≤ N ≤ 500 rpm, 25 mm/min ≤ f ≤ 125 mm/min and 0.2 mm ≤ d ≤ 1 mm. Basically, obtaining the best optimal results depends on some criteria. The major criteria most influencing the optimal result that must be given consideration are the number of the initial population size, the type of selection function, the crossover rate and the mutation rate. By using the fitness function formulated in Eq. (8), within boundary condition of speed, feed and depth of cut and setting the values like Population size: 80, Elite count: 4, Crossover rate: 1, Mutation rate: 0.8 and Cross over function 2 point in MATLAB GA optimization toolbox, optimum cutting condition is obtained for minimum surface roughness. From GA it is observed that the minimum surface roughness value is 2.1655 μm for cutting conditions spindle speed is 486.25 rpm, feed is 47.85 mm/min for and depth of cut 0.306 mm.

It is indicated that the optimal solution is obtained at the 51th generation (iteration) of the GA algorithm. From Fig. 9, the plot functions indicate that the mean fitness value is 2.1655 μm with the best fitness value is also 2.1655 μm.

5 Conclusion

Back Propagation Neural Network model have been developed by using experimental data. Optimum architecture 3-5-1 with learning rate (η) = 0.2 and momentum co-efficient α = 0.9 as best architecture on the basis of minimum mean square error (MSE) and this architecture are validated by regression analysis. It has been observed that neural network could learn well the pattern and could be used for future prediction of surface roughness. The predicted surface roughness from the present neural network model is very close to the values measured experimentally.

By using the experimental data, the second-order response surface models for the surface roughness in keyway milling process were developed. Therefore, it is possible to predict the surface roughness before conducting end milling operation. The effect of end milling parameters on the surface roughness was evaluated with the help of the response surface plots. It is found that lower level of depth of cut, feed and high level of spindle speed minimizes the surface roughness.

Both RSM and GA optimization techniques are used to obtain optimum keyway milling parameters. Results obtain from both techniques are near about same. So it can be concluded that GA validates RSM optimization technique. The numbers of experiments in the same or similar area in keyway milling operations were reduced by artificial neural network model and determine optimum cutting condition using RSM and GA. Satisfying results were obtained which could be used for future academic or industrial study.

Modelling and optimization can be done using different techniques like PSO, Ant Coolony, ABC etc. Analytical approach can also be used for modeling and optimization of the key way milling.

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A Thinking Process Model Based on the Perspective of Editing Constraints to Design Innovative Things

Masami Maekawa

Abstract Design methods tend to be described by the perspective of work steps and processes. For actual designers, however, the invisible internal thought process is deemed to be more important to achieve innovation and better designs, than the obviousness of step-wise tasks toward the completion of work. Thus, design activities focus on discovering, articulating, and editing constraints. This study shows a thinking process model in the early stage of design activities. The model was designed based on the perspective of two kinds of constraints: (1) external constraints that were induced by social needs or conditions and (2) internal constraints that were necessary to design objects to be formed in an orderly process. The model showed that in the thinking process, constraints were edited cyclically, and that three types of internal constraints were edited in this mechanism. Finally, the model was validated in a case of design activity.

Keywords Design · Constraint · Systems thinking

1 Introduction

Innovations are longed for in industry. However, these are phenomena that are yielded after hypotheses are realized. The designer or planner is concerned as to how to make innovative things, although most innovations cannot be planned or predicted. The starting point is the first part of development process, because there are a lot of choices to be made in defining requirements, values to be offered, concepts, users, use situations, and so on. These activities include investigation, planning, and conceptual design. After these activities, the next stage of engineering

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design is concerned with the embodiment of the plans. Prerequisites are roughly determined in the engineering design stage, therefore, there is a high possibility of using various realized information, such as what is the optimum design process [1]. Moreover, designs in progress can be evaluated to be substantively improved. Therefore, techniques and tools that support design thinking and decision making are easy-to-use in the engineering design stage. On the other hand, in the previous stage, consideration of objects is ambiguous, such as values, meanings, concepts, and relations among these objects. Therefore, methods or tools to support the thinking in the first stage of design activities are required.

Recently, service-dominant logic in the marketing field and in product-service systems has been spreading rapidly. It is advocated to search widely for the vehicles to achieve value and function to lessen the negative environmental impact and to offer a more effective value. Changing vehicles has significant impact on the creation of new value. Therefore, it is believed that advancing the research on the method of discovering preferable vehicles leads to the creation of innovative things.

In this paper, a thinking process model in the early stage of design activities is described. Research on design process has existed for a long time. The purposes are efficiency improvement of design work, the quality assurance of work, organizing collaborative design, systematizing of design education, and so on. However, most of these purposes only represent the phenomena that have been observed in design activities, and attention to the driver of the phenomena is scarce [2].

Constraints are considered to be the main drivers. They are requirements and also necessary conditions for the design of objects that are in this world. Moreover, in the early stage of design, constraints can be edited and changed. Finally, they lead to the final design. Editing constraints are thought to occupy a significant amount of individual design thinking.

In Sect. 2, the past research design processes are reviewed. In Sect. 3, it is explained that the point of creativity is in individual thinking process. In Sect. 6, a model derived by applying the Saussure theory based on linguistics is shown, and it explains the thinking process with editing constraints in the early stage of designing innovative things. Finally, a case study of the design activity of a bicycle is shown, which is a validation of the thinking process model.

2 Design Process Models in the Past

There are design process models that show that ideal processes can be observed from the outside or by partitioning each activity, according to the content. Following samples are the model of Noguchi et al. model, and the model of ISO9241-part210 (as shown in Figs. 1 and 2) [3, 4]. These have some utility as guidelines on the business process, because they are easy to understand. However,

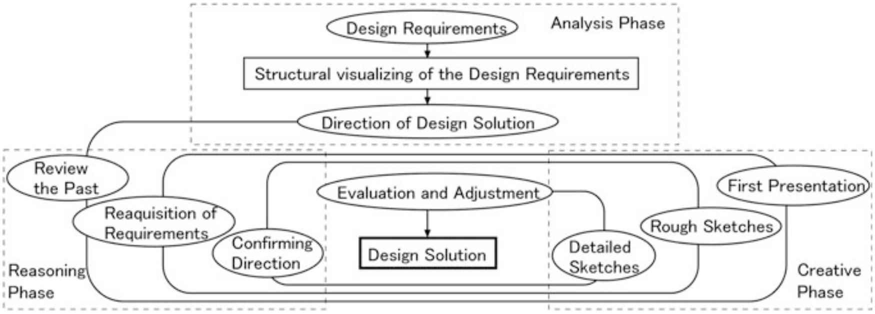

Fig. 1 Noguchi's et al. model

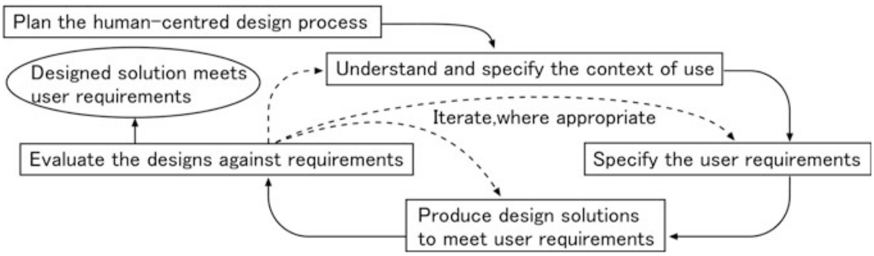

Fig. 2 Human-centred design process model of ISO9241-part210

an excellent result cannot be achieved only by designing according to these procedures. Moreover, they hardly refer to constraints that are the feature of design activities.

3 Focusing on Individual Thinking Process

It is believed that truly innovative ideas originate from individual thinking. Although brainstorming is popular, the ideas are naturally limited to the content expressed by language or words during brainstorming or talking. Additionally, there are various faults such as an evaluation apprehension, Ringelmann effect, and so on. There are many research results that show the superiority of individual thinking [5–8]. Therefore, an individual thinking process is thought to be critical for designing truly innovative things.

4 Saussure Theory

The starting point of a design activity that aims to make innovative things is to understand external contexts, especially in user-centric approach. Facts like nature, economy, technologies, and societies can be included in external contexts. The design is determined by the interpretative result of the external contexts. If it is an ordinary interpretation, hidden needs cannot be understood, and no new things will be designed. Conversely, if hidden needs can be discovered by a new interpretation, or by a reframed understanding, innovative things may be designed. The method of promoting a new interpretation or reframing is still unclear; however, such phenomena may be described based on the rule of thumb.

The Saussure theory is applied as a method to understand the above-mentioned phenomena based on linguistics, as follows [9]: only things that are perceived as having worth can be recognized in the situation. Consequently, something is identically classified, or are distinguished, or are unrecognized. "Words" and "meanings" are given to the matters that are recognized and distinguished. Hidden needs or new values are discovered in accordance with the way that the matters are articulated. At this time, only "meanings" are generated for a certain matter in the individual, because "words" are unnecessary to think alone. Reframing is thought as discovering new meanings through a new articulation. This is done at the stage where value is not shared beforehand.

It is possible to say that the articulation that the individual provided exists first as a tacit knowledge. Next, if the articulation is shared in the community, some "words" are made as explicit knowledge. Concepts expressed by drawings or photographs show that they have not reached the phase of making "words" to share, yet the concepts are almost tacit knowledge. Innovative concepts are normally indispensable to design innovative things. The Saussure theory serves to recognize the thinking process of generating and sharing concepts.

5 Constraint

5.1 Handling of Constraints

Handling of constraints is the feature of design activities [10]. Constraints might be recognized as problematic. However, design activities are different from activities involving the creation of pure art. To create useful or valuable things, it is necessary to utilize, or destroy, or evade constraints. In fact, constraints are effective elements to obtain an excellent design result [11, 12]. For instance, Norman pointed out the advantage of taking constraints to the design of controlling elements, to avoid hesitation and user errors [13]. Concepts can be viewed as constraints, because they define values, the elements, and the range of correct solutions. A concept directs the thinking of designers. Consequently, the state of things is suited to be optimum.

5.2 Definition and Classification of Constraints

In this paper, constraint is defined as a factor that leads to preferable design in relation with the stake-holder, context of use, social circumstances, and so on. Additionally, it provides the component and the state of design objects to be achieved. Constraints can be roughly classified into external constraints and internal constraints, from the viewpoint of the systems thinking [14].

An external constraint indicates the factor imposed on things to adjust to the outside world, the society, the market, the use state, and so on. For instance, the user, gravity, the forming method, and the region used are included. On the other hand, internal constraint is the internal factor of design objects. The external and internal constraints are related to each other. Figure 3 illustrates their relationship. Additionally, an internal constraint can be divided into α, β, and γ. α indicates the constraint necessary to compose things that satisfy an external constraint [15]. For instance, it includes the recycling structure and the miniaturization. β indicates the constraint in the component of things. For instance, it includes the thickness of the cover and the size of power unit. γ indicates the constraint in the relation between components. For instance, it includes the heat radiation efficiency by the position of contents, the composition by the parts layout, etc.

5.3 Edit of Constraints

Design activity is the adjustment of various constraints for the things to be designed, and obtaining the state of things that suits the constraints. Constraints are modified during the process.

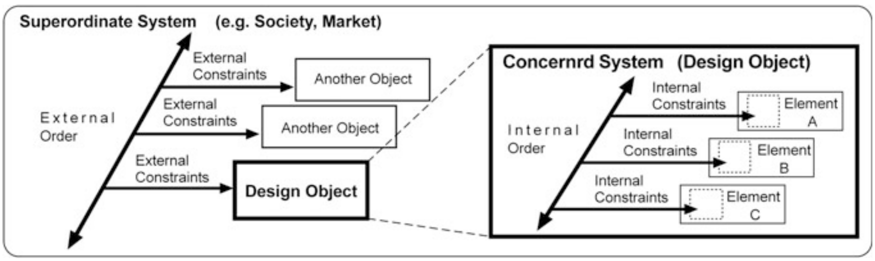

Fig. 3 Relation of external and internal constraint

In general, design activity was executed between the planning stage and the engineering design stage of product development. However, at the present time, it has not been a sequential process by applying concurrent engineering method or front-loaded definition style development. In a way, design activity is executed at the first stage now, because the necessity of making new value has increased more than ever. This means that a constraint becomes more ambiguous with the increasing frequency of editing that constraint. Consequently, adequate editing of external and internal constraints becomes even more important.

6 Thinking Process with Editing Constraints

It is supposed that the thinking process in the editing of the state of things can be expressed from the viewpoint of articulation and editing constraints, as follows: Fig. 4 shows the model of thinking process with editing constraints. Internal constraint α, β, γ, and the state of things are edited by repeating the below-mentioned process. The following numbers correspond to the one in Fig. 4.

1. Matters of the environment or the context of use are investigated, and a part of them is recognized.
2. Facts are interpreted by articulation. Moreover, a part of the external constraint is defined. Concepts are included in the external constraint.
3. The first state of things is formed with the projection of the defined external constraints. At this time, to satisfy the external constraints, an internal constraint α and abstracted functions are generated. As the initial external constraints are insufficient, initial internal constraint α is also insufficient.

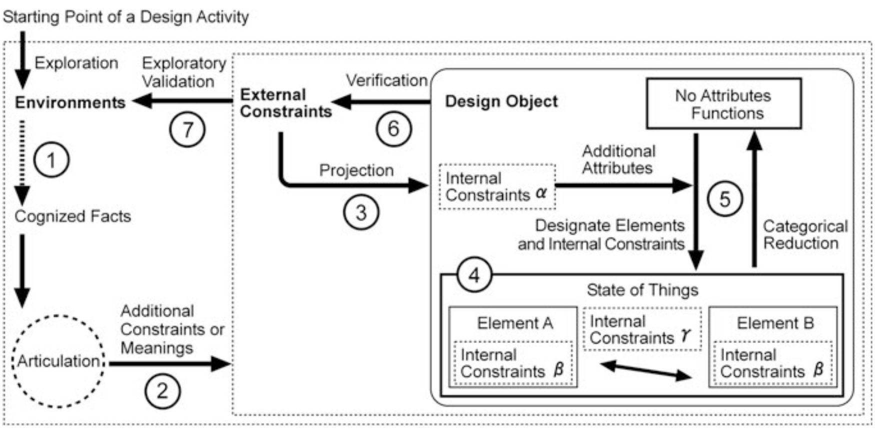

Fig. 4 A model of thinking process with editing constraint

4. The first state of things is visualized, and the content and the relation of the elements are imaged. Then, internal constraint β and γ appear. In particular, β originates in the attribute of elements. Contradiction between the constraints is easy to find, because β and γ are based on objective images.
5. Attributes are removed to avoid the contradiction between constraints, and the state of things is converted into an abstract function. This is called “categorical reduction” [16]. Then, a new attribute which is without contradiction between the constraints is given to the abstract function.
6. It is necessary to verify the adaptability of the design object to the external constraint. If the adaptability is insufficient, α is updated.
7. Moreover, validation in supposed environments or contexts is also necessary. If the result is insufficient, the other matters are investigated, articulated, and interpreted such that they become new external constraints.

7 Validation of the Model in the Case of Design Activity

This case is an activity of designing a bicycle that contributes to the use of bicycles in Japan. Figure 5 shows the design result. First, external constraints were “Design object was bicycles” and “Secured of safety in use”, etc. However, they were not sufficient to provide a preferable bicycle design. Therefore, to acquire concepts and external constraints, research of the real environment and the context of use was conducted by observing bicycle users and reviewing past research questionnaires. Concepts were derived by articulating the obtained objects, as follows: “adaptability to the shopping”, “satisfying the happiness of running and comfort”, and “easy handling”, etc. These were added as external constraints. Next, a process state table (ProST) is used to project the external constraints to design objects [17]. Figure 6 shows the entry sheet form of it. It helps clarify the requirements of design objects by the analytical description of the context of use. For instance, the

Fig. 5 A designed bicycle in the case

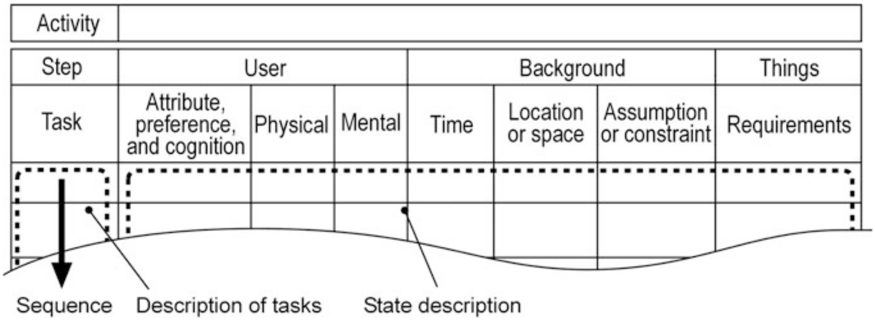

Fig. 6 The form of process state table (ProST)

following requirements were derived; “easy turning”, “possibility of running with a 10 kg package of rice”. As for this example, abstract functions to satisfy external constraints are set. Next, the issues among internal constraints was identified by visualizing the functions. For instance, the following dilemmas were found; “the center of gravity of luggage may be too high and unstable as there was a rear wheel”, “small rear wheel ruins running”, and “short length bicycle lowers loading capacity”. Moreover, the visualized bicycle helped the exploratory validation of the environment or context of use by imagining the use state, user psychology, and safety. This validation resulted in the addition of external constraints. For instance, the trailer designed first was wide, and the rear wheels existed on both right and left side. However, it was recognized that the bicycle inclined by the difference of the height of footway and roadway; this was considered to be an external constraint. In addition, “a lot of luggage might be loaded only when returning from shopping” was found as an external constraint.

From this case, the following facts were observed: the state of things is examined based on the first external restriction, and visualized while simultaneously addressing the contradictions among internal constraints by editing them. External constraints are added and edited by the process of evaluating visualized design objects. As for this process, the validity of this model was suggested because it roughly agreed with the model.

8 Conclusion

In this paper, a thinking process model based on the perspective of editing constraints was described for the early stage of a design activity. It was described that constraints were not fixed, could be edited, and could also be added to improve the design. In addition, the process where external constraints and three kinds of internal constraints were repeatedly edited was modeled. This model was validated using the case of a bicycle design activity. The results show that it was able to explain the thinking process of the case.

However, there are certain limitations. The explanation of the additional process of external constraints requires further research. It is necessary to clarify the method of discerning the insufficiency of external constraints and the selection appropriate constraints. In addition, future research is scheduled to investigate the similarity and the difference between this approach and affordance-based design [18] to refine this model.

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Audience, Participant and Agency: Need for Role Definition in Interactive Visual Narratives

Krishna Kumar Radhakrishnan and Ravi Poovaiah

Abstract In this paper we look at the role and a new definition for audience, participants and agency that can be used for analysis of Interactive Visual Narratives (IVNs). The definition of characters or actors from the semiotic elements of narrative studies cannot be directly used to investigate IVNs because, as interactivity comes to play, the actor could be the participant in the narrative or the agency that forms that constraints. Similarly, role of audience and author of the narrative changes based on the level of interactivity provided. In order to support our preceding premise, our analysis begins by looking at the influencing disciplines and building a conceptual model of digital agents that can play the role of actors in an IVN. Having looked at the role of actors and action in IVNs, we ensue our discussion on influencing applications and sample IVNs where the actors, their environments and the plot comes into play. We draw from the various examples examined to summarize the different approaches towards providing interactivity; narrative structure based on nodes and a simulation or an open-ended virtual world that contains procedure based narrative elements. We also try to distinguish the interactivity available at various levels and take a critical look at the role of author and participant. In conclusion we arrive at a new definition of Audience, Participant and Agency suitable to carry out investigation of the IVNs.

Keywords Interactive visual narratives · IVN · User role · Agency · Interactive storytelling

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1 Introduction to Interactive Visual Narratives (INVs)

The latest advancements in technology provides us with paradigms and methods that facilitate new interaction possibilities. It offers a platform for exchanging information and telling stories, extending the boundaries of social interaction.

Interactive Visual Narratives (IVNs) [1] are environments created to communicate ideas and information in the form of stories. The goal here is to design a visually and cognitively engaging experience that maps to the user's mental model. Thus by virtue of communication and experience design, it falls in the domain of Design.

IVN is a field that benefited from many fields like Human-Computer Interaction (HCI), the gaming industry, Artificial Intelligence (AI), Virtual Reality (VR) and Augmented Reality (AR). These fields have helped authors' model artifacts that the user can interact with facilitating the progression of the story. The technical solutions like UI patterns however fail to capture the factors that influence ones understanding of causation, its representation and other elements of narrativity which can bring about engaging interactions. Thus a systematic research into IVNs from a narrative (communication design) perspective is imperative to understand different modes and its functions.

In this paper we look at different streams of IVNs where the actors, their environments and the plot comes into play, to understand the broader approaches to IVNs. We also look at existing models used for analysis, to get a clearer understanding of role definition used by them and finally we put forth our proposal based on the observations.

2 IVN Environments

To understand the roles involved in an IVN environment we analyze (1) Façade [2, 3], art-E-fact [4, 5] and Scenejo [6] which are Interactive Digital Storytelling experiments, (2) Mass Effect 2[1] a Role Playing (Computer) Game, (3) SimCity[2] and The Sims[3] which are simulations and (4) Geist [7] which is a walkthrough.

[1]Mass Effect 2 is a sequel to the original Mass Effect. It was developed by BioWare and published by Electronic Arts. It was released on 26th January 2010 for Microsoft Windows and Xbox 360, and on 18th January, 2011 for PlayStation 3.

[2]SimCity designed by Will Wright was released on 3rd October 1989. It was produced by Maxis a subsidiary of Electronic Arts (EA). The SimCity source code was released under the free software GPL 3 license under the name Micropolis on 10th January 2008 (http://www.simcity.com).

[3]The Sims was designed by Will Wright and was released on 4th February 2000. It was developed by Maxis and published by Electronic Arts. In 2002, The Sims became the top-selling PC game in history and sold more than 6.3 million copies worldwide (http://thesims.com).

From the analysis we understand that as interactivity occurs at various levels, the users at times have to (1) navigate through a predefined narrative structure or (2) in some cases author the narrative development through their interactions.

3 Approaches Towards Creating Interactive Visual Narratives

There have been two broad approaches towards creating IVNs, (1) narrative structure based on nodes and (2) a simulation or an open-ended virtual world that contains procedure based elements.

(1) **Narrative structure based on nodes**. These structures appear as graphs, networks or flowcharts. The nodes have information such as a particular plot, event, information regarding the characters, or a discrete location in the environment. The nodes are connected by paths or links to a small set of other nodes. The player traverses though the network of nodes and the resultant sequence spawns the narrative experience. The complexity and interconnectedness of the nodal network defines the limit and coherence of the narrative. It could vary from a limited node, coherent narrative to a complex fragmented, cyclic or never-ending narratives. The responsibility of providing numerous options within the narrative that can engage the user for a long time and yet have a coherent narrative lies with the author.

(2) **A simulation or an open-ended virtual world**. This contains procedure based elements such as objects, environments and autonomous computer based agents called Non Player Characters (NPCs). Each element maintains its state based on a rule set or procedure that defines its behavior on how it can act or react to other elements in the virtual world. Simulations do not have a predefined narrative structure. The narrative possibility lies in the way the objects, non-player characters and players interact based on their action and reaction capabilities. The player has a high degree of freedom of expression and options for intervention that is not possible in a narrative graph structure. The agent based conversation can take the shape of Emergent Conversations [8]. Based on the closeness of the sequence of events, the players may perceive narrative experiences. A player who has experienced a sequence of events over time, which under normal circumstances may not be interpreted as a narrative; due to the closeness of the sequence of events may be regarded as Emergent Narratives [3]. As Pearce [9] rightly points out, "The role of the "author" in this context is, rather than creating content, is to create context." (8)

While the traditional role definitions used in narratology can be used for narrative structure based IVNs, Emergent Narratives, where the player influences the narrative and becomes the coauthor of the narrative, needs a new model for analysis.

4 Models for Interactive Visual Narratives

Several models of INVs have been suggested. We analyze (1) Conceptual Models for Storytelling and Agency, (2) PING (Passive-Interactive Narrative-Game) model, (3) Mapping of Interactive Digital Narratives, (4) Multiple Dichotomies and (5) N-Dimensional Diagrams where interactivity between users and the system is explored further.

Spierling [8] has proposed four distinguishable levels with the intention of adding interactions to form a classification. The terminology makes it ambiguous as to who has the control and autonomy; is it the author or the participant? From the examples given about The Sims, where the participants are the ones who create the stories, we can derive that if the slider is to the extreme right then the participant has full control at each levels. To investigate the participants' classification of their understanding of the concept of Aporia, Passive v/s Interactivity of the participant forms one of the axis in the PING model [10]. In Stephane Bura's mapping of (Interactive Digital Narratives) IDN [11], exploration of the story and the system v/s direct or indirect control is used as the axis to map IDNs, where direct control refers to user control and indirect control maps to system control. Multiple Dichotomies [12] map Author's control vs. Audience's/Player's control as one of the dichotomies to determine the amount of control and power that the author has and how much the audience can contribute to the final instantiation of the narrative. N-Dimensional Diagrams [12] uses Agency—the variety of actions that a user can undertake, Dramatic agency—the degree of influence the user has on the course of the narrative and Narrative complexity as the three axis to map IDNs.

Looking at the models, it is imperative that we have a formal role definition and common terminology that can be used for analysis of IVNs.

5 Role Definitions

Let us now examine the various terms that we have come across to define the roles of the person who is interacting with the narrative.

Lindley remodels Pohjola's definition [13] of Dramatist and Immersionist into three attitudes towards narratives within a game:

The audience, is a passive receptor of a narrative. This model is inherent to the use of predefined cut scenes in computer games that convey the game plot. This can also be extended to any moves for reading the in-game narrative material, such as virtual books presenting game scenarios and fictional game world history material, and conversations with Non-Player Characters (NPCs or virtual characters).

We adopt the term **audience** to represent the user during those sections of the narrative where they are just passive receptors and does not have any interactivity capabilities.

The performer, is the one who does the active performance of a character role within an unfolding story. This could be based on selection of a particular character or a race (human, elves, dwarfs, etc.). The immersionist role happens when the player-character distinction is dissolved into a unified persona within the game world. This state is achieved when the player is allowed to personalize the character that they can relate to and may require a long presence within the game environment by the player. Most role playing games try to achieve this state of immersion.

We are more inclined towards the use of a role independent terminology of the person within the interactive narrative timeline. A **participant** is such a term that can encompass the two separate roles mentioned above and henceforth we would be using this to explain the role of the person interacting with other characters in the narrative and in some cases co-creating the narrative.

Aarseth, in Narrative Theory of Games [14] refers to characters as the most important element, after universe. The game Agents/Characters is classified in terms of their depth/shallowness, and their malleability or potential for player control as: Bots, Shallow characters or Flat characters who stays the same no matter what happens to them and Deep characters or Round characters who change and develop as the story progresses [15]. The same game can contain a mix of these categories. The level of malleability determines the authorial affordance of the game. The richness of character is an important authorial tool that characterizes the positive potential of authorship in games, where malleability and user control limit authorial affordances.

The definition of characters is based on its involvement in the progression of the narrative. Bots and Shallow characters closely maps to the Agency character where they are passive roles or has less influence over the narrative. Deep characters could either be an agency character in cases where AI controls their progression or player characters who can influence the course of the narrative.

In traditional narratives the role of a narrator, who in most cases would be the author, was unambiguous. They are the ones who decides the narrative progression. When it comes to interactive narrative the author's role is sometime taken over by the participant who is at times the co-author of the narrative.

There still exists the role of an author who sets the platform for the participant to interact with the narrative. Agent is a commonly used term for this role. Laurel [16] uses the Aristotelian definition of an agent as the one who initiates and performs actions. Crawford [17] defines Agency as the one that 'listens', 'thinks' over suitable reactions and 'talks' to the audience. Murray [18] also uses the same term, Agency, defined as the satisfying power to take meaningful action and see the results of our own decisions and choices. To clarify that the agency is a rule set and not a physical manifestation Spierling [19] clarifies that engine could be another word for agents.

In interactive digital games, a player is able to influence a world, which in turn responds to her doings. By doing so she experiences the feeling of Agency, a feeling that one is in control of the situation, and can exert her will on the world to some extent [20].

Fig. 1 Actors in an IVN; agency characters and participant characters

In N-Dimensional Diagrams, Koenitz et al. [8] defines Agency as the variety of actions that a user can undertake, Dramatic Agency as the degree of influence the user has on the course of the narrative and Interactor's (user) Agency as the ability to alter the narrative development.

Agency being the commonly used term with a known set of role definition, we propose to use the same term in our thesis.

6 Conclusion

In conclusion we arrive at three roles that could be used to analyze and understand the structure of IVNs.

Audience—the state of the user when they are passive receptors of a narrative within IVN and have no or minimal interactive capabilities to alter the course of the narrative. This could be while they are looking at predefined cut scenes that convey the game plot or reception of any in-game narrative material.

A **participant** is a person interacting with other characters or actors in the story and in some sense co-creating the narrative. They have an active role in the progression of the narrative in an IVN. They could be the ones who determines the course of a narrative that has predefined structure or the one who alters the course in an emergent narrative. Participants could be one of the actors in the narrative or in its most active form be considered the author of the (emergent) narrative.

Agency sets the platform for the participant to interact with the narrative. For structured narratives, agency could play the role of the author who guides the users through the possible plot options. For emergent narratives agency could be setting the platform where narrative unfolds (Fig. 1).

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Thermo-Structural Design of Strut Based Flame Holder for Scramjet Combustor

Anupam Purwar

Abstract Flame holders are critical for efficient combustion in scramjet engines. There are various flame holder concepts, among them strut is one of the most prominent ones. Strut based flame holders decelerate the supersonic flow, providing more time for fuel air mixing and combustion. Although, this exposes the strut to very high as well as spatially varying pressure and heat flux giving rise to high temperature and stress across its structure. Thus, its structural design becomes highly challenging and its thermo-structural behaviour needs to be investigated for a robust design. In this work, spatially varying pressure and heat flux have been estimated using computational fluid dynamics analysis, which are used as boundary conditions for subsequent thermo-structural analysis. Based on thermo-structural behavior of strut, a multi-layer material system consisting of ZrB_2-SiC and phenolic cork has been proposed to mitigate high temperature and stress. This novel multi-layer material system, effectively reduces the temperature and stress experienced by the strut's metallic interior to 910 K and 102 MPa respectively.

Keyword Flame holder · Strut · Computational fluid dynamics · Finite element method · Thermo-structural analysis · Design · Zirconium diboride · Phenolic cork

1 Introduction

Hypersonic flying vehicles are powered by scramjet engines which generate thrust by sustaining combustion in supersonic flow. Efficient combustion in supersonic flow requires flame holding measures; strut is one of the prominent flame holder under investigation for scramjet engines [1, 2]. Struts involve an intrusive fuel injection method which uniformly distributes and rapidly mixes the liquid fuel. It aids in flame stabilization by creating sufficiently large recirculation zone down-

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stream of the strut. Another advantage of strut based flame holder is the concentration of combustion in the core flow, avoiding heat release near the scramjet combustor walls. But, it has its own limitations like total pressure loss and increase in drag. This necessitates design of strut to minimize flow blockage which in turn puts constraints on its dimensions. Besides, it experiences very high thermo-structural loads as it stagnates the supersonic flow and directly experiences heat release due to combustion. Particularly, the thermal load is a dominant factor in strut design and has to be contained to avoid its erosion, oxidation and subsequent failure. Different researchers have proposed active cooling techniques to mitigate this [3, 4], but this increases complexity due to requirement of coolant pumping mechanism. Another research group, tested cooled struts made of Niobium super alloys but have reported erosion at the strut nose after 20 s of flow [5]. Hence, thermo-structurally safe design of strut is a challenge and continues to be an active area of research. In this perspective, a novel design of strut consisting of multi-layer material system has been proposed. The entire design process has been carried out for a strut mounted in generic scramjet engine, flying at Mach 7 for duration of 200 s at 30 km altitude.

2 Flame Holder Design

2.1 Design Objectives

The main goal of current work is structural design of a strut based flame holder for scramjet powered flights of durations up to 200 s. Following objectives have to be met through rigorous design:

1. Maximum principal stress in the ceramic layer and Von-Mises stress in the metal layer shall be limited in accordance with principal stress criterion and Von-Mises stress criterion respectively.
2. Temperature of strut shall be limited in accordance with maximum operational temperature of respective materials.
3. Interfacial shear stress at all the interfaces shall be limited in accordance with maximum shear stress criterion.
4. Strut material shall have low density as well as good resistance to ablation and oxidation.

2.2 Structural Sizing

The strut has been designed for a scramjet combustor, as shown in Fig. 1. Based on the principle of minimizing flow blockage, the width of strut base has been set to 14% of combustor width with a semi-angle of 4 degrees (nose radius of 2.5 mm).

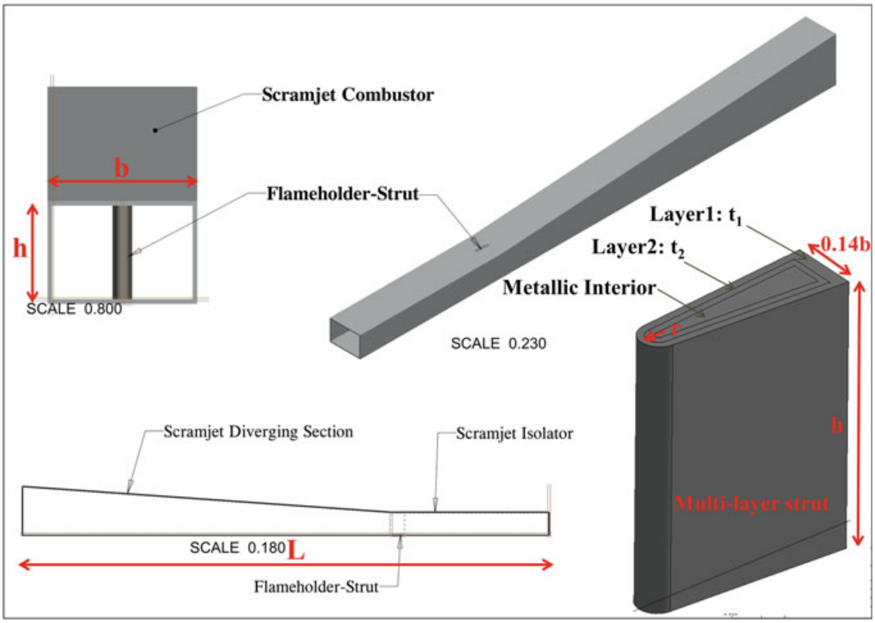

Fig. 1 Configuration of scramjet combustor along with strut

A bi-layer protection system for the metallic strut has been envisaged with outermost layer providing protection against ablation and oxidation, inner layer acting as a thermal barrier between metallic interior and outermost layer as well as contain interfacial shear stress. Accordingly, material selection for each layer has been done, followed by estimation of thickness of outermost layer t_1 and inner layer t_2. In first step, an initial thickness was provided to each layer and multiple coupled thermo-structural analyses were performed to find appropriate t_1 and t_2 values to meet the design objectives.

2.3 *Supersonic Flow Around Flame Holder*

The flame holder has been designed for a 2-D scramjet engine designed to operate at Mach 7 hypersonic flow at an altitude of 30 km. The scramjet has been designed with multi ramp air intake system, which converts the Mach 7 hypersonic flow into supersonic flow. This supersonic flow enters the scramjet combustor, exposing the strut based flame holder to high speed flow of Mach 2.52, as shown in Fig. 2. The supersonic flow decelerates around the strut creating subsonic regions at its rear, where liquid kerosene fuel is injected. The scramjet engine is designed to operate at fuel equivalence ratio of 0.65 [6]. The release of heat due to kerosene combustion along with the flow stagnation exposes the strut to heat flux as high as 5.85 MW/m^2.

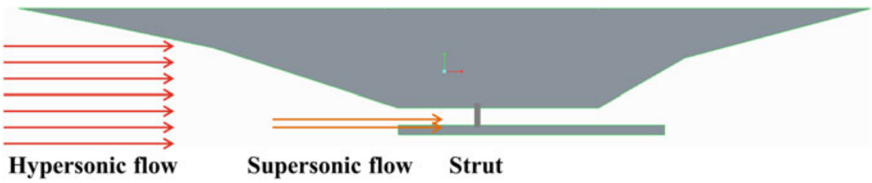

Fig. 2 Scramjet configuration depicting its air intake and supersonic flow experienced by strut

3 Computational Model Formulation

Computational modeling of the fluid flow and structural domain has been done, as shown in Fig. 3. Fluid flow around the structural domain has been simulated by performing Computational fluid dynamics (CFD) analysis. This provides estimate of heat flux and pressure experienced by the strut, which is then mapped to its structural domain. Temporal variation of strut temperature is then estimated by performing transient thermal analysis. The temperature at the end of 200 s of transient heating along with additional displacement boundary conditions are used to perform Finite element method (FEM) based thermal-structural analysis.

3.1 Computational Fluid Dynamics Modeling

CFD modeling has been done using ANSYS Fluent. Semi-structured grid for fluid domain has been generated using ANSYS. Density based solver has been used to account for compressible effects which become significant for supersonic flow. Boundary layer has been captured by providing multiple layers of refined mesh around the strut (solid domain), as shown in Fig. 4. Spallart-Almaras turbulence model has been used, as it has demonstrated to give good results for supersonic

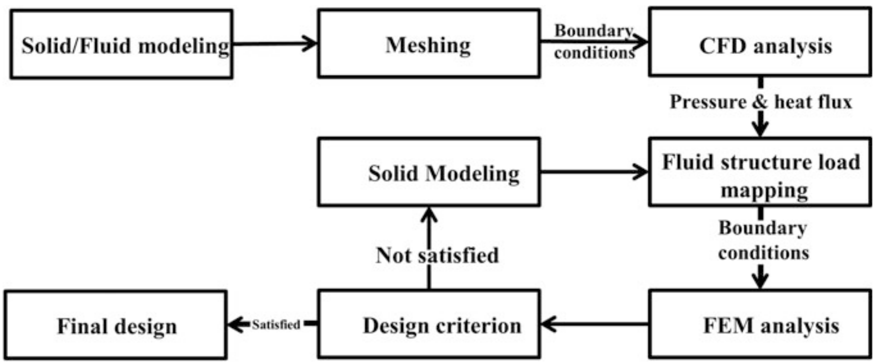

Fig. 3 Computation modeling and design loop

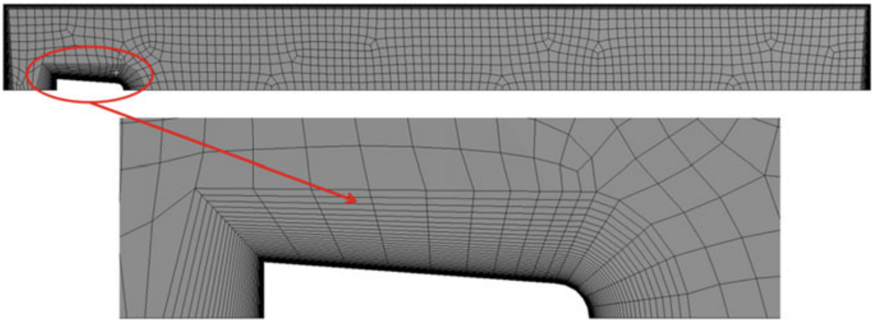

Fig. 4 3-D mesh with refined boundary layer around the solid domain of strut for CFD analysis

Table 1 Heat flux and pressure estimated by CFD analysis as a function of wall temperature

Wall temperature (K)	Maximum heat flux (MW/m^2)	Pressure (kPa)	Maximum heat flux in literature [9] (MW/m^2)
300	5.84	908	5.52
600	4.74	914	4.55
900	3.67	921	3.57
1200	2.67	941	2.60
1500	1.56	961	1.62

flow [7, 8]. Steady state solutions have been calculated with absolute convergence criterion, till residuals have dropped to the order of $1e^{-4}$. CFD analysis has been carried out with different wall temperatures to calculate heat flux and pressure as function of wall temperature (refer Table 1). This ensures that heat flux values change in accordance with change in wall temperature of solid domain, essentially ensuring realistic temperature estimation. A comparison of computed heat flux values with the reported heat flux values [9] shows a maximum variation of 6% (refer Table 1).

3.2 *Finite Element Model*

The thermal-structural analysis has been carried out by using the commercial Finite element (FE) package ANSYS, which has been previously used by other researchers for similar analysis [10–12]. The 3D mesh of the strut assembly model is presented in Fig. 5. Refined mesh has been generated around the strut nose (radius = 2.5 mm) to accurately estimate temperature and strain. Similarly, multiple elements have been placed along the thickness direction to capture the temperature variation across difference material interfaces. Second order elements with mid-side nodes, SOLID90 "3D 20-node thermal solid" and SOLID 186 "3D 20-node structural solid" have been used to discretize the structural domain. The mesh

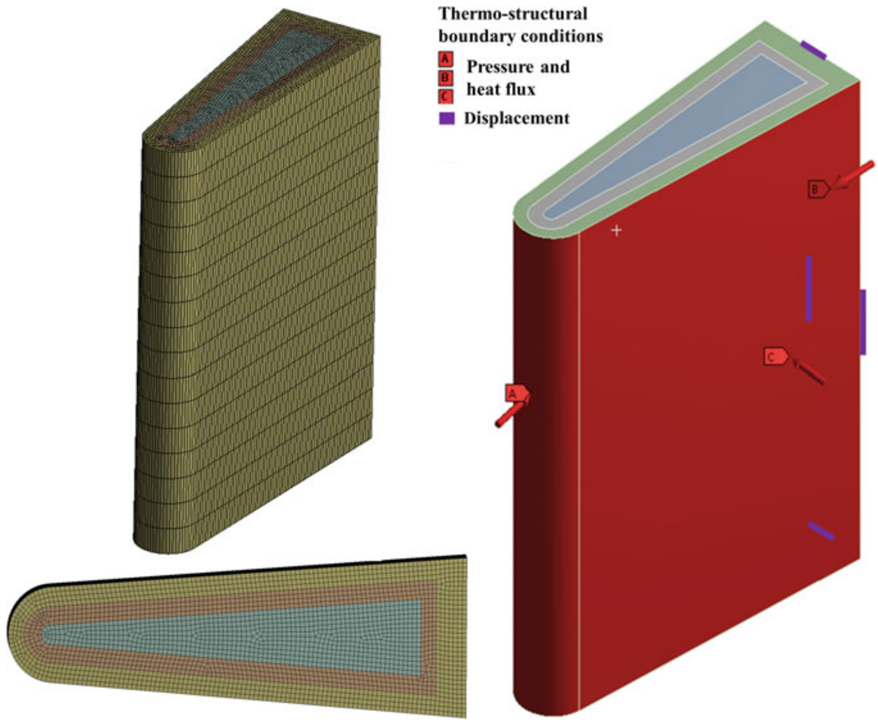

Fig. 5 Strut based flame-holder design: Strut finite element mesh depicting multiple elements along thickness (*left*) and thermo-structural boundary conditions viz. spatially varying pressure heat flux and displacement boundary constraints applied on strut external surface (*right*)

density has been selected after suitable convergence studies. CONTA174 "3D 8-node surface to-surface contact" elements have been used to model the contact between different strut layers. Following boundary conditions have been used to perform FE analysis:

1. Wall temperature dependent transient thermal heat flux, simulating the flight condition, calculated from CFD analysis, has been applied on the strut external surface;
2. Radiation to supersonic flow at 780 K has been applied on strut external surface;
3. The initial temperature of the model, namely the temperature at the beginning of scramjet operation, has been presumed to be equal to 300 K;
4. Contacts at interface of different strut layers have been considered as perfect, that is, all interfaces across the strut layers have been model as bonded contact.
5. Air has been considered as ideal gas for CFD analysis with constant specific heat capacity, which serves as a conservative measure for heat flux estimation.
6. Temperature dependent material properties have been used for ZrB_2-SiC and Haynes alloy, whereas room temperature properties have been used for phenolic cork.

3.3 Finite Element Modeling: Coupled Thermo-Structural Analysis

FEM modeling has been done using ANSYS Mechanical. Structured grid with second order elements for higher accuracy has been generated using Altair HyperMesh to discretize the solid domain. After discretization, wall temperature dependent pressure and heat flux calculated from CFD analysis, have been mapped from fluid to structural domain. Transient thermal analysis is performed to estimate nodal temperature of structure. Then, the nodal temperatures are mapped from thermal to structural domain. This is followed by coupled thermo-structural analysis, which involves solving Eq. 1 to calculate stress and strain.

$$\begin{bmatrix} \mathrm{M} & 0 \\ 0 & 0 \end{bmatrix} \begin{Bmatrix} \ddot{u} \\ \ddot{T} \end{Bmatrix} + \begin{bmatrix} \mathrm{C} & 0 \\ 0 & \mathrm{C^t} \end{bmatrix} \begin{Bmatrix} \dot{u} \\ \dot{T} \end{Bmatrix} + \begin{bmatrix} \mathrm{K} & 0 \\ 0 & \mathrm{K^t} \end{bmatrix} \begin{Bmatrix} u \\ T \end{Bmatrix} = \begin{Bmatrix} f + f^{th} \\ q \end{Bmatrix} \quad (1)$$

In above equation, [M] = element mass matrix, [C] = element structural damping matrix, [K] = element stiffness matrix, {f} = sum of element nodal force and pressure, {f^{th}} = thermal strain force vector, [C^t] = element specific heat capacity matrix, [K^t] = element thermal conductivity matrix, {T} = temperature vector, {q} = sum of element heat generation load and convection surface heat flux, and [u] = displacement vector.

4 Material Selection

Preliminary investigation was carried out by exposing metallic strut to heat fluxes estimated using CFD analysis. It was found that the temperature levels exceed the maximum working temperature of most metals. In this perspective, materials with high operational temperature need to be investigated. ZrB_2-SiC based ultrahigh temperature ceramic (UHTC) has been selected as material for first layer as it has superior mechanical properties, resistance to oxidation and ablation at high temperature [13–15]. Although, it has a thermal conductivity of 50–60 W/m-K [16]. This can expose the metallic strut interior to high temperature, hence an intermediate insulation layer is necessary to protect the metal. Many low conductivity ceramics including Lanthanum Zirconate, Gadolinium Zirconate, Zirconia, YSZ, Aluminum oxide, Mullite, Silicon carbide, Titanium dioxide, Thorium dioxide, Hafnium dioxide and Cerium dioxide have been reported in literature [17–20]. Lanthanum Zirconate was investigated as the insulating material owing to one of the lowest thermal conductivity and high operational temperature. However, it was found that temperature of metallic interior crossed 1500 K limit after 15 s of operation. Hence, it was not found applicable. Another, potential material which can be used as insulator is phenolic cork owing to its very low thermal conductivity of 0.07 W/m-K. Besides, phenolic cork is process friendly, light weight, easily available and well proven [21, 22]. Hence, phenolic cork has been selected as the intermediate layer for the multi-layer protection system with ZrB_2-SiC as the outermost layer. Haynes-282 alloy has been selected as the strut metallic interior owing to its excellent creep strength in the temperature range of 649–927 °C. Besides it has good thermal stability, weldability and manufacturability [23, 24].

5 Results and Discussion

Coupled thermo-structural analysis of strut has been carried out by using heat flux, pressure and displacement boundary conditions, as shown in Fig. 5. Temperature dependent properties have been used for all the selected materials [16, 21–25]. Suitable t_1 and t_2 values (0.75 mm each) to meet design objectives have been estimated by performing multiple thermo-structural analyses. Thermo-structural integrity of proposed strut design with the selected materials and estimated thickness values has been analyzed in the following sections.

5.1 Transient Thermal Analysis

In first step, transient thermal analysis (200 s) is carried with heat flux values estimated earlier using CFD. These heat flux values have been further multiplied by 1.5 and then applied as wall heat flux to strut for a more conservative design. Besides, radiation to the supersonic flow at 780 K has been applied to outer surface of UHTC layer with emissivity 0.75.

5.2 Thermal-Structural Analysis

Coupled thermal-structural analysis has been performed using ANSYS based FEM solver to calculate the stresses. Maximum deformation and maximum temperature of 0.48 mm and 1945 K has been estimated at the nose of strut respectively, as shown in Fig. 6. Maximum stress regions (principal stress = 166 MPa) have developed towards the rear face of UHTC layer, where displacement constraints have been applied. Factor of safety (FOS) for each layer has been calculated using Eq. 2.

$$\text{F.O.S.} = \frac{(\text{Material strength})}{(\text{Maximum stress})} \tag{2}$$

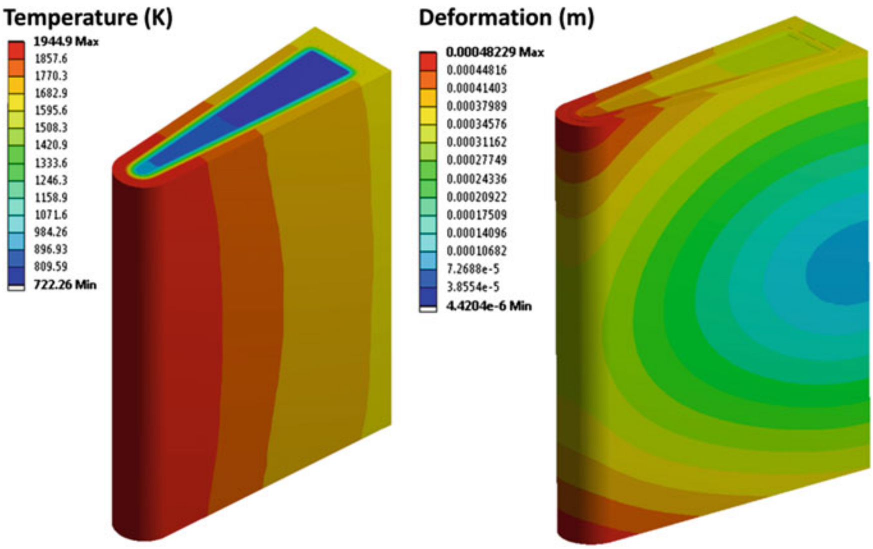

Fig. 6 Thermal-structural response for 200 s scramjet operation: Temperature (in Kelvin) (*left*) and Deformation (in metres) (*right*)

Table 2 Maximum temperature, stress experienced by UHTC, Phenolic cork and Haynes alloy

Layer	Maximum temperature (K)	Interfacial shear stress (MPa)	Maximum stress (MPa)	Thickness	Factor of safety
UHTC (ZrB_2-SiC)	1944	10.7 (UHTC-cork interface)	166 (Principal stress)	0.75 mm	1.31
Phenolic cork	1520		0.82 (Principal stress)	0.75 mm	1.82
Metallic interior	910	2.3 (metal-cork interface)	102 (Von-Mises)	4.8 mm (width)	7.64

The temperature and stress in each layer has been found to be well within material strength limits, as shown in Table 2. Thus, the bi-layer material system consisting of ZrB_2-SiC and phenolic cork with thickness of 0.75 mm each ensures structural integrity, with factor of safety greater than 1 for all the material layers.

6 Conclusion and Further Work

Strut is one of the promising flame holder concepts for scramjet engines, but it has to endure extreme thermo-structural loads for extended durations. Metallic structures would fail under such severe conditions without a suitable protection system. This necessitates thermo-structural design of a protection system for metallic strut. In this perspective, a bi-layer protection system comprising of ZrB_2-SiC as outer layer and phenolic cork as intermediate layer has been proposed. First, spatially varying and wall temperature dependent thermo-structural loads have been estimated by performing rigorous CFD analysis. Then, these loads have been mapped to the strut structure. Multiple iterations of coupled thermal-structural analysis were carried out and it has been found that thickness of 0.75 mm for each layer can protect the strut for scramjet operation up to 200 s. In particular, ZrB_2-SiC based UHTC protects metal from ablation and oxidation, whereas phenolic cork provides thermal barrier to metallic interior of strut. The main novelty of proposed design is the simplicity of the two layer ZrB_2-SiC and phenolic cork combination, which effectively limits the temperature and stress experienced by metallic strut interior to 910 K and 102 MPa respectively without any requirement of cooling. In future, the fabrication and testing of this strut is planned to take place in the upcoming Supersonic Combustion Test Facility, IISc Bangalore.

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Blending Rapid Ethnography and Grounded Theory for Service Experience Design in Organizational Setting: Design of a Peer to Peer Social Micro-Lending Service

Pramod Khambete, Gurunath Sabnis and Amit Jain

Abstract Service design projects done in organizations face constraints of resource, time and budgets. We discuss the blend Rapid Ethnography and Grounded Theory for the research conducted for the service experience of Rang De (www.rangde.org), a social venture running a Peer to Peer Social Lending service. The breadth, depth and richness of research outcomes required to design developmental and social impact services are higher. The methodology made a significant difference in comprehending the complexity of the service ecosystem and provided deep insights into the contextual and experiential aspects of the service seekers. We identified rich, actionable directions for service design leveraging the interconnected, tangible and intangible value flows across the service ecosystem. The advantages of using a strong methodological foundation for conceptualizing and executing rapid ethnography to overcome organizational constraints while designing complex services were established. Further, it points to the potential of seamless integration of participatory research and design thinking as synergistic components of the methodology.

Keywords Service experience design · Rapid ethnography · Grounded theory · P2P lending · Social lending

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1 Introduction

Service experience design, whether for new innovative services or incremental, is based on the understanding of the state, context and experiential aspects of the service users situated within the service system operating in a social-technical environment [1, 2]. Human Centric Designers, including Service designers use ethnographic research methods to comprehend the service users, the environment and acquire empathy, at all times paying attention to the experience of the users in their context [3, 4]. However, mere procedural use of ethnography rarely leads to meaningful insights. Service Designers therefore adapt variety of methods, including ethnographic methods to their unique project context and objectives [3, 5–8]. Canonical ethnography poses challenges in garnering adequate resources and time in organizational context, which Rapid Ethnography (RA) aims to overcome [9, 10]. We present the adaptation of RA blended with Grounded Theory (GT), which led to rich insights for service design without sacrificing requisite rigour despite organizational constraints. Further, the application in a complex service experience design project gave confidence in the benefits of the approach and wider applicability.

2 Background

The research (and service design that followed) was done for Rang De (RD) (www.rangde.org), a not for profit social business working for livelihood creation for the poor people in India. Social businesses are driven by a social cause, rather than profit motive aspire to be a change agent in the society [11]. Microcredit at affordable interest rate, rather than charity, fosters dignity and self-reliance in the poor [11]. RD runs a Peer to Peer (P2P) affordable micro lending multi-sided service platform (operations depicted in Fig. 1). Their credo is: ethical conduct, trust and transparency.[1]

Multisided platforms facilitate two or more distinct sides affiliated to the platform (i.e. the intermediary organisation) to interact with each other without relinquishing control on the nature and terms interaction [12]. Platforms succeed and grow only by offering compelling value to customers on both sides [13]. RD's the value propositions were tangible (e.g. borrowers receiving low cost loans), intangible (e.g. SIs receiving gratification of contributing to the society) and experiential (e.g. borrower selection based on empathy). An obvious requirement for service

[1]Commercial P2P lending platforms (e.g. Lending Club (https://www.lendingclub.com/) and Prosper (https://www.prosper.com/)) have a different service model. As well, social P2P lending platforms such as Kiva (http://www.kiva.org/), myELEN (www.myelen.com) and Milaap (https://milaap.org/) might be following different models and objectives. Though there are similarities to Rang De there might be variations in the way they function.

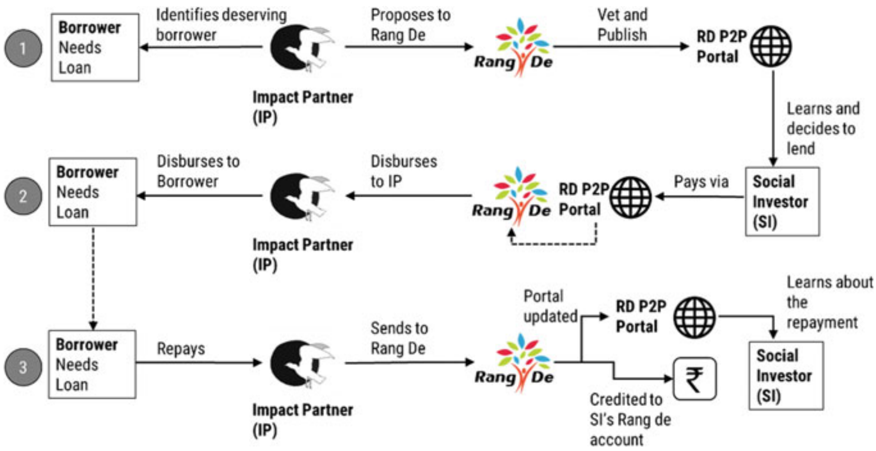

Fig. 1 How Rang De P2P Lending Works. *Stage 1* borrower identification and making their need known. *Stage 2* social investment and disbursal. *Stage 3* repayment and notifications

experience design was: no dilution of social impact goals and value system—trustworthiness and transparency.

Platforms encompass social interplay of people belonging to multiple networks [14]. The platform design should, therefore, be based on sound understanding of transactional flows of information, products and people. Understanding the dynamics of information and "product" (i.e. money) flows as well as intangible flows was critical for us. P2P interactions are affinity driven social interactions [15], i.e. they are influenced by the sense of kinship the selected person evokes. We can equate affinity with empathy. Empathy, and the decision to lend is influenced by an effective narrative ("identity claim") about the borrower which highlights trustworthiness, economic hardships, authentic need, and qualities like being hard-working and honest [16]. Though "identity claims" are unverifiable disclosures, they do influence positively the lending decisions [17]. However, providing visibility of RD's role as a trusted, transparent and ethical mediator and verifier was critical for the service design. As well, the platform's social features that allow influence to spread were important. It would be evident the service design for RD was challenging as it required to address the complex interplay of tangible and intangible elements. Manzini [18] advocated a "Social Innovation Design" strategy suitable for situation like RD predicated on comprehension of real problems, identification of the social resources that could be co-opted to solve them, creating organisational and economic structures, and building mechanisms to orchestrate and align a range of local contributions. Extensive literature study did not point to proven practices in service design of multisided platforms, though Osterwalder and Pigneur [19] recommend user centric design and design thinking, laying stress on high quality research. We decided that Ethnography was the ideal choice in spite of the anticipated organisational constraints to acquire deep insights into the attributes, nature, circumstances, contexts and environments of both the borrowers and Social Investors (SI), as well as the interconnections across the ecosystem.

The project was a part of the affiliated organisation's social responsibility initiative. Even though they were generous and aware of the project complexity, budgetary constraints on resources and time were unavoidable. We therefore adapted Rapid Ethnography blending with Grounded Theory to help in overcoming the limitations of the former, as well as to tackle the constraints, highlighted later. The objectives were:

a. Acquire comprehensive understanding of the platform, the service, the end service users (borrowers, Social Investors), as well as the socio-technical ecosystem in which the service operates
b. Extract actionable insights to inform Rang De's service design
c. Validate the understanding through conceptualisation of a component service

The knowledge as well as illustrative component service design was to be handed over to Rang De for comprehensive design. It was expected that in particular, the knowledge created pertaining to usefulness of the methodology would be transferable and useful in similar design problems and situations. As well it might present several additional insights to the researchers of Grounded Theory and Rapid Ethnography.

The theoretical or practice based knowledge for designing P2P Micro lending services, or even multisided platform services was scant. As such, we sensed the opportunity to create relevant design knowledge. Accordingly, we treated the project as a practical design project conducted within Research Through Design [20] or Research Through Practice[2] [21] paradigm. We were guided by Cross's [22] suggestions: ensuring purposiveness, being inquisitive, informed and methodical. As result, we safeguarded a strong, articulated methodology, meticulous collection and retention of data as well as disciplined interpretation.

3 Rapid Ethnography and Grounded Theory

3.1 Challenges with Applying Traditional Ethnography in the Project Context

We operated within several constraints alluded to previously. To highlight: limited number of associates with requisite skills, demands on their time and availability for business purposes, uninterrupted efforts they could devote to the project and allocated budget, with an added obligation to support unanticipated business demands. Traditional ethnography needs spending significant time in the field with communities

[2]"Research in which the professional and/or creative practices of art, design or architecture play an instrumental part in an inquiry [21]".

to be studied [23]. However, Rang De service encompassed multiple, geographically dispersed service users and Impact Partners (IP) across India. Therefore, "classical" immersive, long duration ethnography was not feasible. To be sure, this was not a novel situation. Ethnography conducted within corporate set up needs to adapt to several constraints [9]. Ethnographers have responded to the requisite fast pace and limited resources by resorting to Rapid Ethnography (RE), which uses alternate ways to collect data within limited time, without compromising the coverage and quality of data [10].

3.2 Adaptation of Rapid Ethnography (RE) Within Grounded Theory (GT) Framework

Despite trade-offs, RE can be utilized to leverage strengths of ethnography [9]. RE suggests using flavours of traditional field study methods to collect in a short duration adequate yet comprehensive understanding of the context of service users. To accomplish this, the research is scoped to encompass "essentials" and limited, appropriately selected set of key respondents are engaged with. It enables channelling the efforts to capture relevant and comprehensive data. Ethnography in organisational context for product enhancement or development requires a balancing act in at once broadening and narrowing the scope of the inquiry [24]. Another balance is to adopt the situated individual's perspective (cultural, social, economic …), and study the situated behaviours rather than overly focusing on the situation itself. The orientation is to use the knowledge for immediate application. Various techniques of RE are suggested, which include observation, interactive observation and open ended depth interviews/group discussions [10]. Dourish [25] observed that design professionals have appropriated the ethnographic tools and techniques, but tend to only "report" the data, often missing the reflective and interpretive ethos, and failing to draw up interrelationships among the observations. We concluded that using a theoretical framework based on reflective practice would enable us to overcome the pitfall. Goulding [26] noted that even though managers are more concerned with actionable outcomes, a theoretical framework to the research imparts credibility and appreciation of the value added. The pragmatic consideration of convincing the stakeholders of the value and utility of the outcomes was relevant too.

Grounded Theory (GT) [27], with origins in late 1960s, is a well-established methodology in several fields including in HCI and allied domains [28]. It is ideal for comprehending complex social situations. GT is a methodological framework, principles and practices rather than prescriptive steps of execution [29]. The insights are built progressively in cycles of data collection and interpretive analysis, with the insights from the previous cycles informing data collection in the next. The final set of refined insights emerge through a process of "constant comparison". No predetermined sample size is prescribed, but the studies are concluded once "theoretical saturation" is reached and no new insights emerge [30–32]. Charmaz [29] noted that ethnography and Grounded Theory complement each other well, enabling ethnographers to build better conceptual understanding of the phenomenon being studied. Due to their compatibility together they can provide organizations a detailed understanding of customers' experiences [33]. Researchers often integrate GT principles and practices with those of other qualitative methodologies to afford order and structure to the analytic process [34]. This approach suited our context, providing a framework to maintain rigour.

3.3 Execution of the Methodology

We needed to take into account the multiple perspectives that influence RD services. Accordingly, the participants were: Rang De team, borrowers, Social Investors and Impact Partners. We tried to cover as wide a spectrum as possible e.g. borrowers from urban settings and rural settings.

In line with the GT-RE blend the field study and analysis ("A" in the figure) progressed concurrently (Fig. 2). Acquiring insights that will help in designing services that bridge the evident gulf between the borrowers' and the social investor's socio-cultural-economic world was a key requirement.

It was likely that a subset of the research team would participate in a cycle, we attempted as far as possible to match the team combination in terms skills, expertise and background to the needs of each cycle. e.g. we ensured that the team that collected data in slums of Pusad, a small town in the heart of rural Maharashtra included a woman associate, and members who had familiarity with the "small town" social setting. Creation of shared, communicative artefacts for use in design with as less reductionist methods, is essential in ethnography done in corporate contexts [35]. We took special effort to maintain the richness and details of the

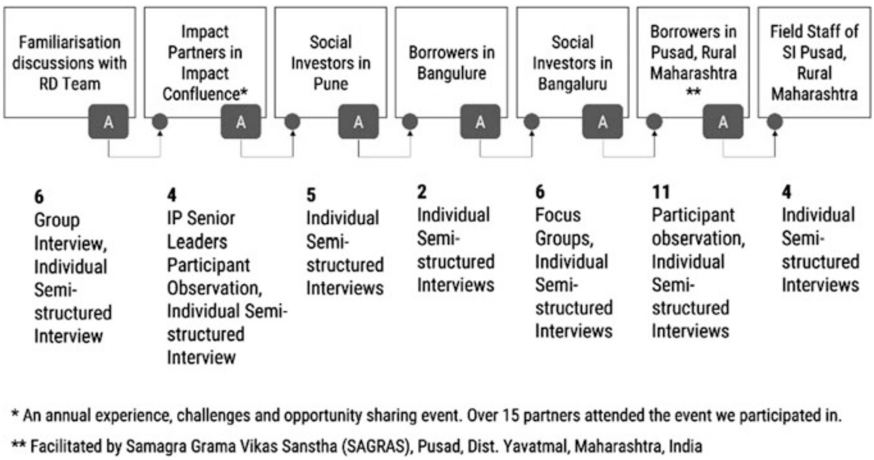

Fig. 2 The methods, participants and their numbers in the data collection and analysis cycles

recorded observations. Comprehensive, meticulous records were kept using multiple media and individual field notes e.g. annotated photographs, videography, photography and field notes which complemented others in order to eliminate gaps. They were digitized for easy sharing. As can be seen in Fig. 2 a range of data collection techniques were used best suited to the context. Though purposive sampling was used, the participants were sufficiently representative. However, no participant was selected beforehand. The selection specific individuals at each field location was done to build on the emergent understanding of the issues. We had to assume the likely sample size for planning purpose. However, we adhered to the GT principle of "theoretical sampling" and concluded on reaching the "theoretical saturation". In case of Rang De and Impact Partners, people associated with all key aspects of the service (e.g. those who interact with the borrowers and social investors, finance, technology and operations teams as well).

We recognised after introductory interactions with Rang De the possibility of incorporating the ethos and elements of Participatory Research. Participatory Research values active engagement of the stakeholders who will be affected by the outcomes in the research process [36]. It leverages the knowledge, expertise, and resources of the stakeholders. However, success is predicated on mutual respect, agreement on the goals, collaboration, and effectively weaving research and stakeholder education [37]. Accordingly, though not part of our original methodology framework, we involved RD team selectively in the data collection and analysis process. The involvement of the stakeholders in data analysis sessions enabled us to integrate *emic* and *etic* viewpoints, which offers advantages like mutual stimulation, comprehensiveness in analysis and richness [38].

In all, the blend of these compatible methodologies helped in rigorous, comprehensive, well-triangulated data collection and analysis.

4 Analysis, Interpretation and the Actionable Insights

The analysis happened progressively in cycles (Fig. 2) and was refined through constant comparison and juxtaposition of insights. The analysis was done by individual researcher, collectively as well as jointly with the Rang De team. Considering the objective of the project (e.g. service design) and available time, a group process was followed to synthesise the insight. We present some of the findings.

P2P social lenders have altruistic motivations and resort to pro-social behaviour such as helping others, being compassionate, honest and reliable [39]. They expect reciprocal behaviour from the borrowers, and we might infer, from the platform service provider as well. Similar motivations and behaviours were observed in our study. Current RD services and communications do exhibit reciprocity to an extent, but we uncovered opportunities to enhance service design (e.g. interactive impact reports that have an element of reciprocity, live streaming of field visits by RD associates) and offer new services. Investors in crowdfunded ventures who support social causes beyond monetary contributions actualise the human needs of fulfilment and belonging to the community [40]. Accordingly, three design principles for the crowdfunding platforms are suggested: enable resource exchange, facilitate community formation and sustain it, and operate transparently. Our study as well revealed the desire of SIs to contribute beyond investment. RD services do have such features (e.g. chapter formation, encouraging investors to create campaigns), though they appeared to be "passive" enablers. We believed services designed for active engagement of social investors in "contributing beyond money" was a fertile possibility. As mentioned later, design of one such service is in progress.

Use of ethnography in design is expected to generate directed recommendations not only for product improvement but to aid in group decision making [24]. We were able to identify several behavioural and systemic insights which could inform service design and strategic decisions to engage with the stakeholders. We highlight some of them.

4.1 Experience Design Themes

We adapted the powerful construct "core concept" form GT, i.e. a defining characteristic of the phenomenon under study, as Experience Design Themes. At the end of the final analysis we identified two service experience design themes. They were: Evident Trust and Transparency, and Sustained Empathy Driven Collaborative Engagement among all stakeholders. There was an agreement among the stakeholders that these themes do represent the defining attribute of RD services and must serve as quality and appropriateness benchmarks for the service design outcomes.

4.2 Empathy and Trust Flows

A representation termed ERAF System Diagram (Entity, Relationships, Attributes and Flows) can help in better comprehension of the system characteristics and help in design [41]. The notion of "service" flows appeared incongruous in Service design context. We had identified during the analysis that empathy ("Looking at the photograph, I can see RD loan can change her life. I should support her.") and trust ("I implicitly trust Rang De. I know they vet the borrowers and partners thoroughly.") were critical, and these flows must be mapped. We accordingly focused on money, information, empathy and trust flows across Rang De's Service Ecosystem Diagram. Further, empathy and trust flows depend on the transitive property of the linkages (e.g. Borrower > Field Partner > Rang De > Social Investor) among the nodes where degradation could occur (e.g. the evocative empathy generating narratives about the borrowers originate in the field and are transmitted to the SIs through several intermediate humans, technology and media). For RD, retaining the fidelity of the original without degradation during the flow became be a key service design objective.

4.3 SI Behavioural Typology and Engagement Journey

It was clear from the initial data collected in interviews with the RD team that there are significant variations in the SI behaviours. For instance, some SIs invest very regularly, some do it only once and never return, and so on. We probed this aspect in the sessions with the SIs, and uncovered four distinct patterns of behaviour and engagement with Rang De: Committed—growing, Committed—plateauing, Convinced—tapering and Impulse driven. Clearly, the service design to ensure sustained engagement for each behaviour type would have to be different. E.g. The keenness expressed by committed types to contribute more than just giving money could be leveraged (see Conclusion). One of the significant finding was the "chasm" between being convinced to making the first investment, which could be as long as a couple of years. Clearly an issue that must to be handled in the service design.

There were certain specific findings as well. For instance:

- Emotional gratification ("I am doing something good for the society"), rather than monetary gains was the primary motivation
- Initial investments were done typically to their home states
- The needy from North-East India and education loans were top choices

Some negative issues, mainly concerning the portal design, were uncovered as well. For instance, there were adverse views about the investment data presentation and terminology, searchability and presentation of borrower details (which would have direct bearing on the empathy it can evoke). The partners expressed certain operational efficiency concerns (e.g. lead time from borrower identification to loan disbursal). Hearteningly for Rang De, there were virtually no significant negative perceptions about Rang De. On the contrary, they enjoyed immense goodwill and trust among the borrowers, Social Investors and Impact Partners.

All the insights cannot be presented here. However, they appeared foundational, and when taken into account had the potential to significantly transform the service experience. The Rang De team concurred with this. We believe the blend of GT and RE was considerably advantageous to arrive at rich, comprehensive and actionable insights.

5 Advantages of the Blend of Rapid Ethnography and Grounded Theory

The blend enabled disciplined and progressive build-up of multiple perspectives drawn from the key stakeholders SI, Borrower, IP and RD team. Further we could integrate and make better sense of two or more perspectives (e.g. RD had told us that several Social Investors want to participate actively beyond providing money, but the intensity of the keenness turned out to be surprisingly high). Since the scope of the study was kept malleable, we were able to continuously refine the aspects that called for close attention (e.g. when the "chasm" referred previously was spotted in the initial two interviews, we probed the reasons in the subsequent interactions). We as well continuously refined of the data sources as we our comprehension of the system evolved by planned or even opportunistic inclusion of new data sources (e.g. once the field team learnt of the legal structure the IPs used for inducting new borrowers, they requested a participant observation of a borrower assessment and group formation session). We were able us to use the available resources (people, time) effectively by refocusing the efforts and changing the mix. GT concepts like "axial coding" and "core category" (discussed previously) provided the discipline in analysis always seeking current and potential relationships among the insights (e.g. a joint analysis workshop with stakeholders uncovered new relationships among the entities comprising the service ecosystem, indicating potential service offerings).

As a collateral benefit the perceptible build-up of the rich insights provided a sense of progress boosting the enthusiasm. The team felt midway that the knowledge was adequate to confidently commence the service design conceptualization even as the research progressed concurrently. These effects can be of great importance to the design process, particularly for time bound project execution and need further study.

6 Means Used to Overcome the Challenges

We had two preliminary familiarizations, knowledge sharing and joint planning sessions with Rang De teams. As a result, excellent rapport and concurrence on several issues was established. Attending the Impact Confluence and spending time with the IPs teams in a semi-formal setting helped to build a relationship of trust with them as well. RD facilitated the interactions with SIs and IPs. However, due to the rapport and mutual understanding established previously they kept at arm's length unless invited to participate in the research process. This helped in reducing, if not eliminating the selection bias.

Particular attention was devoted to the practical aspects of the research. The research team was based in Pune in Western India, RD in Bangalore, South India and SAGRAS in Central India. Travel logistics arrangement and organisation of the sessions with the participants was done meticulously (including seemingly trivial details like identifying and reserving a venue convenient to SIs for the Focus Group). The team members' availability was planned well in advance and "negotiated" as needed to avoid disruption to their other business commitments. Similarly, it was ensured that the requisite participants were available for sessions with RD teams and impact partners.

The data collection and analysis spanned a period of three months, but it took place intermittently as the team had to handle their other business-related work as well. The use of knowledge artefacts created during the formal and informal discussions (e.g. digitised sketches, snaps of whiteboard discussions …) as well as the shared repository of the data collected in the field ensured continuity and coherence within the team despite the intermissions. The team had regular progress reviews and work planning meetings as well. Taken together, the work practices mentioned above contributed significantly to the quality of the outcomes.

7 Conclusion and Contributions

Rapid ethnography can produce excellent outcomes through teamwork, focus, regular and effective communication and overcoming the limitations imposed due to the available time [9]. This was not only validated, but in addition, the discipline imposed by grounded theory effectively and efficiently enabled us on all these aspects. The supportive strategy of digitising the rich data, central repository Internet accessible repository enabled us to maintain an unbroken thread in communication and involvement of team members who were not present during the data collection. Equally important, it provided traceability of the insights to the source during the analysis. This was critical as every researcher was not present in all data collection and analysis cycles. It as well enabled a productive mix of synchronous team work and asynchronous individual work (e.g. on one occasion an off-site team member analysed the digitally shared data and pointed to the widespread acceptance of mobile phones. The field team triangulated and validated the insight through additional data the next day). The disciplined flexibility of GT, theoretical sampling and theoretical saturation allowed leveraging "on the fly" new sources as data collection progressed by tuning the scope, refocusing or spreading the coverage. We believe the quality of the outcomes was significantly higher as a result. This is one of the significant advantage the blend provided as it reduced, if not removed altogether, the risk of incomplete pre-determined scope or misdirected attention based on faulty assumptions and perceived constraints.

The participation of RD team in several joint analysis sessions did demonstrate the advantages noted previously [38]. They added more data/insights (e.g. the research team had prepared the ecosystem map which was refined by RD team based on their knowledge, together we acquired deeper understanding of the issues in the service experience journeys of disbursement and collection). Another example: RD teams had emphasised the value of the embeddedness of the Impact Partners in the community. The research team was not convinced initially. However, after the experience in the field and direct interactions with the IPs, they not only appreciated the viewpoint, but were able to offer alternate complementary viewpoints about the role of the impact partners and implications on service design (e.g. opportunity to leverage their community embeddedness by automating certain tasks they do and instead utilise their time more for impact assessment). The rapport driven participatory analysis as well helped uncover each other's tacit and at times incorrect assumptions. Thus, apart from the blend of GT and Rapid Ethnography, even partial incorporation participatory research paid rich dividends.

There were several lessons from the way the project was executed. We highlight some of them. Establishing rapport with the stakeholders. (e.g. RD team, SAGRAS at Impact Confluence) at mutual convenience and more relaxed timeframes prior to commencement of the study not only helped in tuning the study but as well saved valuable time in the field. The careful selection of the team members helped in establishing rapport with the participants. The meticulous planning of the logistics led to efficient execution. While some of these are well known suggestions to conduct ethnography, our experience points to their criticality in Rapid Ethnography done in organisational setting.

The insights were used in the design phase which is in progress. Inclusion of the design concepts being worked on based on the outcomes is beyond the scope of this paper. Suffice it to say though that RD are satisfied at the outcomes which not only led to new insights but uncovered several tacitly held insights and assumptions. As such, they expect significant enhancement of their services and social impact. The design in progress, has led to several new service concepts (e.g. based on leveraging the SI's desire to contribute beyond money, and using their social ties). The research outcomes as well indicated several opportunities in enhancing the existing services and enabling greater empathy (e.g. possibility of including short videos as part of the borrower profile, video conferencing and live streaming to augment the reach of SI field visits currently organized by RD).

There appears to be sparse knowledge of human centric experience design of P2P lending services, and multi-platform platform services overall. These are emerging business models which would become common in the future. Rapid Ethnography and Grounded Theory blend seems to offer a sound and fruitful methodology to gain rich and comprehensive actionable insights to guide service design in general, and specifically that of Social Ventures which are likely to face complex socio-technical challenges. It as well appears to have the ingredients to allow seamless integration of compatible methods like participatory research to enhance the collective power. We confirmed the compatibility of GT and Ethnography identified in literature. In addition, we identified how the compatibility could be leveraged in complex service design projects carried out in organisational setting. In all we believe the outcomes of the research adds to the theory as well as offers relevant and useful guidance to service design practitioners.

8 Directions for Future Work

One of the limitations of this study, as in any single case, is that it pertains to one specific design setting (P2P Micro Lending Platform). The GT and RA blend seems a promising combination, and needs further studies to uncover additional advantages and pointers to practical application. An interesting line of investigation could be the integration of Grounded Theory, Rapid ethnography and Participatory Research. While it seems to have given excellent results in our project, the approach needs to be studied in a range of settings, which would reveal advantages and challenges in wide applicability. As mentioned previously, the design commenced midway as the research was in progress. Commencing design based on insufficient data is not uncommon. However, it might be worth exploring the psychological impact in having confidence in the incomplete date that we observed. As well, it could be interesting from a GT methodological perspective to examine whether and how design can be integrated in GT. The iterative process that both espouse, and design as a way of thinking comprising analysis-synthesis-evaluation seem compatible. GT analysis informed by designedly thinking seems an interesting and promising proposition both for theory development and practice.

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Part II
Human Factors in Design

Anatomically Shaped Tool Handles Designed for Power Grip

Dhananjay Singh Bisht and Mohammed Rajik Khan

Abstract The work proposes two different approaches to ergonomically design and evaluate tool handles considering optimal power grasp posture. The first investigation deals with the evaluation of handles of different shapes for fitness in hand, preferred subjective gripping experience and maximum hand-handle contact area. Initially 67 participants were utilized to determine optimal diameter for power gripped based cylindrical handles. On the basis of preferred optimal diameter, six handles of different shapes were developed. Based on a cluster analysis, a group of 17 participants were used to evaluate these handles through subjective responses and an image mapping technique. The second investigation involved the evaluation of an anatomically shaped handle for a kitchen paring knife. Five different commonly used knife handles and one anatomically shaped knife handle were evaluated by 27 participants using subjective comfort questionnaire.

Keywords Hand tools · Anatomically shaped tool handle · Comfort questionnaire for hand tools (CQH) · Point cloud digitized data

1 Introduction

Hand tools have been tremendously important to the human species in its progress to the technology advanced state of today. Hand tools are one of the most important product segments for any domestic, outdoor and industrial use. Ergonomic hand tools being more comfortable and usable are being produced today that can be used

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easily by different kinds of users. Do it yourself (DIY) trend has gained pace and many people, earlier less familiar to hand tools are now increasingly buying and using hand tools.

Researchers like Taylor et al. [1] and Kuijt-evers et al. [2] have conducted assessment of hand tools like screwdrivers in DIY shop. Similarly, Vergara et al. [3] employed users with experience in do-it-yourself (DIY) in their study on understanding perceptual constructs of interaction with hammer designs.

Poor design of hand tools can also lead to health problems. Researchers like Lipscomb et al. [4] have pointed at the extensive scale of occupational injuries among carpenters. Adoption of ergonomic principles helps in the design of tool handles with increased comfort and performance enhancement along with user safety. Paivinen et al. [5] found that tool design factors such as length of the handle and the blade's cutting ability/sharpness, affect subjective experience of the users with axes [6]. Presently, in the design process there have been a big paradigm shift from a use-centered model to a user-centered model. Research on design and evaluation of tools such as drywall sanding tools and screwdrivers by employing techniques such as user centered task analysis [7, 8], stakeholder mapping and user modeling [9] illustrates this fact. Anthropometry plays in important role in design and evaluation of hand tools. Many researchers have used anthropometric data for the design of hand tools and equipment for agriculture, screen textile printing, laparoscopic surgery, etc. [10–12].

Handle shape plays an important role in determining user comfort and tool usability. Various studies have been conducted to assess subjective preferences through subjective comfort questionnaires, physical responses, ratings of discomfort, acceptability of reaction forces, etc. [13–16] and objective physiological capabilities such as electromyography, static and dynamic contact pressure distribution, tool productivity, etc. [16–19].

The present work shows two different user centric approaches to design more comfortable power grip based tool handles. In Study I, six different handles based on optimal diameter selection have been fabricated and evaluated for comfort, fit to hand and greater hand-handle contact surface area. Subjective comfort evaluation has been performed on fabricated handle prototypes. An image mapping based objective evaluation has also been conducted to determine the optimal handle shape for best fit and comfort. In Study II, a kitchen paring knife with an anatomically shaped handle has been designed to evaluate its performance with five existing handle designs.

2 Design and Evaluation of Tool Handles

Two different methodologies for studying tool handle designs on the basis of user evaluation were adopted by the authors. In the first method, the relation of optimum grip diameter was utilized to determine optimal diameters using anthropometric data of the selected participants. Based on this reference size, six handles of different cross-sectional shapes were fabricated and compared to find the best handle shape. The second methodology focused on comparing the overall comfort in the use of an anatomically shaped kitchen paring knife handle against five existing designs.

2.1 Evaluation Study I: Optimal Handle Shape Determination

Sixty seven participants, mostly students from undergraduate and post graduate programs having soft hands with no cuts were chosen for this study. This group consisted of fifty eight males, age range of 20–33 years (median 22, mean 22.84, SD 2.65) and nine females, age range of 22–24 years (median 22, mean 22.33, SD 0.82). The experimental protocol was explained to the participants, and an informed consent for their participation prior to the study were provided. The first step was to collect relevant hand anthropometric data of the participants.

2.1.1 Anthropometry Measurement

The hand anthropometry parameters collected for this study were (a) hand length, (b) hand breadth without thumb (at metacarpals), (c) distal phalange length of the thumb, (d) distal phalange length of the middle finger, and (e) grip inside diameter. Anthropometry data was measured using a digital vernier calliper, a steel rule and a wooden cone fabricated specifically for measuring inner grip diameter. Relevant images from the anthropometric survey are provided in Fig. 1a. A generic relation of optimal handle diameter (D_{opt}) and maximum grip inner diameter (D_{grip}) were utilized to determine the optimum diameter of handle. The relation can be expressed as [20, 21],

$$D_{opt} = (D_{grip} \times \pi - \mathrm{C})/\pi \tag{1}$$

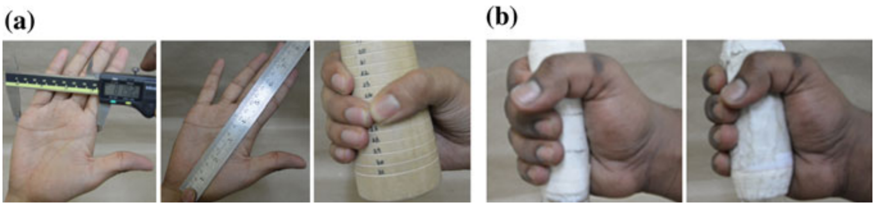

Fig. 1 **a** Anthropometric measurements using a digital vernier calliper, a steel rule and a wooden cone (*left* to *right*). **b** Prototypes for handles of diameters 35 and 41 mm (*left* to *right*)

where, C is a constant with a value of 10 mm. Again, optimum grip diameter is obtained using lengths of the distal phalanges of thumb and the middle finger using the following relation [22],

$$D_{opt} = (D_{grip} \times \pi - (L_{d,3} + L_{d,1})/2)/\pi \qquad (2)$$

where, $L_{d,3}$ is the length of distal phalange of digit 3 (middle finger) and $L_{d,1}$ is the length of distal phalange of digit 1 (thumb).

2.1.2 Comfort Assessment

Optimal handle dimension values were found using Eqs. (1) and (2) to calculate D_{opt} by utilizing the collected anthropometry data. Two different dimensions (35 and 41 mm) resulted for the optimum handle diameter, one from each equation. A cylindrical prototype of each dimension is fabricated (as shown in Fig. 1b) and then tested for fit and comfort. As the shape of the hand can be roughly defined by the length and breadth of the hand, the participants were grouped into three groups of relatively homogeneous hand shape by performing a hierarchical cluster analysis. Hand length and breadth is taken as input variables for cluster analysis. In order to reduce the number of participants (67; initially selected), one of these groups with seventeen participants were selected to participate in the next phase of study.

A subjective study was conducted to compare the two cylindrical handle prototypes (Fig. 1b). Each participant was asked to rate how well each of the two handles fit into their hands, and what was the overall comfort level in handling each of these handles. The rating scale for responses in each of these questions was 1–5 (1 being the worst rating and 5 being the best rating). On the basis of the optimal diameter of 35 mm preferred by most of the participants, six handles with different cross-sectional shapes were fabricated. The shapes used in this study were circular, triangular, pentagonal, hexagonal and two combinations of circular and triangular (Fig. 2). The size of those cross sectional shapes corresponds to a periphery enveloped by a circle of diameter equal to the preferred D_{opt}. Figure 3a shows the five different prototypes that were fabricated. Figure 3b shows two different hand grip orientations corresponding to the cross-sectional shapes of design V and VI of Fig. 2 respectively.

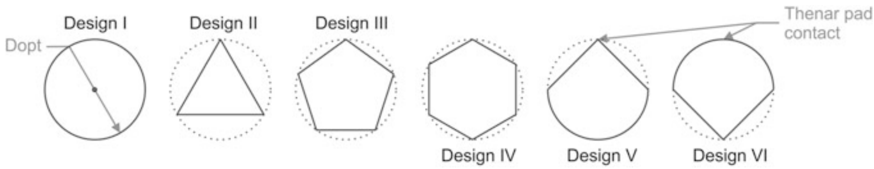

Fig. 2 Six different cross-sections used for comfort evaluation (Design I–VI) taking D_{opt} as the common peripheral circular dimension enveloping each shape

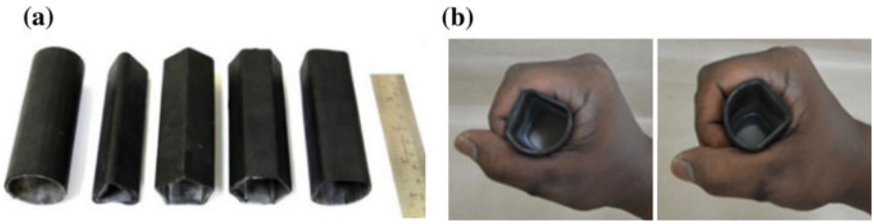

Fig. 3 **a** 3D prototypes of tool handles corresponding to chosen five cross-sections: Design I–V. **b** Hand grip orientations for Design V and VI of Fig. 2 (*left* to *right*)

Comfort evaluation was conducted in two stages. First, subjective responses were collected from the participants to determine their overall comfort with each of the six different handles. Second, an image mapping technique is adopted to determine the hand-handle surface contact area. Temporary water based paint was applied on the surface of each prototype and each participant was instructed to hold the prototype in a power grip position, with no grip adjustments. Each participant was then asked to put its hand on a white paper to create a hand print. This hand print provided an estimate of the extent of volar hand region that came in contact with the handle. An estimate of the area covered by paint was calculated by importing the scanned images of hand prints for pixel count in Adobe Photoshop. This pixel count data corresponded to the area of contact. Greater area of contact with the handle is a desirable quality for design of an ergonomic handle [13]. However, not every case of greater hand-handle contact area should qualify as an indicator of user comfort. For e.g., in case of a convoluted, hand-hugging handle, the contact area with hand might be high, but the complex geometry might impede any adjustments to hand grip during work. But, as none of the six configurations considered in this study was a complex one, the authors concluded that hand-handle contact area could safely be used as a determining factor for comfort in this study. Hence, the most favorable handle shape was determined on combining the results from the subjective comfort preference exercise and the surface contact area data evaluation.

2.1.3 Results and Discussion

Table 1 present comparative results of the subjective analysis test for fitness in hand and overall comfort conducted using in house fabricated optimum diameter handle prototypes. As can be inferred from the table, nine as against two subjects rated the 35 mm diameter handle to be an excellent fit in comparison to the 41 mm diameter handle. Also, ten subjects as against one rated the 35 mm diameter handle to be overall comfortable in comparison to the 41 mm diameter handle. It is also evident that none of the two handles was rated less than neutral by the subjects. So, considering the optimal diameter selection for cylindrical cross-section, among the selected diameters, 35 mm diameter handle provided better fit and was also rated more comfortable.

Table 1 Comparative results of the subjective analysis test for fitness in hand and overall comfort for handles with diameter 35 and 41 mm

Handle diameter	Subjective response data					
	Rating scale	5	4	3	2	1
35 mm/41 mm	Fitness in hand	Fits excellent	Fits good	Cannot say/Neutral	Fits bad	Fits extremely bad
	No. of subjects	**9**/2	**7**/3	**1**/11	**0**/0	**0**/0
	Overall comfort	Extremely comfortable	Moderately comfortable	Cannot say/neutral	Moderately uncomfortable	Extremely uncomfortable
	No. of subjects	**10**/1	**6**/15	**1**/1	**0**/0	**0**/0

Table 2 shows the combined and comparative result of comfort evaluation using our extensive subjective study and image mapping based objective assessment to measure maximum hand-handle surface contact. Equal weights for comfort score (A) and hand-handle surface contact area (B) were assigned to calculate normalized total score (NTS) for each of the handle designs. The mathematical relation for NTS is expressed as,

$$NTS_i = \left(\left(W_1 \cdot \frac{A_i}{A_{\max}}\right) + \left(W_2 \cdot \frac{B_i}{B_{\max}}\right)\right) \cdot 100 \quad (3)$$

where i is an index for handle design; W_1 and W_2 (0.5 each) represent the weights assigned to each of the factors A and B respectively.

Design VI, defined by a contour shape combination of semicircle and triangle, and gripped with the circular section towards the fingers was rated the overall highest by the participants. However, maximum area of hand surface contact with the handle was observed for design I, the circular contour. Triangular handle (design II) performed the poorest, both in terms of total subjective comfort and the hand-handle contact area.

2.2 *Evaluation Study II: Anatomically Shaped Knife Handle*

27 candidates, all students from undergraduate and post graduate programs having soft hands with no cuts were chosen for this study. This sample was composed of 11 female subjects in the age range of 21–22 years (median 22; mean 21.5; SD 0.49) and 16 male subjects in the age range of 20–23 years (median 22; mean 21.8; SD 0.85). Each subject has been given an informed consent for their participation prior to the study.

2.2.1 Prototype Development

Twenty different families were asked to send images/videos of preferred kitchen knife used at their homes. From this information, the most common hand grip posture was identified for kitchen paring knife operation (Fig. 4a). This posture was used to create impression on a clay handle stock mounted on the handle of a reference paring knife. A 35 mm diameter stock of clay was used for impression. This was found to be the preferred dimension during evaluation study I. The representative candidate from a fairly homogeneous group of twenty seven participants was asked to hold the clay handle in the most common knife holding position identified to create impression of the hand grip. Before releasing the clay stock, the candidate was asked to wiggle each finger a little bit in order to create some extra room around each finger.

Table 2 Comparative results of the analysis using subjective comfort evaluation and pixel count feature to calculate hand-handle surface contact area

Handle designs	Ratings by selected 17 candidates					Score (max 85) A	Hand- handle contact area for 17 subjects (in pixels) B	Normalized total score (Rank)
	Extremely uncomfortable (1)	Moderately uncomfortable (2)	Cannot say (3)	Moderately comfortable (4)	Extremely comfortable (5)			
Design I	0	0	1	15	1	68	182,879	93.59 (3)
Design II	3	12	0	1	1	36	120,924	56.14 (6)
Design III	0	2	10	5	0	54	161,126	78.67 (5)
Design IV	0	0	3	12	2	67	166,781	88.55 (4)
Design V	0	0	2	9	6	72	174,855	93.96 (2)
Design VI	0	0	0	7	10	78	178,445	98.79 (1)

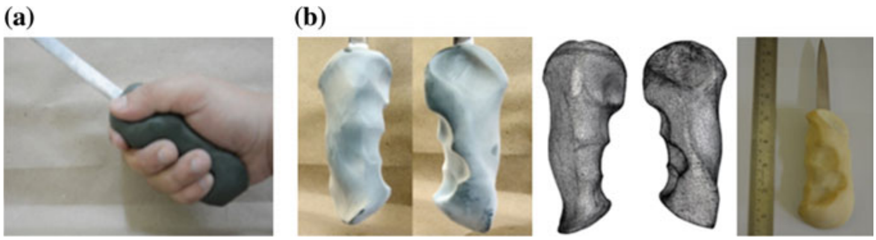

Fig. 4 **a** Most common hand grip posture when using kitchen paring knife. **b** Two different views of anatomically shaped handles over clay, corresponding digitized point cloud data and an ABS based 3D prototype with fitted blade (*left* to *right*)

The impression on the clay was scanned using 7-axis based Faro Arm laser scanner. The captured digitized point cloud data was converted to a surface mesh. The mesh was repaired and smoothened in CATIA V6 environment. The surface generated in CATIA is exported in the stereolithography file format and transferred to a RP system for prototype development. An ABS (Acrylonitrile butadiene styrene) based anatomical shaped handle prototype was fabricated using Stratasys Dimension 1200es RP system. Figure 4b shows two different views of the anatomically shaped handles developed using clay and corresponding digitized point cloud data and an ABS based 3D prototype via RP system fitted with a blade respectively. This handle was fitted with a blade and used for a comparative evaluation with five other designs of knives.

2.2.2 Comfort Assessment

Figure 5a shows the six different knife handles used for comfort evaluation. A comfort questionnaire for hand tools (CQH) with seventeen different questions (Table 3) was used for assessing these six knives. The questionnaire was synthesized from existing research in the field of hand tool comfort [1, 2]. Each of the twenty seven subjects were asked to first rate each comfort descriptors in terms of

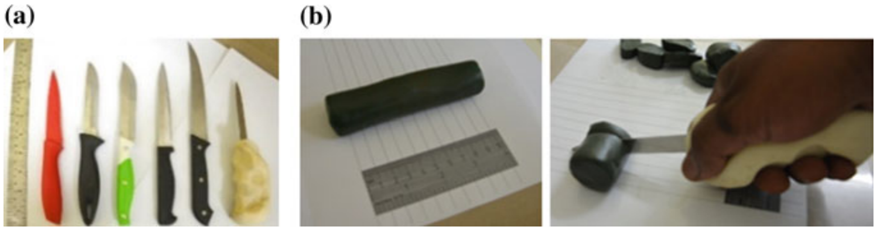

Fig. 5 **a** Six knife handles used for the evaluation (Knife 1-6, *left-right*). **b** Experimental task, a soft clay block (*left*) and a candidate cutting the clay block using knife having anatomically shaped handle (*right*)

Table 3 Overall performance score considering ratings of the relative importance in buying decisions and subjective evaluation performances of different knife handles against various comfort descriptors

Comfort descriptors	Importance rating (1–10) 1 = least important 10 = most important (Averaged for 27 subjects)	Knife performance											
		Knife 1		Knife 2		Knife 3		Knife 4		Knife 5		Knife 6 (Ergonomic)	
		IS[a]	WS[b]	IS[a]	WS[b]	IS[a]	WS[v]	IS[a]	WS[b]	IS[a]	WS[b]	IS[a]	WS[b]
Is functional?	9.0	5.96	35.76	5.75	34.49	5.48	32.85	5.13	30.76	4.11	24.64	5.99	35.91
Is easy to use?	8.6	4.53	27.15	5.22	31.31	5.6	33.61	4.73	28.37	4.06	24.35	5.61	33.68
Has high task performance	8.5	5.23	31.37	5.05	30.31	4.78	28.69	4.64	27.84	3.95	23.67	5.41	32.43
Has good force transmission	7.7	4.66	27.98	3.96	23.74	4.1	24.62	4.06	24.33	2.81	16.85	4.25	25.51
Has good friction between hand and handle	8.0	4.87	29.24	4.63	27.77	5.25	31.51	4.88	29.30	3.85	23.08	5.06	30.38
Does not cause peak pressure	7.6	4.25	25.48	3.97	23.84	4.25	25.48	4.29	25.74	3.18	19.10	4.27	25.61
Does not cause pain	8.6	4.96	29.77	5.01	30.06	5.07	30.42	4.46	26.77	4.03	24.19	5.49	32.92
Low grip force requirement	7.5	4.35	26.11	4.47	26.80	4.1	24.62	4.08	24.49	4	23.99	4.79	28.73
Does not slip	8.2	4.34	26.03	4.77	28.63	4.44	26.64	4.97	29.79	3.52	21.09	5.4	32.40
Does not cause sweat	7.3	3.69	22.11	3.99	23.93	4.05	24.3	4.07	24.42	3.87	23.20	4.74	28.43
Light weight	7.8	2.91	17.48	4.92	29.52	4.59	27.51	4.91	29.46	5.73	34.38	4.46	26.74
	8.1	4.05	24.31	4.44	26.62	4.86	29.13	4.49	26.96	3.96	23.77	5.47	32.80

(continued)

Table 3 (continued)

Comfort descriptors	Importance rating (1–10) 1 = least important 10 = most important (Averaged for 27 subjects)	Knife performance											
		Knife 1		Knife 2		Knife 3		Knife 4		Knife 5		Knife 6 (Ergonomic)	
		IS[a]	WS[b]	IS[a]	WS[b]	IS[a]	WS[v]	IS[a]	WS[b]	IS[a]	WS[b]	IS[a]	WS[b]
Offers comfortable holding posture													
Has a nice feeling	6.7	3.49	20.93	4	24.00	4.24	25.46	3.6	21.60	2.92	17.53	3.91	23.45
Looks professional	6.2	4	23.99	3.69	22.14	3.24	19.46	2.69	16.11	2.39	14.36	3.67	21.99
Good finishing	7.4	4.63	27.77	5.09	30.56	4.28	25.66	3.68	22.07	3.06	18.35	4.39	26.35
Safe to use	9.3	5.35	32.12	5.73	34.37	5.12	30.73	5.16	30.96	4.61	27.63	6.03	36.15
Good styling	6.9	4.32	25.91	4.53	27.17	4.05	24.31	3.63	21.80	2.85	17.12	4.59	27.51
Overall performance		75.59	453.51	79.22	475.26	77.5	465	73.47	440.77	62.9	377.3	83.53	500.99

[a]IS = Individual actual score of knife handle
[b]WS = Weighted score of knife handle (IS multiplied by rating of each factor)

its relative importance to the subject in buying decision. This exercise provides the information on the relative weights of the seventeen factors of CQH among the selected group of candidates. Then, the subjects were asked to perform a simulated cutting task. The candidates used each of the six knives to cut ten slices of a standard block of clay (Fig. 5b). They were asked to rate (on a rating scale of 1–7; 1 = poorest, 7 = best) each of the six knives based on the factors listed in the CQH.

2.2.3 Results and Discussion

Based on the aggregated scores from the evaluation (Table 3), it was found that the three factors considered most important in buying decision of the users are ‘safe to use’, ‘functional’ and ‘ease to use’. All these factors roughly correspond to core functionality associated with knife use. Safety assumed highest priority in terms of buying decisions of participants. It was also observed that the anatomically designed handle (knife 6) was rated highest in terms of safety. This may be due to the steadiness and stability this knife offers as a result of anatomical features available on the handle. Another reason might be the hand-handle contact area being higher in case of anatomically designed handles. The three factors considered relatively least important in the buying decisions for the subjects in the order of decreasing priority were ‘styling’, ‘has a nice feeling’ and ‘looks professional’. These factors roughly correspond to user’s emotional experience with the handle. Knife 1 was perceived the best on the factor of ‘looks professional’ (factor with least importance rating/weight of 6.2 in Table 3), and so it is greatly disadvantaged in the overall performance score.

In terms of user evaluation of the six knives with corresponding knife handles—the newly designed anatomically shaped handle based knife was rated best in ten of the seventeen different factors from the CQH. These 10 factors are ‘functionality’, ‘ease of use’, ‘high task performance’, ‘do not cause pain’, ‘low hand grip force supply’, ‘does not slip’, ‘does not cause sweat’, ‘comfortable working position’, ‘safe to use’ and ‘styling’.

3 Conclusion and Future Work

In terms of the comparison between the two studies, the handles involved in the first study (six configurations) can be labelled as purely geometric forms. The handles in the second study (knives) can be broadly termed as organic in form. And hence, these two sets could be seen as complementary to each other. However, different sets of methodologies were employed to evaluate these two sets of handles, and therefore the authors believe that any generalizations that could be drawn from the two sets of results should be verified through a common set of methodological framework before any direct application. There are certain generalizations that could be drawn as a consequence of the results from this work. First, it can be safely claimed that greater hand-handle contact area is an important factor to design comfortable handles. Design I, V, VI in the first study (Table 2), and the anatomically designed handle in the second study (Table 3) illustrate this fact. Second, slimmer and sleeker designs, sometimes with sharp creases on the surface could lead to overall discomfort in general (Table 2), but such designs may value additions in terms of their lighter weight, professional looks, good force transmission, etc. (Table 3).

Two methodologies suggested for the design of tool handles have immense potential for designers to conceptualize and assess tool handle geometries. From the first study, it can be inferred that in terms of surface area, circular cross section geometry offered the greatest hand-handle contact. However, in terms of overall preference for handle cross section, creased features on handle surface affect handle preference. Therefore, a combination of circular cross section with creased profile offers a good geometrical design solution to the handle design problem.

The anatomically shaped handle developed for kitchen knife handle is also significantly bulkier than the other handles, and future work could address this issue. Specific re-work could be performed upon the surface so that the excessive and non-functional surface features may be removed, and some other functional and usable features may be included. Only a limited number of cross-sectional shapes were evaluated in this study. However, other geometrical primitives and their combinations could be evaluated in future work. Also, the handles could not be evaluated for specific tools, or for specific tasks in this body of work, but the same could be taken up in a later study. In terms of structure, investigations inquiring optimization in terms of hollow/honeycomb/other light weight ergonomic handles could also be undertaken. Focus on tactile and force exertion criteria during actual use of different shaped handles can add value in the future work.

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Design Modularity in the Assistive Devices for the Elderly People

Swati Sarkar and Amarendra Kumar Das

Abstract India although has the largest numbers of young people, numbers of elderly people are also increasing. However with aging, human being starts losing their physical prowess and ability to take care of themselves. Various assistive devices have been already designed and manufactured outside the country so far for the elderly people. These assistive devices enable them to be self-dependent in carrying out their daily tasks. One of the very useful assistive devices for elderly with mobility impairment is a powered wheelchair, controlled manually and automatically in special cases but except providing mobility it cannot solve other problems associated with an elderly person. Every elderly person has different disabilities and adding each feature will only increase its cost. This paper deals with various issues of disability in the elderly people and incorporating modularity in the assistive to provide mass customization.

Keywords Elderly · Assistive device · Modular design · Functional modularity

1 Introduction

The term disability is not necessarily be targeted to only a particular age group. It may affect people of any age group. People start showing various declinations in their prowess with their increasing age. The likelihood of disability increases with aging, but it is not the only reason of a person's disability [1]. It is a condition which can be initiated due to various reasons. It can be also being triggered due to any unwelcomed accident, some serious mobility impairment disease, or due to aging [1]. According to the International Classification of Functioning, Disability and Health (WHO, 2001) disability is a result of various factors which are inter-related

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such as, the health condition of the individual and some personal factors and also the external factors like the environment in which the individual lives [1].

If these people are provided with some assistive aids it will bring hope in their lives. Modularity in such assisting devices will add more independence in their lives as there are certain limitations in those existing assisting devices.

2 Disability Among the Elderly People

All of a sudden, one does not grow old. It is a gradual process [1]. Physical health declines with aging, but it does not imply the person has become incapacitated [1]. According to the estimation of WHO (2003, 2006), 10% of the people in the total world population has some form of a disability. Out of that 10%, 20% are aged 70+ and 50% are aged 85+ [1]. But the rates vary in accordance with the country [1]. The rate in Kenya and Bangladesh is less than 1%, in New Zealand it is 20% and in Caribbean and Latin America, it is 19% [1].

The low disability rates in the developing parts of the country has been lead from the poor healthcare, poor nutrition and unsafe living conditions [1]. According to Velayutham et al. (2016) in 2011 a total of 53,76,205 elderly individuals were disabled in India which accounts for 5178 per 100,000 elderly population which is about 5.1% (2011 Indian elderly population 103,836,714) [2]. Chronic diseases are particularly considered as the main reason of old age disability [3].

Effective programmes on disability prevention are urgently needed and should be introduced majorly among the poor [3]. It is often thought that the risks of disease are a normal part of the old age and those people can't look positively towards life as their disability cannot be amended [3]. Although it is not the case.

2.1 Common Causes of Disability

There may be many reasons behind the disability of a person. Some reasons include Chronic diseases like cardiovascular diseases, muscular skeletal diseases (osteoporosis), mental health conditions (dementia) and visual impairment [1]. Other reasons may be due to injuries or any other communicable diseases. It can also be due to malnutrition.

Cardiovascular diseases, chronic obstructive pulmonary disease, diabetes, cancer, muscular-skeletal disease like arthritis and osteoporosis, mental health conditions like dementia and depression and blindness and visual impairment comes under some of the major Chronic diseases [1]. Some of these may lead to physical disability for instance, stroke, cognitive impairment, visual impairment, arthritis and diabetes [1]. Multiple Sclerosis is known to cause a wide variety of neurological deficits and disability in ambulation is the most common and obvious [4].

Smoking can also be the reason of someone's disability which may indirectly lead a person to such a situation. It has been observed that people who are much likely to get addicted to smoking are the poor and the uneducated males [1].

2.2 Some Factors Related to Extent of Disability

(a) **Gender differences**—Women experience more disability in old age as compared to men. This gender difference has been reported by Jagger et al. [5] that in U.K. women, as they get old, are less likely to be disability free. Similar reports are observed in many regions. But Murray and Acharya (1997) [6] reported exceptional findings for Sub-Saharian Africa where severe disability was observed among both men and women, along with higher rates of mortality. Women are more prone to disability as they live longer with poor health. The exact reasons for these reports are yet unknown [1].

(b) **Socio-economic status**—It has been observed that the extent of disability matters on the fact that to which part, to which ethnicity a person belongs. Poverty causing malnutrition induces disability. Also poor health services and sanitation causes disability. In addition, the unsafe working conditions are also responsible to aggravate the disability to higher extent [1].

(c) **Unhealthy lifestyle**—If a healthy lifestyle is adopted, the extent of the negative effects of disability can be minimised [1]. It includes proper nutrition, inclusion of physical activity in daily routine and less obesity, avoid smoking etc. The risks of diabetes, CHD and stroke can be minimised with all these habits [1].

3 Assistive Devices and Technology

Assistive devices are the equipments which assists the disabled person in carrying out their every day's task with ease. Various assistive devices are available for different types of disability. Canes, Crutches, Walkers, Wheelchairs and Scooters are some common assistive devices for mobility impairment [7] (Fig. 1).

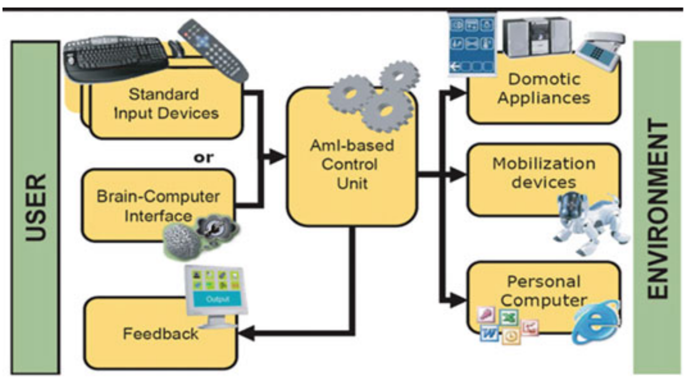

Fig. 1 Outline of ASPICE Project [9]

Rehabilitation technology has been developing in the fields of flexible and adaptable robots. Three main developments have been focused upon in the rehabilitation technology, which includes: static systems capable of operating in a structured environment, robotic systems mounted on a wheelchair for personal and care applications and mobile manipulator companion which can follow the person [8]. In Brain Computer Interface technology, the communication and the control channels are not dependent upon the brains normal output channels of the peripheral nerves and the muscles [9]. In the ASPICE project [9], the user is interfaced to the surrounding environment by the system. Inputs from one of the possible input devices are accepted by the system and one or more of the output actuators receive these commands received from the input devices.

Some BCI uses microelectrodes implanted within the brain to control the prosthetic devices or the robots. Whereas some BCI uses the non invasive methods in which the electrodes are placed over the scalp of the user. The motor imagery tasks induces some modulations in the Electroencephalography (EEG) rhythmic activity located over the scalp sensorimotor areas and these modulations can enable trigger other actions like controlling a cursor over a computer screen [10].

Advantages of robotic assistive devices technology

1. New avenues have been opened for the patients having severe motor disabilities with the development of the environmental control and the assistive technology which provides assistance in communication and control needs [10].
2. Impressive advancement in the field Robotics also comes under this development. There is a evolution in the morphology of the robots resulting into a variety of mechanical structures. Using the legs or wheels, these structures can provide the locomotion [10].

Limitations of robotic assistive devices technology

1. Due to the lack of the residual motor ability (e.g. head, limb or eye movement or speech etc.), people with very severe motor impairments still suffers [10].
2. In extreme pathological conditions (e.g. no control over the muscles or only unreliable remaining muscle controlling ability), the patients can't benefit themselves from this kind of assistive systems [10].

Advantages of Brain Computer Interface technology (BCI) [10]

1. BCI Technology enables even those patients to communicate with the surrounding environment who are completely paralyzed. The activation patterns in the brain corresponding the users' intent are detected by the BCI.
2. Any voluntary modifications can also be detected and translated into an action reflecting the users' intent.

(a) Seat
(b) Backrest
(c) Arms
(d) Footrest
(e) Leg rest
} Front rigging
(f) Wheels and tires
(g) Casters

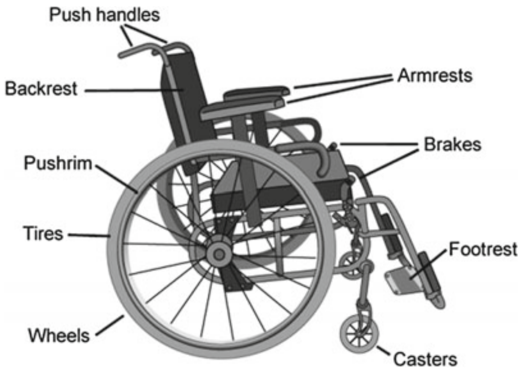

Fig. 2 Basic wheelchair [25]

3.1 Wheelchair as an Assistive Device

Wheelchair as a mobility aid enables the people with mobility impairment to move independently without much assistance. The first ever evidence of the existence of the wheelchair is dated back to 5th century B.C. [11]. After that many new designs have evolved and development has been done in designing the wheelchair. The first ever folding wheelchair was developed by Harry and Jennings in the year 1932 [11]. Wheelchair can be either manually controlled or through power. In the present time people has the opportunity to control their wheelchair through their brain signals. The power controlled wheelchairs are very costly and can't be afforded by the people belonging to socio economic status.

The components and the dimensions are necessary to be taken into consideration while detailing a wheelchair [12]. Proper dimensions lead to comfort or stressful otherwise. Following are the factors on which the comfort level of a wheelchair depends upon (Fig. 2).

4 Modularity and Its Need

According to John Young, modularity is fitting or grouping the individual components into a functional sub-system or unit [13]. In accordance with the engineering and product design, it is a subsystem having a self-constrained and testable function and to form a working product which would be capable of being combined with such similar units [13]. Designers and product engineers shall focus on producing new product lines deliver the necessity of the user and the industry [13]. Re-engineering of the products which already exist won't provide any solution to the issue [13]. Hence modularity serves the purpose in developing the variety of the product lines. Wide range of customer requirements has been met with modularity while designing a product [14]. According to Antonio et al. a general approach has not yet been achieved to test and treat those people with physical disabilities. Different strategies are needed to solve the different combination of symptoms in each patients. Intellwheels platform was presented by Antonio et. al. It focussed on the modular concept and multiagent paradigm [15]. Flexibility of the system is ensured to get increased and on almost every commercially existing wheelchair, which in turn can assist different people with different impairments. They also focused on making the product cost effective so that it can be easily accesses by the target population [15].

First autonomous wheelchairs for the people with physically disabled was proposed by Madarasz et al. [16] and it incorporated a digital camera, an ultrasonic range finder and a microcomputer. Their aim was to avoid collisions and provide the comfort to the user in populated without any human intervention [15].

Tin Man I was developed by Miller [17] and it ensures the following modes of operation: movement forward, movement to a specific point and human-guided with obstacle avoidance. Evolution of Tin Man I produced Tin Man II. It included some new capabilities like Backup, wall following, backtracking, docking doorway passing. And the Maid Project included the Tin Man's capabilities and also ensured proper navigation in narrow cluttered environments and also in wide crowded areas [15].

A hybrid wheelchair was proposed by Wellman et al. [18] in which two legs were equipped in the wheelchair along with the existing wheels It enabled the wheelchair to climb up the stairs and move over the rough terrains [15].

ACCoMo (Autonomous, Cooperative, Collaborative MObile) ensures safe maneuvering in indoor environments. SENARIO (SENsor Aided intelligent wheelchaiR navigation) incorporates intelligent navigation system and looks into the problems which are generally faced by patients having physical injuries and provides the solution to the same. Other intelligent wheelchair systems are: i) Obstacle avoidance and shared control system of Rolland, ii) SIAMO (*Sistema Integral de Ayuda a la Movilidad* ["Integral System for Assisted Mobillity"]) through its innovative user interface provides guidance, safety and comfort to its user, iii) FRIEND (Functional Robot arm with user-frIENdly interface for Disabled people) is the semiautonomous robotic system and it has its robotic arm named as MANUS iv) VAHM (*Véhicule Autonome pour Handicapé Moteur* ["Autonomous Vehicle for People with Disabilities"]) [15].

4.1 Modular Tray

A robust multi wall tray has been invented by Goschy, Thomas Sedor which is retrofittable to a wheelchair [19]. Although the tray is light weight but is more rigid than any other conventional wheelchair trays. It is fitted to the wheelchair with such novel means which enables the surface free from screws or Velcro™ [19]. A wheelchair tray is beneficial for carrying out multipurpose tasks such as eating, writing etc (Fig. 3).

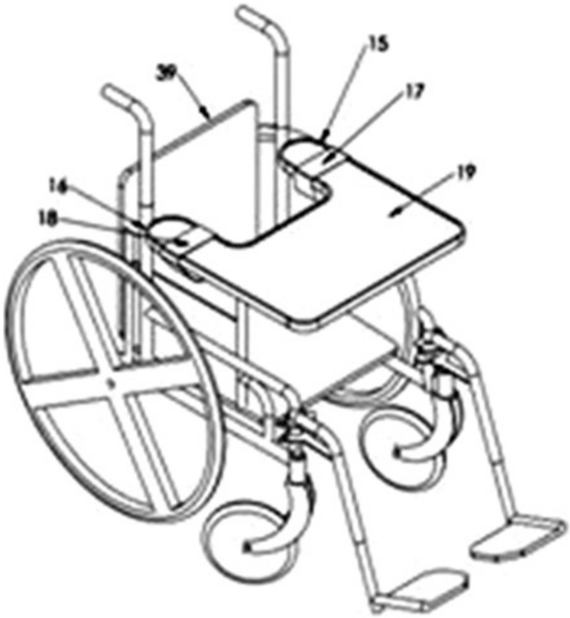

Fig. 3 Modular multi-wall tray [19]

A wheelchair was designed in IIT Guwahati, India, which has the provision of a folding surface which serves as the tray and can be used for eating and reading purposes. It has the facility of getting transformed into a bed to facilitate sleeping. The product has been named as "Tirthrup" and is available in three categories [20]. Different people have different extents of disability. If the height of the tray provided as modularity in the wheelchair can be adjusted, it would enable the user to be comfortable while reading/writing or eating.

4.2 Leg Exerciser

In Elderly people, with growing age their muscles gradually declines and it is the case with most of the elderly people worldwide. Now they can't be left alone with the situation. Prolonged seating may affect the muscles of the legs and many other dangerous diseases may occur. Research says that number of health problems has been associated to prolonged sitting for longer duration. Some of the health concerns include obesity, and many other problems like high blood sugar, high blood pressure and abnormal cholesterol levels. Death risks are also increased from cardio vascular disease and cancer [21]. Many fitness equipments are available in the market so far but for elderly people having some kind of mobility disability, many of these are not advisable. Designers have to think over this issue and provide some solution.

Hence the elderly people should be provided with some modularity in their daily used assistive devices for example a wheelchair. Even if they are not using any assistive devices then also they need to do exercise for the legs sitting on the chair. Also the exerciser may involve hand movements also which will benefit and strengthen the arm muscles as well. Although the idea of adding a leg exerciser module into the Wheelchair would benefit the elderly but the idea of mass customization should be taken care of. Different elderly has different body postures and different issues to get resolved. So provision of adjusting the height of the exerciser should be enabled. Also people whose one side is paralyzed, should be able to get benefited by exercising through one side. This can be resolved by designing the exerciser in such a way that moving one side makes the other side move in the alternate direction or may be the same.

4.3 Mobile Charging Unit

It is a daily routine to charge the mobile phones but the charging units are situated in particular places and it is a tiring job for an elderly person specially the wheelchair user to get their mobile phones and gadgets charged. In the power controlled wheelchair there is a power unit which provides motion to the wheelchair. The same charging unit can be used in designing modularity in the wheelchair which would be capable of charging the mobile phones and some other gadgets etc. (Fig. 4).

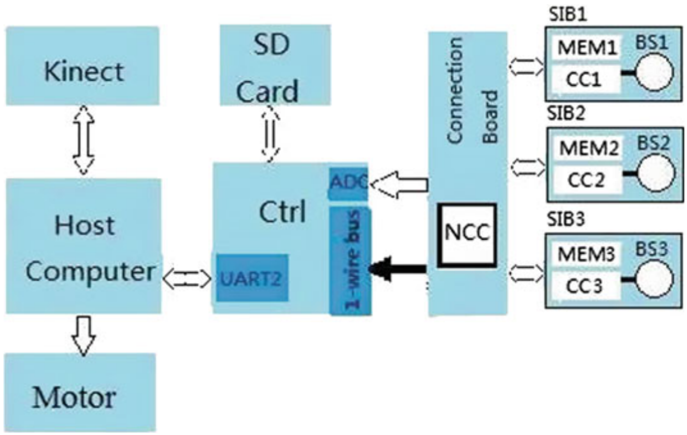

Fig. 4 The block diagram of smart wheelchair system [22]

4.4 Vital Signs Monitoring Unit

In aged and disabled people, monitoring and measuring their physical conditions is very necessary and in order to fulfill this requirement the skin conductivity sensors, photoplethysmography and ballistocardiography are widely used in monitoring the vital signs. In the work done by Miao Chi, the embedded sensor systems in the intelligent wheelchair for vital signs can be controlled using the hand gestures [22].

5 Discussions

With aging elderly people undergo a change in the physical and the mental state. They are not adapted to the declines that occur in them gradually. With growing age the muscle gradually weakens and exercising with self-dependence is not feasible due to the risk of fall. But exercising of the legs is very essential to avoid risks associated with prolonged seating. And round the clock monitoring of the elderly people is not possible for the care-takers or the family members. So a leg exerciser, as modularity in the wheelchair would be a positive approach towards solving the problem faced by the elderly due to prolonged sitting postures. Modularity in the wheelchair would enable an elderly person to be confident enough to carry out their daily tasks with some comfort. Reading newspaper for longer duration holding it is a tiresome job. But keeping it over the tray provided as a module in the wheelchair would make this problem get solved. The mobile charging unit will be an added benefit to the electrically powered wheelchair user. The vital signs monitoring system would enable the care givers and the family members to be aware of the physical condition of the elderly or the disabled and also would give confidence to the user and the well wishers. While designing the functional modularity the cost and comfort has to be analyzed so that it can be afforded by economic class people as well. According to Ulrich et al. modularity is the most important characteristic of a system architecture [23]. But also they argue that modularity is not always desirable mainly for the high performance system using high power as compared to the systems consuming low power. Also the argument holds good for the systems which is known to have highly coupled structures like in automotive and aerospace vehicles [24]. But in this proposed case study the modularity in the assistive devices would be a great idea as provided the idea of making it cost effective and ease in handling is not violated.

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Wayfinding Challenges and Strategies in Mumbai Suburban Railway

Shikha Agarwal, Abir Mullick and G.G. Ray

Abstract This paper reports findings from semi-structured interviews conducted with local train commuters with different level of vision-full vision, low vision, no vision and different level of familiarity-first time, occasional, daily commute. The study had two objectives (1) to understand how the current train and station environment limit or support wayfinding of train commuters (2) to explore and compare the wayfinding experiences of people with different level of vision and familiarity with station use and local train travel. The findings from the study highlight 'universal design' considerations that should be taken to improve the wayfinding experience in the existing station and train environment for wider population.

Keywords Vision impairment · Familiarity · Wayfinding · Mumbai local trains, semi-structured interviews · Universal design

1 Introduction

Access to information is very crucial for quick decision making in context of dynamic environments like mass transit system [1]. Mumbai Suburban Railway network is an example of one such mass transit system that is known for its overcrowded train and station environments, complex and diverse station layouts. Such factors strongly affects way finding experience of commuters especially those with low level of familiarity and vision. Mumbai was rated world's sixth most populated city with a population of 21 million in 2016 [2]. Local train commuting system is most preferred mode of public transport by the population of Mumbai, including people with vision

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impairments (VIs in later references) as it offer the cheapest and fastest way to travel around in the city [3], primarily used to earn livelihood. Due to the benefits of travel and city population, Mumbai Suburban Railway is one of the busiest and most overcrowded commuter rail systems in the world. It carry 7.5 million commuters daily [4]. Unlike new modern metro systems in India and other parts of the world, Mumbai Suburban Railway is an old system started in 1853 [4]. Since then the rail network and station infrastructure has been under the constant expansion with the city population growth. Hence the railway stations and trains lack standardization in spatial layouts and deprived of modern wayfinding signage system.

Ability to find way in station environment and travel from trains in peak hours is a very strenuous wayfinding task of daily commuters who have vision. Hence for commuters with VIs, the severity of wayfinding challenges faced is much high and also interlinked with their safety. It is important to recognize that people with disabilities like other able bodied people have rights to travel in the train safely. Under PWD Act, 1995, the planning authority of Mumbai local trains implemented several rules to ensure access to people with disabilities inside railway stations and trains. A coach termed as 'handicap coach' was reserved for them in the local trains to provide opportunity to travel from trains. Railway pass system for fixed route was initiated for regular commuters to reduce queue for tickets. First-time/occasional commuters with disabilities were preferred over general commuters in queue for tickets. Architectural modifications like installation of ramps and escalators were done at few stations. At some stations textured tiles were laid at the edge of the platform to avoid people with VI from falling on railway tracks and facilitate them in finding the handicap coach entry. Signage were painted on the coach interface for identification and were also installed at the platform to earmark the waiting area on the platform where the reserved coach stops. Along with the visual signboard, auditory beepers (i.e., sound indicators) were installed that help to identify the waiting zone for commuters with VI. The impact of these measures on way finding experiences of commuters with VI will be discussed in detail in Sect. 5.

2 Literature Review

The term 'wayfinding' was first introduced by Kevin Lynch, in his book *Image of the City* in 1960. It means "find one's way" [5]. Wayfinding is a user-oriented process that involves cognition, behavior and strategic planning of movement from point A to B [6]. Further, it also involves the process of collecting information from the built environment to know where we were, where we want to go and how to get there [7]. Wayfinding behavior involve interactions between the traveller and the environment [8]. Wayfinding experience is measured by "how communicative elements facilitate getting from point A to B" [9]. According to Weisman [10], there were three characteristics of the built environment generally accepted to affect wayfinding—sign system, architectural differentiation and building plan configuration [10]. Personal factors like degree of-perceptual access [11] and spatial familiarity [12] with the environment play a significant role in wayfinding process.

Wayfinding systems need to take account of communication needs of people with varying abilities in a built environment [9]. Lack of wayfinding information is a hidden barrier to universal access [13]. If the building information is not conveyed in formats accessible to wide range of abilities, access to content of the building become limited [14]. In addition to this lack of inclusive approaches further had a negative psychological and health-related impact on the users [14]. Hence, Hunter (2010) suggests that wayfinding aids should not be limited to visual signage, there is a need to incorporate multi-sensory cues, landmarks that help visitor in orientation, direction and identification of places [14].

Spatial familiarity means "how well we know a place" [12]. With increase in familiarity, people refer to past knowledge stored in the brain for way finding [12]. Hence there is a decrease in the tendency to use a map or ask other people for directions. Further, familiar users also look for selective information and disregard overall general information [12]. Spatial familiarity is affected with the amount and type of information received from the environment [12]. Thus this dimension of wayfinding determines differences that occur in knowledge acquisition and strategies employed to find way as one becomes more and more familiar with the environment.

The dimension of vision in wayfinding study becomes interesting when we study the interaction of the person with environment through his/her multi-sensory modalities [11]. Since vision is considered as the most important modality to gather spatial information, how people interact with environment in the absence of vision is of interest. Visual signs offer restricted or no access to those with VI, as a result the later customize his or her own individual wayfinding strategy to gather spatial information [11]. Golledge and Stimpson (1997) in a study found that there was no overlap in the cues used by blind and sighted [15]. Due to lack of vision, much effort, concentration, memorization capacity and ability to mark non-visual reference points to gather spatial information is needed for successful wayfinding [16]. Architectural finishes and details, textures, lighting, color, etc. were communication factors in wayfinding of people with VIs [16–18].

Learning new routes and experiencing new settings lead to tension, anxiety and feeling of insecurity especially among people with VIs [15].

Though there are few evidence-based studies performed in developed nations on way finding in a real life environments with real participants, no research has been conducted in mass transit environments related to economically developing nations like India. Past research in way finding had exclusive focus on visual impairment and spatial familiarity, but no research conducted to study how level of-familiarity and vision impairment together affect wayfinding behaviour. This leads to question-What design issues people who have visual impairments and different levels of familiarity reveal as they way-find in a train station environment.

3 Methodology

The study had two objectives (1) to understand how the current train and station environment limit or support wayfinding of train commuters (2) to explore and compare the wayfinding experiences of people with different level of vision and familiarity with station use and local train travel. Twenty participants were selected based on two primary criteria: (1) Level of familiarity with local train travel: novice, occasional and regular commuters; (2) Level of vision: full vision, low vision and no vision (together called as people with vision impairments). Purposive and snowballing sampling methods were used to recruit participants for the study. Participants with VIs were recruited from two NGOs in Mumbai—National Association for the Blind (NAB) and National Association of Disabled's Enterprise (NADE). Whereas sighted participants were recruited from Indian Institute of Technology, Bombay. There were 5 males and 5 females in the age group of 22–57 in the group of participants with VI. There were six males and 4 females in sighted group. The education spectrum ranged from standard 4th in school to graduation for people with VI and for sighted it ranged from graduation to doctorate. Five commuters had low vision and 5 commuters were totally vision impaired. Seven participants had mobility training and braille knowledge. Only two participants with low vision used android phones. All commuters with VI used cane for outdoor mobility. Semi-structured interviews were conducted based on participants' past experiences of wayfinding in station environment. They were preceded by field observations [19], informal and unstructured interviewing. An interview guide with mostly open-ended questions were used to allow participants to express their views. Probing was used as a strategy to elicit responses from participants [20]. The questions were developed, tested, refined after every interview. All interviews were recorded and conducted face to face at the participant's place of work or home. Interview duration was between 1 and 1.5 h. The interview recordings were transcribed into text. All interviews were coded and key responses were sorted. From the interviews an understanding was built on the past experiences of the participants regarding outdoor travel in other mass transit systems and local trains, coping strategies and their learning process to become active in local train travel, assistance of peers and family members in outdoor mobility, encounter of personal, environmental and social wayfinding barriers and enablers. In the next section we discuss the findings in context of wayfinding challenges, coping strategies and suggestions reported by participants.

4 Findings

There were four types of wayfinding challenges faced by train commuters (1) Information (2) Identification (3) Direction (4) Safety.

4.1 Wayfinding Challenges

Information: These were challenges faced by the commuters related to information about features, function and services of the facility, e.g., rules and regulations of station use. All local train commuters mostly face challenges related to dynamic information update about trains and platforms. Some of the most frequently discussed challenges were lack of information to novice commuters (both sighted and those with VIs) about the Mumbai local train coach typology and boarding criteria based on user and ticket type. Lack of awareness among novice commuters lead to boarding in ineligible or undesired coaches. Similarly novice commuters also face difficulty in selection of platform and train since train indicators were difficult to comprehend due to use of acronyms. Public announcements were the only way to access information of platform nos. and trains for commuters with VI. However they were ineffective due to lack of timely updates, low audibility in peak hours and reduced clarity. Lack of audio/visual alert of the departure time left for trains parked on platform lead to hasty uncertain decisions for boarding creating a life risk situation at platform-train interface especially for commuters with VI. Lack of audio update inside trains on train stoppage between two stations due to signal result in blind novice commuters fall on rail track.

Identification: These were challenges where commuters were unable to identify their self location on station. Identification signs help to recognize places on station with the help of names, numbers, words, alphabets etc. Mumbai local train stations have several identification signs for station facilities, platform nos. and train types. However they suffer from poor placement, standardization and lack of multisensory signs to make them perceptible to all commuters.

Most frequently discussed challenges were lack of non-visual sign to identify station entry and its type by unfamiliar commuters with VI as the station can be entered through ticket hall/footbridge/circulation path/platform. Ticket hall entry/exit identification sign in not presented in a single sensory format. Sign differentiation between male and female washrooms are unclear to both sighted and low vision commuters, whereas those without sight cannot use the washrooms without help. All unfamiliar commuters independent of vision face difficulty in selection of right foot over bridge as they connect to different parts of the station. Unfamiliar commuters with VI were unable to identify decision points on the footbridge for platform nos., connecting footbridge and station exit since the signs were only in visual format. Unfamiliar commuters with VI find hard to maintain path on desired platform when it is joined with another platform. Chances of deviations were high due to lack of non-visual sign of platform no, on platforms. The current identity signs painted on train coach interfaces were difficult to comprehend by unfamiliar commuters especially those with low vision. Further totally blind commuters find hard to locate handicap coach entry as the train stops left/right to the place where commuter with VI wait for the train and there were no non-visual sign associated with it for easy detection. This lead to delay in boarding and sometimes boarding in non-handicap coach. There were no non visual information of the platform no. of the destination station where the train stops, this information is crucial for commuters with VI as they cannot access the visual sign board of platform no. on platform disembarked.

Direction: In order to move from one point to another one needs information about distance between two points, direction, landmark and identification sign for both point A and B. Directional signs aid in movement from point A to B, e.g., arrow heads. On local train stations there were hardly any directional signs in a single sensory format. Lack of directional signs lead to major wayfinding error in route selection inside station by unfamiliar commuters both sighted and those with VI. Factors like distance between two points, no. of floor level changes [21] in the route taken, no. of decision points [18] impact perceptual accessibility of destination. However the level of difficulty was less for sighted as compared to blind as route information to destination inside station can be gathered rapidly using visual clues than auditory and olfactory cues [11].

Findings from the study reveal that all unfamiliar commuters find hard to locate destinations that were beyond perceptual access like route to ticket halls, washrooms, offset platforms, desired station exit. A regular totally blind commuter reported "*Washrooms were located at the extreme end of the platform. I don't know whether they were located on all platforms or not.*" Lack of vision lead to inability to detect route to destinations places even at arm' length due to lack of non visual identification sign associated with spatial elements like ticket windows inside ticket hall, ticket hall exit, staircase of the footbridge, that were very obvious to be perceived by sighted. Commuters with VIs were only successfully able to locate the handicap coach due to the allocation of auditory visual signboard that earmarks waiting area on platform. However the auditory beeper has several limitations like, lack of installation on all platforms, mostly found in non-working state, they were of no use when trains of different coach order arrives at the platform, surrounding noise make them unheard in peak hours. On unfamiliar train routes, both sighted and non sighted commuters were unable to anticipate left/right side location of platforms of the upcoming stations inside the trains in the absence of updated directional signs.

Lack of direction sign lead to wayfinding error resulting in time loss and frustration for all. However they have a much stronger impact on the wayfnding experience of people with VI. Absence of wayfinding aids that guide movement right from station entrance to exit, generate stronger emotions like anxiety, fear, helplessness, poor confidence and safety [15] among them.

Safety: Safety is one of the biggest challenge faced by commuters with VI during station navigation. Poor safety during station navigation and train travel is interlinked with lack of wayfinding aids. The findings are very crucial and unique to Mumbai Suburban Railways. Station navigation for blind commuters were subjected to fall and slip resulting in injury, loss of life or limbs due to inadequate built environmental protection. Another important aspect of poor safety is collision with commuters resulting in getting physically hurt or damage to their cane due to lack of control on crowd movement.

Built environmental limitations were erosion of walking surface and presence of potholes and stones lead to unsafe walking at immediate station entry. Tiles laid on staircase were mostly subjected to frequent erosion lead to fall. Poor environmental protection against monsoon rains lead to commuters getting wet inside the station building, further rains reduce visibility of low vision commuters and make walking surfaces slippery. Lack of warning signs that help to anticipate walking surface level change from floor to steps or staircase lead to fall among totally blind commuters. Ramp cum staircase were difficult to use for the same reason. Steep ramps were difficult to negotiate by all commuters. Lack of environmental protection to avoid fall in the gap between-train and platform interface, handicap coach and neighboring coach is one of the major wayfinding challenge faced by commuters with VI. A stripe of textured tiles are laid at some station platforms as an indicator of platform edge detection. However, these stripes lack standardization both in width and placement. There is lack of protection from getting hit by overhead architectural elements like overhead wall, girder, freestanding pole and seating areas. Absence of door closing feature in all train coaches is a high risk factor for all train commuters.

Poor safety is also due to collision with people and their belongings like luggage, baskets etc. Presence of fast moving swarming crowd inside station makes commuters with VI less visible to the sighted crowd, in spite of carrying cane and wearing black glasses. Problem of collision were reported by participants with VIs especially at high crowd dynamic points like platform train interface when people rush to board and disembark from trains, footbridge and staircase where crowd moves in a high speed to board the approaching train. Collision at such places lead to fall and severe injuries. A vision impaired commuter shared an experience, "*When we walk people don't see us, they push us, many a times they break our stick. I can't say anything to them. People don't see that a blind person is coming.*" Similarly collision happen when a blind commuter is unable to gauge the presence of a commuter in the his/her path during navigation. In such situations, intolerant and insensitive behavior of sighted commuters were reported by participants. For example, a blind boy shared his station experience, "*I collided with women sitting on bench, she called me mad and then I gave an answer that I am not mad, I am a handicap.*" From the insights we can conclude that for effective way finding there is a need to make the navigation collision free and safe for commuters with VI.

4.2 Coping Strategies

Coping strategies are ways commuters have developed to overcome wayfinding challenges based on their level of familiarity and vision. A study of coping strategies help to understand the limitations and the abilities of commuters and how they find way inside railway station.

Travel with escort is a strategy especially employed by commuters with VI at early stages of commuting when they learn to become travel active in local trains.

All commuters with VI learn travel from local trains with the help of family members, friends and visually impaired peers. After attaining sufficient knowledge and experience about station navigation and train travel through repeated journeys on the same train route and inside station route, they begin independent travel. However, all commuters independent of familiarity level with VI reported poor confidence in visiting unfamiliar stations unescorted. Whereas there was a little dependency on escort to learn to travel from local trains among novice sighted commuters.

Social Communication: refer to verbal and non-verbal communication between people to ask and receive help for wayfinding. Asking people for directions were considered as the most helpful wayfinding tool by commuters with VIs, inspite of many limitations. Availability of so many people around, make them only source of information access at any point of doubt in the entire journey in the absence of accessible way finding signs. A totally blind commuter reported, "*We are dependent on public help for station mobility. If I do not have information, we rely on public help. Without public help, I cannot travel in trains.*" However there is relatively less reliance on social communication among sighted commuters irrespective of familiarity as they have advantage of vision to perceive environmental information.

Social communication in itself has several limitations mostly reported by participants with VI: Firstly, the chances of getting response from public depend upon level of sight and spatial crowd dynamics. People with VI, ask for help at instances when there is no one around or unable to make eye contact with the person. Hence their queries many a times remain unheard by public on station. A totally blind commuter shared, "*After saying aloud 10 times, 11th time some commuter will respond, what do you want, this is the biggest difficulty, nothing is as difficult as this.*" Chances of getting help also depend upon spatial crowd dynamics i.e. how crowd moves in a built environment. There were more chances to receive help inside ticket hall and platform as people wait for ticket purchase and train. Whereas it is difficult to take public help on footbridge and staircase as these spaces involve fast crowd movement. Secondly, miscomprehension of verbal help lead to misguidance. Verbal commands like "*go straight*", "*take right*", "*go there*", "*ahead*", "*infront*", given by sighted commuters were very confusing for participants with VIs as they fail to understand keeping what orientation in mind these commands were given. Such commands if misunderstood lead to fall on rail tracks or collision with built environment. Thirdly, commuters face difficulty in identification of specific type of people for specific help due to low or no vision e.g. women with VIs prefer asking help from same gender to protect themselves from eve teasing. Also for certain task like locating toilets, they prefer seeking help from same gender. Further, all commuters independent of level of vision find hard to locate railway staff at the point of confusion unlike general public. Fourthly, misguidance also lead to major wayfinding error like selection of undesired footbridge, platform, train and coach. As a result people with VI had to pay penalty in terms of time and energy loss.

Wayfinding cues: Cues are environmental information people use to make sense of the environment. Wayfinding cues are understood using Donald A. Norman's framework of environmental information. According to Norman (1988) there are two kinds of environmental information people use for wayfinding: "affordances" and "signs" [22]. Signs are specifically designed to serve as wayfinding aid for example auditory beepers and warning tiles at platform. Affordances include environmental physical (tangible) or non-physical features (intangible) that have personal or social significance, developed by the commuters to combat deficiency of signs e.g. people follow outgoing crowd movement to exit from station, in the absence of exit signs. Environmental information on railway station is perceived through mainly four types of sensory cues-tactile, olfactory, auditory and visual. Train commuters develop affordances as they earmark single or multiple sensory cues to physical and non physical characteristics of station architecture and elements inside and outside station that are—interior fixed, exterior fixed, interior dynamic and exterior dynamic [18]. Use of affordance depend upon level of vision and familiarity with environment. Most affordances were developed by commuters with reduced vision and high familiarity. Sound was the most important mode used to perceive environment among totally blind commuters. Whereas sight is the primary mode of information perception for low vision and sighted commuters.

Tactile Cue: Blind commuters used both hand and cane for tactile information There were no wayfinding signs in braille on station. Interior/exterior fixed affordance like changes in floor and wall surfaces using cane were a way to establish landmark and also provided a useful tool to delineate a path through open spaces. Further cane was used to sense objects like seats, pole, luggage; in the path during navigation to avoid injury. Placement and order of interior/exterior fixed objects both inside and outside station building like poles, vendor shops, water stall, washroom served as landmarks for place identification and route direction. Similarly path was also memorized with the help of architectural attributes like handicap coach location is below the ramp, wide footbridge connect platforms of two train lines, footbridge are identified with and without hawkers. Path that are aided with references like walls of platforms and footbridge, handrails of staircase perceived through cane and hand touch supported walk without deviation. Whereas paths without any reference like middle platforms had rail tracks on both sides were very difficult to delineate especially by unfamiliar totally blind commuters.

Auditory cue and Olfactory cue were used in combination or in isolation depending upon the sensory quality of the object or place, like sound of glasses and smell of food helped to perceive food stalls, presence of cobblers around were perceived through shoe polish brush sound and smell of polish. Toilets were perceived through bad smell. Environmental sounds like noise or silence were an indicator of train stop location between two stations or on platform. Calm or hasty body language of people reflect train standing on platform or not. Presence of staircase was understood with the sound produced by the footsteps of the crowd. Handicap coach in the absence of auditory beepers are identified with sound of ladies on the platform as handicap coach is next to ladies coach.

Visual cue: Low vision commuters can only read signs that have information in big fonts, good color contrast and use symbols. The sign boards should stand out from the background environment for better readability. Sighted commuters especially those with smart phones use web based information to-track direction to station exit in the absence of way finding signs, select train due to difficulty in comprehension of train indicators, get informed of the upcoming station in the absence of public announcements inside the station.

4.3 Suggestions

From Commuters with VIs: (1) Provide audio cue to locate handicap coach entry, (2) Provide safety measures to avoid fall on railway tracks, (3) Ensure installation of auditory beepers on all platforms. (5) Provide audio inputs at different decision points on the footbridge informing commuters about different platform nos. (4) Incorporate change in surface texture as a warning sign to detect platform edge, staircase and steps.

From Sighted Commuters: (1) Install dynamic maps both inside train and station. Map inside the train should help commuters visualize the train route and its stop locations. The map on station should be interactive that inform commuters about the different train lines, stations and train type. Further it should also inform commuter' location on the station. (2) Start online ticketing system to avoid queue (3) Install visual signs for all type of train coaches (4) Develop wayfinding app for all railway stations (5) Increase no. of help desks and place them at locations like station entry, platforms and other junctions where people ask for maximum help.

From Sighted and VI commuters: (1) There should be provision of telephonic Interactive Voice Response System helpdesk, that provides answers to station- and train-related queries. (2) Information should be provided to all novice commuters about train coach typology and train type. (3) There should be multisensory information that help in selection of footbridge before climbing stairs and creation of identity signs for footbridge easy recognition. (4) Install path direction signs to locate nearest washrooms and ticket halls. (5) Use bright colors and contrast in signboards for better readability even in night. Big fonts should be used for easy identification of ticket hall, washrooms and station exit from distance. (6) Provide timely update of the upcoming trains on different platforms as information of train indicators are inaccessible to people with VI and both novice and occasional commuters with sight find hard to understand train indicators due to use of many acronyms. (7) Public announcements inside all trains should announce name of upcoming stations, their platform no. and left/right direction. (8) Provide information of nearest popular locations to select exit point and directions signs for path guidance.

5 Conclusion

Many suggestions made by the commuters have been already implemented in other transport systems internationally. These suggestions need to be prioritized from user lens as a future scope of this work and addressed through an action plan with short- medium-long term goals.

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Study of Wayfinding Behaviours in an Outdoor Environment

Irfan Haider Khan and Saptarshi Kolay

Abstract Effective wayfinding is important for people to make their way through spaces, as it improves efficiency, accessibility, and safety. This study focusses on understanding the importance of wayfinding behaviours of people in an outdoor environment. The study area is an archaeological heritage site in the city of Delhi, India. Three navigational exercises were conducted to study the wayfinding behaviours among the users. Findings from each of the exercises are compared and evaluated. The correlation between the studied wayfinding measures is calculated and analysed to study the significant patterns in the behaviour of the participants. The results show that verbal directions for wayfinding are found to be the simplest, while directional signs and maps help in strengthening the cognitive maps of users. Users avoid unfamiliar routes, and tend to walk on the routes with more wayfinding aids, and physical structures.

Keywords Wayfinding · Wayfinding behaviour · Navigation · Outdoor environment · Cognitive behaviour

1 Introduction

Wayfinding is a part of everyone's daily life, and more so, when people experience an unknown environment, as they need to rely on the environmental cues, routes, and spatial organization of a space [1–3]. The wayfinding process, usually considered a simple and effortless task, involves complex cognitive processes [3]. Researchers of a varying field including and not limited to—cognitive psychology [4, 5], neurology [6], and architecture and urban planning [7], have therefore studied the wayfinding behaviours. The solution to a wayfinding problem is therefore, to produce a perceptible information that is easily understood by the

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users. In order to deliver an appreciable design, it is crucial to understand how the users behave in the given space [8]. There is still a need of research based design projects that implement the findings of wayfinding behavioural study through environmental design. The gap between the behavioural studies and design outputs is huge, and needs attention.

Wayfinding design is an integral part of a cohesive design scheme in architecture, urban design and landscape. Often misunderstood for signage design, wayfinding is much more than just signs. Wayfinding design has to take into consideration elements of architecture, landscape, landmarks and additional visual cues such as lighting, user interaction all as an interconnected scheme. The signage design is therefore only a medium to inform the users about their environment. Wayfinding research in terms of study of users' behaviour, perception and their navigational needs inform the design needs to achieve a consistent and functional scheme.

Navigation in an unknown outdoor environment is a challenging task. In a real life experience, people generally rely on pre-planned route maps and more commonly—verbal directions [9]. The comprehension of map involves the placement of self with reference to the map, reorientation, identification of the goal, and thereby remembering the way to the goal [10]. The information learned from the map is dependent on the orientation and perspective in which the map is viewed [7]. On the other hand, information received through verbal directions help in creation of mental maps in users, based on the route based directions (i.e. right, left, straight, etc.), or cardinal directions (i.e. north, south, west, etc.) and the reference points (landmarks) used by the source. An earlier study by Melinger (2008) suggest that the information received through maps and verbal directions are equally useful in wayfinding [9]. Various researchers have studied and compared the wayfinding performance of people using physical maps and GPS [7], maps and verbal directions [9] by measuring various wayfinding variables (time, distance, speed, direction, etc.) and assessing the performance. Other studies focus on the differences in wayfinding performance based on gender differences [4], culture [11] and age [12] by measuring similar wayfinding variables.

This paper aims to place wayfinding design research as a significant part in the formulation of urban design schemes. The correlations among various spatial measures forms the basis of this study, in order to study the wayfinding behaviours in users of a novel outdoor environment. This study integrates some of the existing work by other authors, and intends to build up on them. We aimed to study the similarities and differences in users' wayfinding behaviours based on information received through different means i.e. direct experience (environmental cues), map, and verbal directions through a set of three carefully designed exercises, carried out with participants in a naturalistic setting. The measurement of wayfinding variables (sense of direction, distance, time, pointing error, etc.) and the comparison between the three exercises help in evaluating the wayfinding behaviours, followed by a discussion on the translation of behavioural research into wayfinding system design.

2 Method

2.1 Study Area

The study area is a heritage site (Mehrauli Archaeological Park) in the Mehrauli region of the city of Delhi. The selected site is an outdoor space with an area of approximately 100 acres, containing several historic monuments.

2.2 Participants

Fifteen participants (7 males and 8 females) participated in the study. The participants were aged in the range of 23–30 years (Mean = 26.67, SD = 2.02). All the participants were first time visitors.

2.3 Experiment Design

In each of the exercise, participants navigated from one point to another, without taking any external help from the visitors of the area. All the pre-decided destinations were one of the monuments located within the park, chosen during a pilot. Participants were encouraged to think aloud while walking. This helped the experimenter to observe for follow-up questions and discussion.

Exercise 1 involved navigation based on direct experience, to test user's wayfinding behaviour in the absence of a map or verbal directions. Exercise 2 focussed on the study of map usage and their impact on users' wayfinding abilities. Additionally, the participants were unrestricted to refer to the directional cues (signage installed on site). Exercise 3 aimed to study the behaviour of the navigator, and mark any significant behavioural changes while navigating based on verbal directions, when compared to map based navigation, or while using environmental cues alone.

2.4 Materials

The experimenter recorded the video of the navigational exercises using the video recorder on his mobile phone device (Xiaomi Redmi 2). To measure the distance walked and the average walking speed, a pedometer was used. The time taken to reach the destination was recorded using the mobile clock application.

Self-Report Measure for Sense of Direction. The Santa Barbara Sense of Direction (SBSOD) scale was used to assess the participants' sense of direction,

Fig. 1 Map of the area, showing the extent of the park. The reference points used in the experiment are numbered sequentially 1–5

orienting abilities and their spatial understanding. The scale has an established consistency and reliability proven in earlier research works [5]. The scale has also been used by various authors in different fields, and has shown significant results [7, 10].

Map and Direction Statements. For Exercise 2, the participants were given a coloured scale map of the area (only a portion of study area) printed on an A3 sheet, showing the pathway layout, and all the structures. Figure 1 shows the map given to the participants. The reference points (starting points and destinations) used in the experiment are numbered sequentially (1–5).

In the final exercise (Exercise 3), the participants were given the directions to their destination verbally, in the form of sequential statements. This set of directions were determined in a separate pilot study, following the skeletal descriptions [13]. The instructions given to the participants were—(1) Head straight until the next intersection. (2) Turn right and follow the path until the next turn. (3) Follow the curving path and turn left. (4) *Jamali Kamali's Tomb* is on the left side, head straight from there, until *Rose Garden*. (5) Take left from the *Rose Garden*, and head straight. (6) Follow the curved path, until the next intersection. (7) Take right from the first intersection. (8) Head straight and walk until the staircase on your left. This is the entrance to *Quli Khan's Tomb*.

Direction Estimation (Pointing) Task. In all the exercises, to measure the directional error in the pointing task, a circle of 5 cm was drawn on an A4 sheet, and divisions were marked at 1° intervals, the centre of the circle denoted the position of the participant while pointing towards the starting point of the journey.

2.5 Procedure

Prior to beginning of the experiment, participants filled out the consent forms and questionnaire relating to SBSOD. Once the participant filled up the consent form, and cleared his doubts, he was taken to the starting point of the exercise i.e. the pedestrian entry gate. Since, the gate is located outside the park boundary, on the main road; it was not possible for the participant to gain any spatial or visual information about the area while travelling to the starting point, before the actual wayfinding exercise.

Exercise 1. The participant was given the name of the first destination (i.e. *Rajon ki Baoli*), and was asked to start walking towards the goal. The participant was restricted to seek any kind of external help, from the visitors. While navigating, if the participant took a wrong turn and walked more than 5 m, the experiment informed him and corrected his direction. During the process of wayfinding, if the participant did not reach the goal within 15 min, the experimenter took him to the destination.

Exercise 2. At the starting point (*Rajon ki Baoli*), the experimenter handed the map to the participant, and gave sufficient time to find and locate the starting point on the map, and then identify the destination (i.e. *Balban's Tomb*). The participant was unrestricted to choose the preferred route based on the map (as there were primarily two possible routes). The participant was asked to make a mental note and remember the preferred route, and when the participant gave the consent to proceed with the wayfinding exercise, the map was taken from him and the exercise started.

Exercise 3. Prior to beginning the main wayfinding exercise, the experimenter gave the verbal directions to the participant. Once the participant gave the consent, the exercise started. The participant was asked to start the navigation from the origin (i.e. main entry gate) towards the destination (i.e. *Tomb of Quli Khan*).

2.6 Recording and Observations

In all the exercises, the experimenter walked about 2–3 m behind the participant while recording the video, in order to allow the participant to lead the way, and to observe the participant's behaviour. It was left to the participant's disposition to refer to any environmental cues (i.e. the signs installed on site), in addition to his internal cognitive memory or the provided tools (i.e. the map or the set of verbal directions).

At the end of each exercise, the participant was asked to estimate the distance travelled, and to point towards the starting point, by drawing an arrow (on the paper with a circle with marked degree divisions) towards the estimated direction. At the end of the final exercise, the experimenter asked the participant to point in the direction of starting points of all the three wayfinding exercises. This was done to understand the strength of the mental map created by the participant after he had become familiar with the area.

At the end of all the exercises, participants were asked to rate the difficulty level for each of the exercise in relation to one another, on a scale of 1 (very easy) to 5 (extremely difficult).

3 Results

The different variables taken into account for the purpose of this experiment were measured and analysed to assess the wayfinding performance of the participants. The experiment did not focus on the study of gender difference as a measure of wayfinding behaviour; however, some of the findings suggest a significant difference between males and females.[1] Table 1 summarizes the findings of the experiment, with a comparison between the three wayfinding exercises.

3.1 Sense of Direction

Participants answered the SBSOD questionnaire for the self-report measure of sense of direction. To calculate the sense of direction score, the mean of the responses to the 15 questions is considered. The responses to positively stated questions were reversed, in order to calculate the sense of direction score, therefore, higher score (on a range of 1–7) refer to higher (or better) sense of direction [5].

Average score of 4.31 (N = 15, Range = 3.47–5.73, SD = 0.67) was reported through the SBSOD scale (Table 1, Row 1). A higher score was reported by the male participants (N = 7, Mean = 4.52, SD = 0.53) as compared to their female counterparts (N = 8, Mean = 4.12, SD = 0.72). Higher sense of direction in males in comparison to females has also been reported in previous studies [4, 14].

[1]A number of studies have reported noteworthy gender differences in wayfinding behaviours of males and females; however, this paper does not focus on gender differences, due to the small sample size of participants.

Table 1 Comparison between the findings of the wayfinding exercises conducted

Variable	Exercise 1 [Mean (SD)]	Exercise 2 [Mean (SD)]	Exercise 3 [Mean (SD)]
Sense of direction	4.31 (0.67)	4.31 (0.67)	4.31 (0.67)
Distance travelled (m)	966.27 (67.49)	938.67 (154.16)	750.13 (26.87)
Speed (m/s)	1.19 (0.04)	1.19 (0.02)	1.20 (0.04)
Duration (s)	882.40 (87.24)	807.67 (100.09)	651.40 (40.09)
No. of stops	3.13 (0.72)	1.60 (0.61)	1.20 (0.40)
Pointing error (°)	46.13 (19.59)	15.47 (8.50)	20.27 (7.58)
Difficulty level	3.13 (0.81)	3.07 (0.68)	1.53 (0.72)

3.2 Distance Travelled and Speed

For each exercise, the distance walked by the participant and average walking speed was measured. There were no significant differences found in the distance measurements between the readings for Exercise 1 (Mean = 966.27, SD = 67.49) and Exercise 2 (Mean = 938.67, SD = 154.16). The larger deviation in the measurement during Exercise 2 is mainly because of the longer route taken by some participants during the map based wayfinding task. However, participants walked considerably shorter distances during Exercise 3 (Mean = 750.13, SD = 26.87), as compared to Exercise 1 and 2 (Table 1, Row 2).

There were no notable differences in the speed measurements in all the three exercises. In all the exercises, female participants walked faster than their male counterparts did, the difference however, was not significant (Table 1, Row 3).

3.3 Duration and Number of Stops

The time taken by all the participants did not differ significantly in the first two exercises, however in Exercise 3 participants took lesser time (Table 1, Row 4). The exercise was considered successfully completed by the participant, if they reached the destination within the stipulated time of 15 min (900 s). To compute the quantitative relationships, the score of 1 was given to the participant if the task was a success and 0 (zero) if they failed to reach the destination within 15 min.

The number of stops made by the participants for 30 s or longer were recorded as an indicator that they were trying to orient themselves, or find their way through the space. The participants tended to make more stops in Exercise 1 (Mean = 3.12, SD = 0.72), as compared to Exercise 2 (Mean = 1.60, SD = 0.61) and Exercise 3 (Mean = 1.20, SD = 0.40) (Table 1, Row 5).

3.4 Direction Pointing

The angular difference (pointing error) between the actual direction and the direction pointed by the participant was calculated by drawing in AutoCAD. There were notable differences in pointing errors observed in all the exercises (Table 1, Row 6). Participants in Exercise 1 made greater error in pointing (Mean = 46.13, SD = 19.59), in comparison after Exercise 2 (Mean = 15.47, SD = 8.50) and Exercise 3 (Mean = 20.27, SD = 7.58). In verbal direction based exercise, the participants were asked to point towards the starting point of all the three exercises, which they had visited. The findings show a reduction in pointing error, as compared to Exercise 1.

3.5 Difficulty Level of Exercises

Participants rated Exercise 1 and Exercise 2 almost equally difficult (Table 1, Row 7). All the participants rated Exercise 3 (verbal directions) as the easiest.

3.6 Exercise Correlations

In order to assess the wayfinding behaviours in participants, non-parametric correlations (Spearman's rho) between various wayfinding measures are calculated, for each wayfinding exercise. Some of the measures of wayfinding behaviour were found to be significantly correlated.

Exercise 1. Table 2 shows the correlations between various wayfinding measures for the first exercise. Females were assigned 1 as a measure, and males as 0 (zero), for quantitative assessment. The findings suggest that—males performed better in estimating the distances and directions, and females rated the exercise more difficult as compared to the male participants. The SBSOD measure is found to be significantly correlated to the number of stops made by the participants (negative correlation, $p < 0.01$), and the pointing error (negative correlation, $p < 0.05$). Participants with higher sense of direction made significantly lesser stops during their journey, and were more accurate in direction pointing. Participants who walked greater distances made lesser error in distance estimation ($p < 0.05$). Evidently, people who walked faster were more successful in succeeding in the wayfinding exercise, as success of the exercise was dependent on time taken. Participants who made lesser stops during the exercise spent lesser time in wayfinding and therefore, were more successful in finding the goal ($p < 0.01$). Successful participants also made smaller angular errors in direction pointing ($p < 0.05$), and rated the exercises easier, compared to participants who did not succeed.

Table 2 Correlations between wayfinding measures (Exercise 1)

	1	2	3	4	5	6	7	8	9
1. Gender	1								
2. SBSOD	−0.403	1							
3. Distance	−0.371	0.568*	1						
4. Error coefficient	0.680**	−0.326	−0.521*	1					
5. Speed	0.111	0.082	−0.303	0.257	1				
6. Duration	0.062	−0.213	0.536*	−0.057	−0.528*	1			
7. Success	−0.218	0.474	−0.252	0.094	0.615*	−0.850**	1		
8. No. of stops	0.336	−0.702**	−0.080	0.269	−0.272	0.618*	−0.722**	1	
9. Pointing error	0.186	−0.550*	−0.327	−0.070	−0.138	0.250	−0.521*	0.540*	1
10. Difficulty level	0.674**	−0.407	−0.008	0.482	−0.038	0.422	−0.536*	0.539*	0.147

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

Table 3 Correlations between wayfinding measures (Exercise 2)

	1	2	3	4	5	6	7	8	9
1. Gender	1								
2. SBSOD	−0.403	1							
3. Distance	−0.310	0.253	1						
4. Error coefficient	0.340	−0.591*	0.161	1					
5. Speed	0.183	0.032	−0.423	0.085	1				
6. Duration	0.062	0.188	0.803**	0.196	−0.507	1			
7. Success	0.200	−0.503	−0.695**	0.000	0.456	−0.694**	1		
8. No. of stops	−0.138	0.204	0.402	0.280	−0.425	0.587*	−0.561*	1	
9. Pointing error	0.280	−0.381	0.287	0.493	−0.393	0.396	−0.271	0.401	1
10. Difficulty level	0.085	−0.354	0.123	0.106	−0.395	0.222	−0.191	−0.101	0.555*

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

Exercise 2. The findings in the second exercise showed similar correlations as in Exercise 1 (Table 3). The participants with higher sense of direction showed smaller error in distance estimation. Participants who made larger error in pointing task rated the task more difficult ($p < 0.05$).

Exercise 3. The observations and findings do not show many significant correlations. The significant negative correlation (r = −0.578, $p < 0.05$) between the speed and coefficient of error is an interesting find, suggesting participants who walked faster were much better at estimating the distances. Since all the participants successfully completed the exercise (reached the destination within the stipulated time), there were no correlations between the success of the participants or any other wayfinding measure. Female participants made greater angular errors in pointing task (r = 0.703, $p < 0.01$), and distance estimation (r = 0.588, $p < 0.05$).

4 Discussion

The study dealt with the study of wayfinding behaviours in participants who received navigational information through direct experience, maps, and verbal directions. The participants performed relatively better when given the navigational information through verbal directions. However, this may be due to the less complicated and sequentially structured directions. Verbal directions are generally considered convenient and easier to translate into actions; however, it primarily depends on the complexity, or clarity of instruction, and the reference points used to direct the navigator.

The results show that the participants faced wayfinding challenges in the absence of navigational information received via maps, or verbal directions. Since all the participants were first time visitors to the area, they did not have any prior cognitive maps formed. They primarily relied on the existing signs inside the park. However, the improper placement or the incomplete information presented by the signs affected the wayfinding experience of the participants. In the absence of wayfinding maps and carefully placed directional signs, people tend to walk longer distances and take more time, as they are trying to get familiar with the environment. One of the reasons for the differing success rate is the lack of wayfinding aids during Exercise 1, while the map-based navigation in Exercise 2 helped the participant in familiarizing with the environment. In Exercise 3, the route based verbal directions and references to landmarks helped the participants more effectively, and therefore, all the participants finished the exercise without failure.

One of the interesting find in Exercise 1 is that participants with higher self-reported sense of direction walked greater distances. This is in contrast to earlier studies [4, 5]. A possible explanation to this can be the environmental context, as the discussions with the participants suggested that participants addressed the exercise as more exploratory than direct origin-destination based experience. The correlations with the sense of direction measure with other wayfinding measures are significant for some variables, resonating with the previous studies suggesting that the participants with higher self-reported sense of direction performed better in the wayfinding exercise.

5 Design Implications

The wayfinding experiment findings, correlations and the discussions with the participants show that the wayfinding performance in users differ with each wayfinding aid i.e. directional signs, maps, information graphics, etc. The observations made during the experiment and discussions with the participants suggest that the study of wayfinding behaviours in users can help in improving the design of wayfinding elements. The findings from the behaviour study can inform about the navigational needs of the users which not only produce basic design requirements but also improve the efficiency of design. The careful placement and providing required information on signs help users to reach their goal more easily, by reducing the time spent on looking at the signs, and thereby strengthening the mental map created by the user.

This paper outlines the importance and need of an effective wayfinding solution in an outdoor environment. Wayfinding as an urban problem is not addressed, as frequently by the researchers, however, the impact of wayfinding in daily life is obvious and important. It is imperative that wayfinding design is thought of in the initial stages of any design project. The design and development of a wayfinding system (including signs, maps, guides, etc.) can become more effective if the wayfinding behaviours are studied and evaluated properly. Further, design guidelines for the wayfinding scheme can also be formulated based on the findings of such behavioural studies.

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Sense of Place—A Tale of Two Recreational Parks Near the Solani Aqueduct in Roorkee

Rabi Narayan Mohanty and P.S. Chani

Abstract Sense of Place is the interaction of the human with its environment, and is an important element of any place making process. Design should be legible to the user, and should be done according to the social, physical requirements of the users. Yet, there are numerous instances, where the users discard the built environment, in this case the public park. In this paper, we have considered the two parks developed near the Solani aqueduct in the city of Roorkee. While the smaller of the two is used by the residents of the city, the larger one is forsaken by the people. This unique case where two parks are in the vicinity of each other, cater to the same demography, but the user interaction with the spaces being markedly different, proves to be an ideal study of behavioral patterns and sense of place for users of a public space.

Keywords Sense of Place · User's experience · Solani Parks · Place making

1 Introduction

"Sense of Place" is the most commonly used phrase to express the feeling of a place. Sense of place can be defined as, "people's perceptions and experiences of an environment" [1]. It is an important factor in maintaining the quality of the environment. Creating a sense of place involves understanding how people develop place attachment and feel part of their physical and social environment [2]. Urban design deals with creation of a sense of place, as it is associated with the feelings and perceptions that people have through experience of a place [3, 4]. According to geographer Edward Relph, Sense of Place is associated with the cognitive, physical

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and social requirements of people for their surrounding recognisable place [5]. Kevin Lynch defined the term Imageability, which is associated with the spatial experience of the user to any site, and these experiences are unique, as each space possesses unique characteristics [6]. Research on sense of place has focused on three theories: place attachment, place dependence and place identity [2]. According to R.C. Stedman, Sense of Place is subjective in nature, so it is difficult to measure Sense of Place, while its subpart place attachment is measurable [7]. Careful integrations of strategies in the place making process will improve the quality of Sense of Place.

Place attributes and characteristics play a vital role in the construction of the sense of place and attachment [4, 8]. The attributes and characteristics indicate the strength and uniqueness of places in comparison to other similar places [9]. Sense of Place is subjective in nature, and researchers have different views on it. It is a phenomenological process of research and is based on the events occurred in a place in different time periods. People's past experiences, backgrounds, memories, personality, knowledge, culture, attitude, motivations, beliefs, age and gender influence the perceived sense of place. According to Canter, Places is a function of 'activities' plus 'physical attributes' plus 'conceptions' [7]. Building on Relph and Canter's ideas, Punter and Montgomery located the components of a sense of place within urban design thought [5, 10] (Fig. 1). This diagram illustrates how urban design actions can contribute to and enhance the Sense of place.

'Primal landscape' and 'Placelessness' are the two terms, which are connected with the process of formation and termination of the Sense of Place.

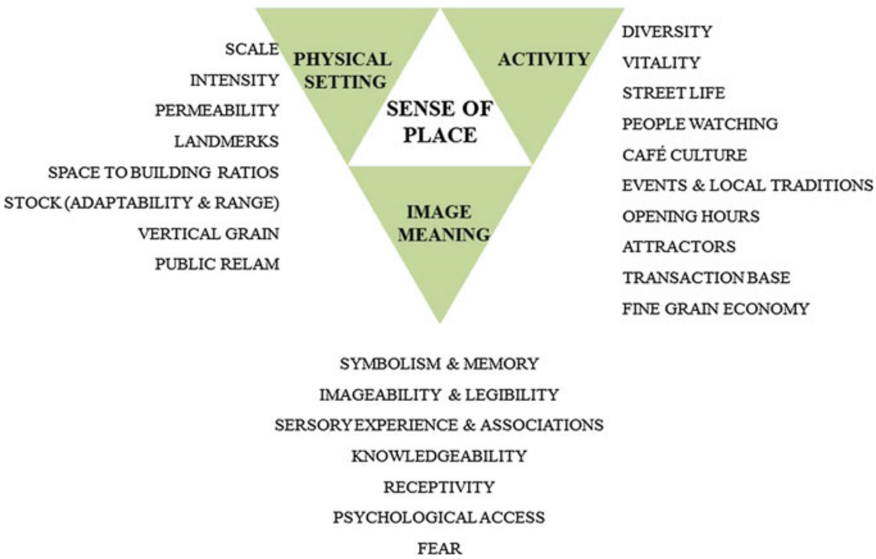

Fig. 1 Components of Sense of Place. *Source* Steve Tiesdell [8]

1.1 Primal Landscape

The environment, in which a person is raised is called the 'primal landscape'. It becomes part of our self-identity and a measuring stick for later experiences. This term "Primal landscape" was coined by a Canadian writer, Don Gayton [11]. This is true not only for natural landscapes, but also of urban landscapes including dense, inner-city neighborhoods. It helps in creating a cognitive image of an unvisited place, and creates the sense of expectation about that place. Topophilia is a strong sense of place, which often becomes mixed with the sense of cultural identity among certain peoples and a love of certain aspects of such a place [12].

1.2 Placelessness

Some places lack the authenticity is referred as Placelessness [7]. Placeless landscapes are those places, that have no special relationship to the places in which they are located they could be anywhere. Placelessness tends to signify absence or loss of meaning of the place. According to Relph, there are three factors which are creating placelessness in the context of urban realm, and these are as follows: Globalisation, Mass culture, and Loss of (attachment to) territory [8] (Fig. 2).

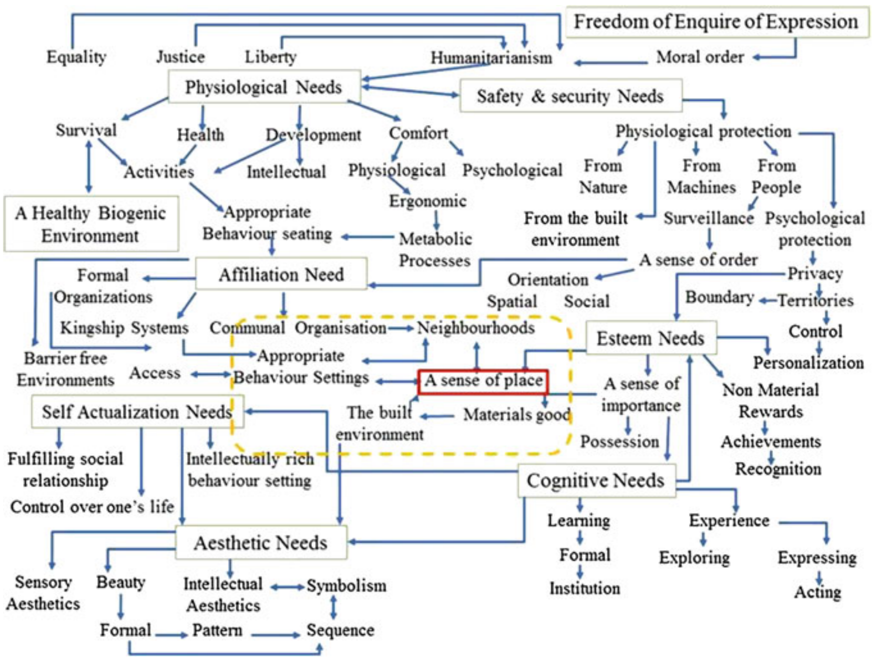

Fig. 2 Jon Lang's hierarchy of human needs. *Source* Steve Tiesdell [8]

2 Methodology

As stated before, Sense of Place is subjective in nature, so survey plays an important role in deciding the efficiency of the public spaces. For the purpose of this study, a series of surveys were conducted on different days in the month of March, where a total number of 92 people were asked about their experiences about the small park. On the first day of the survey, user activities in the park have observed and questionnaires are prepared according to the John Lang's guidelines for public space evaluation. Questions are asked about the experience and expectations of the users. Most of the visitors of this park belong to the old Roorkee area, and the distance between the park and their home is around 2 km. Outcomes of the survey are analyze and observations are concluded.

3 Solani Park, Roorkee

Roorkee is located in the Haridwar district of India. It is famous for institutes such as IIT Roorkee, CBRI, NIH, Army cantonment, etc. Development of this city took paradigm shift, when British general, Lord Cautley, had constructed the Solani aqueduct in the upper Ganga region in the 19th century. A new aqueduct was constructed in 2001, after the formation of new state of Uttarakhand. As a result of this new canal, a delta was formed in between the new and the old aqueduct. This portion of land has converted into two public parks. Figure 3 shows the satellite map of the Solani Park. The aqueduct built in the nineteenth century, was replaced by a newer one, more recently, forming an isle between the two aqueducts. This space has developed into two recreational parks.

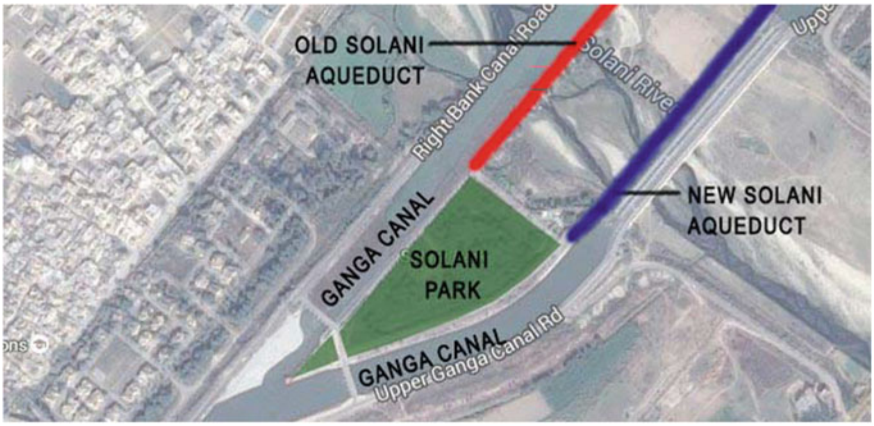

Fig. 3 Map showing Solani Park. *Source* Google earth

3.1 Physical Settings of the Parks

Figure 5 shows the perspective view of the Solani Park (small and large park). Small Park (left part) is at the road level, while the larger park is approximately 8 meters below the road level (Fig. 4). Area of the small park is 1378 m^2, while the area of the bigger park is around 25,160 m^2. Both the parks are separated to each other by a 6 m wide road. Bigger park has a number of trees, while the small park has no trees on its jurisdictions. One temple (Gayatrimata temple) is located in the corner of the smaller temple (Fig. 5). No designated parking spaces have been provided for both these Parks. Timing of the small park in the morning session is from 6 to 10 am, and in the evening session is open from 4 to 8 PM. Peak visit time of the small park is 6.30–8 AM and 6–8 PM. Currently there is no in and out time for the bigger park, though a particular age group (18–32) visit this park during the daytime to do suspicious activities.

Figure 6 shows the degrading condition of the bigger park. Lack of usage and maintenance is considered as the major reason for the existing condition of the park. Figure 7 shows the different users activities in the small park. Figure 7a, shows the canal front (Ghat area) activities, Fig. 7b, c shows the Park inside activities, Fig. 7d

Fig. 4 Existing section of the big park. *Source* Author

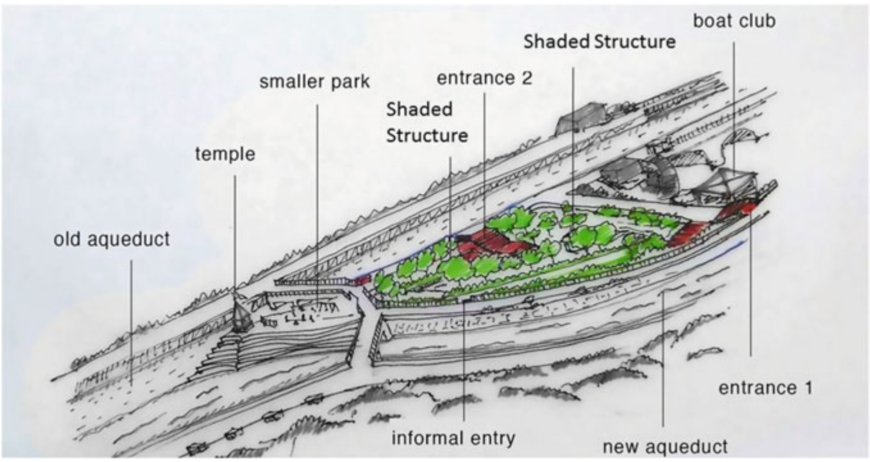

Fig. 5 Perspective view of Solani Park. *Source* Author

Fig. 6 Existing condition of the park. *Source* Author

Fig. 7 Activities in the small park. *Source* Author

shows the temple front activities, and Fig. 7e shows the outside haphazard parking in the park. This Park experiences higher footfalls on the holidays and festival days.

Figure 8, shows the difference of number of parked vehicles, which shows the footfall difference between both the parks. These images were captured at 5.30 PM (peak visiting hours of the park) on Sunday (27.03.2016).

Fig. 8 Entry precinct of small park (*left*) and bigger park (*right*). *Source* Author

3.2 Questionnaire of the Survey

The format of the questionnaire has been kept simple, with the least number of technical questions were asked to the users, where we tried to understand the different aspects of the parts and the user experience by casual discussions. This approach has been implemented keeping in the mind not to disturb the users of the park, as most of the users of this park are female (15–40 age group) and children. Female users of this park tend to avoid discussing with the others, and tried to keep their children away from talking with strangers (first site visit experience), so the simple question format has been implemented for this survey. Surveys were conducted in three different days (Sunday, Tuesday and Friday). Users of different age group were interviewed in this survey process. The questionnaire of this survey his designed based on John Lang's guidelines for public space evaluation. John Lang has provided twelve criteria for evaluations of any public space [6]. The questionnaire of the survey has categorised in a number of queries, on the basis of four design attributes defined by the PPS group (Access, Linkage, comfort and image), in which visitors to this park are asked about the following questions;

- General information regarding Name, Age, etc.?
- Place from where they are coming to this park?
- How they are reaching the park (mode of transportation)?
- How much time do they spend in the park?
- How frequent do they visit the park?
- Which park do they prefer to visit most and why?
- What do they feel about the bigger park?
- Why do they avoid visiting the bigger park?
- Which attributes attract them about both of the parks?
- Do they feel comfortable and safe in the park?
- What changes do they want in the Park?

Visitors of this park were asked to rate the different primary attributes of the park on a scale of 1–5, where 1, is the minimum appealing value, and 5 is the maximum appealing value.

3.3 Findings of the Survey

A total number of 92 people are asked about their experience about the park, out of which 70% of the users of the park expressed that they feel comfortable in the small park. Attributes such as visual connectivity with the surroundings, Canal view (primal landscape, as the canal is the integral part of the life of the dwellers of this city), clean environment of this park, less noise disturbances and evening activities (evening temple prayer and Arati) makes a positive impact on the minds of the visitors. 40% people expressed their desire for up gradation in the physical environment of the small park such as shading devices, designated parking spaces, food facilities, toilet facilities will improve the user's experience of the place. Ganga canal is an integral part of the city, as it is associated with both the social and cultural aspects of the city. Due to its close proximity to the religious city of Haridwar, which pays homage to river Ganga, Ganga canal is considered as the symbol of Ganga. The people of this city share a special relationship with the river and its canals. This acts as the primal landscape, which unconsciously generates "Sense of Place". Visual connectivity of this element makes a significant contribution to the success of the small park (Fig. 5).

Irrespective of the size, large park has become abandoned by the visitors. Due to lack of maintenance, and daily usage, this part of the Solani Park has covered by bushes (Fig. 7). Lack of visual connectivity with the surrounding places is another reason for the current condition of this Park. Speculation of past crime causes conducive environment for the illegal actives in this precinct. This condition of parks discourages the users from visiting this park, while it has become a hub for illegal activities (Fig. 9; Tables 1 and 2).

Fig. 9 Water front activities of the small park. *Source* Author

Table 1 Shows the survey opinions of the major reasons for the placelessness of the bigger park. *Source* Author

Possible reasons for abandonment of bigger parks	Percentage
Lack of maintenance	71
Lack of visual connectivity with the surrounding elements	67
Speculation about past crimes/Sense of fear	55
Lack of contextual design elements	48
Lack of illuminations	21

Table 2 Shows the comparisons between both the parks on the basis of the John Lang's guidelines for urban space evaluations. *Source* Author

Parameters	Bigger park	Smaller park
Type of use	Recreational	Recreational
Site enclosure	No	Yes
Site area	25,160 SQM	1378 SQM
Inclusive design (for differently able person)	No	Partly
Visual connectivity with the surrounding environment	No	Yes
Number of visitors per day	25–30 (approximately)	300–350 (approximately)
Human-scale size and sensibility	No	Yes
Existing condition of the park	Abandoned	Well maintained
A place to walk	Yes	Yes
A place to stop and stand	No	Yes
Protection from crime (surveillance, illumination, etc.)	No	Yes
A place to sit	No	Yes
Things to see	Yes (less)	Yes (more)
Opportunities for conversation	No	Yes
Opportunities for play	Yes	Yes
Opportunities to enjoy good weather	Yes	Yes
Protection from traffic	Partly	Yes
Indigenous design element and activities (for providing the sense of belonging to the users)	No	Adjacent Ganga canal and ghat, evening Ganga worshiping, etc.
Social barrier	Yes	No
	Low sense of place	**Good sense of place**

4 Conclusion

Sense of place is a result of the interaction of human and his living space. Although physical attributes such as scale, size are important elements of sense of place, still cognitive image of the space decides the experiences of the users about the place. Sense of safety and maintenance are important factors for any physical space. It decides the usability of the place. Some places have a high level of sense of place. These places encourage people to dwell, stay a little longer and to connect with one another.

A person, who visits the smaller park (at the road level) feel comfortable as they have visual connectivity with the adjacent road. Continuous flow of canal water creates a positive feeling (Survey findings) in the mind of the visitors. On the contrary, the larger park is located 8 m below to the road level, which breaks the visual connectivity of the users, with the adjacent road, and creates a sense of fear, anxiety in the mind of the visitors (Survey findings). This physical location of the park creates a significant sense of place in the mind of the visitors of both the park. Sense of Place is attached to the human cognitive image setting of the spaces rather than the physical settings, dimensions of the place.

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Determination of Most Preferred Mobile Phone Size Based on Hand Anthropometry and Mobile Handiness

Anirban Chowdhury and Manasi Kanetkar

Abstract Interaction with a smartphone occupies a large amount of time of day. Sometimes people are using mobile phone sizes which are either too large or too small. As per the different task is concern, users may find trouble with the mobile phones having extreme sizes. Hence, perceived handiness is very important factor which may be associated with satisfaction of mobile phone use. On the other side, hand anthropometry may be another determinant of mobile size preference. Hence, this study aims to relate hand anthropometry, smartphone handiness and mobile size preference and to determine the most preferred size of the mobile phone from a range of mobile phones. It was observed that there was a significant negative correlation exists between hand anthropometric dimensions and mobile handiness or size preference scores. This result indicated that users prefer a mobile phone which is comparatively bigger in size than the size of their hands. In addition, people perceived mobile phones as less handy those are either too small in size or too big in size. Smartphone with medium size (H: 138.0 mm, W: 70.0 mm, D: 8.0 mm, V: 77280.0 mm^3) was most handy and preferred by the most users, among studied mobile phones.

Keywords Anthropometry · Design · Ergonomics · Mobile size · Perception

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1 Introduction

Ergonomics or human factor engineering is a field of study that helps us to humanize the technology. In past, products have taken a long time to evolve and these were very tangible in nature. The user could adapt to the products and vice a versa easily. With new technology flooding in the market for the last couple of decades the evolution is happening at a much greater speed. Designers need knowledge of ergonomics to validate the products that demand intangible aspects of an experience. According to IEA—"Advanced technology could make lives of people more efficient and exciting. However, fascination with technology and overly ruthless business expectations can cause humans to ignore human factors related risks. Unfamiliarity to these risks can have adverse downstream effects on manufacturers, suppliers and service enterprises" [1]. Therefore, consideration of human factors to design a mobile phone is essential. A recent study reported that user satisfaction is compulsory in the context of mobile phone design [2].

Today a mobile phone is performing a plethora of tasks; not just making calls. An urban person spends a lot of time on mobile phone per day. Various users are known to use and prefer mobile phones of various sizes, ranging from a small fistful one to the one that is just shy of a tablet. With each different task of typing, surfing, navigating and talking, users may find troubles with the mobile phone size. For example, if the mobile phone is too large or too small it might affect the typing performance on mobile phone. Therefore, handiness of mobile phone is very important factor which may be associated with satisfaction of mobile phone use [3, 4]. We are defining handiness as perception about ease of holding/gripping, ease of task execution (e.g. calling task in case of mobile phone) and usefulness of the physical product. Recently, a grip study for talk and data modes in mobile Phones was conducted [5]. It was evident from this study that the mobile-phone form factor and size are responsible for the inclination of the handset use with respect to the size of the user's head. Many studies have been conducted on different aspects of mobile phone design; for example, look and feel of the mobile phone [6], user performance and mobile screen size [7, 8] etc. However, there is not enough information available on size preferences of mobile phones based on perceived handiness. In addition, hand anthropometry is significant aspect of design of handheld devices [9, 10]. Several studies considered the human hand anthropometry in the different task context using mobile phones [11–15]. Conversely, there are no studies which provide evidence of relationships between hand anthropometry, handiness and mobile size preference.

Based on the evidences presented in literature, it could be hypothesized that variation of mobile phone preference depends on mobile phone size and hand anthropometry. Therefore, the present study aims to find out the most preferred mobile phone size based on hand anthropometry of Indian users and perceived handiness. In present study, few parameters such as perceived handiness and preference were cognitive rather than physical in nature; whereas, hand anthropometric dimensions related parameters were physical in nature. It was important to note that perceptual and cognitive factors are sometimes very important for user preferences towards mobile phones [16].

2 Methods

2.1 Selection of Mobile Phones

A total of seven smartphones were selected from the market. A range of mobile size variations (low, medium and high) were included in the study. Height, width and depth of each mobile phone were measured as primary dimensions and then volume of each mobile phone was calculated. Detail descriptions mobile phone dimensions were given in the Table 1. Mobile phone brand related information present on smartphone was hided using sticker to avoid brand biasness during study.

2.2 Participant

A total of 233 post graduate (Semester-I) design students were participated in the present study. Among them, 36.1% (n = 84) participants were female and 63.9% (n = 149) participants were male. Their mean age was 23.56 (SD = 3.23) years. All participants had minimum 5 years of experience of mobile phone use. Students were recruited from different parts of India for this study. Details of the participants were also furnished in Table 2.

Table 1 Mobile phone dimensions

Volume wise Mobile no.	Volume (mm^3)	Height (mm)	Depth (mm)	Width (mm)	Width wise Mobile no.
Mobile-1	**44550.0**	90.0	15.0	**33.0**	Mobile-1
Mobile-2	58261.5	107.0	9.0	60.5	Mobile-3
Mobile-3	59563.0	127.0	7.0	67.0	Mobile-4
Mobile-4	**77280.0**	138.0	8.0	**70.0**	Mobile-5
Mobile-5	82368.0	143.0	8.0	72.0	Mobile-6
Mobile-6	85773.8	152.2	7.3	**77.2**	Mobile-7
Mobile-7	**88949.9**	111.0	15.5	51.7	Mobile-2

Table 2 Basic demographic parameters and hand anthropometric dimensions of participants

Parameters	N	M	SD	5th Pc	95th Pc
F/M	84/149	–	–	–	–
AGE (years)	233	23.56	3.23	–	–
HL (mm)	233	154.90	58.82	58.14	196.50
HBWT (mm)	233	84.70	32.30	31.57	110.00
HBWoT (mm)	233	71.37	27.32	26.43	93.60
PL (mm)	233	86.85	33.57	31.63	115.00

HL Hand Length; *HBWT* Hand Breadth With Thumb; *HBWoT* Hand Breadth Without Thumb; *PL* Palm Length; *F/M* Female/Male

2.3 Hand Anthropometry

Relevant hand anthropometric dimensions such as Hand Length, Hand Breadth with Thumb, Hand Breadth without Thumb, and Palm Length were measured using 'Samrat Ruler' and 'Spring Caliper'. Hand anthropometric dimensions are presented in Fig. 1. Hand length is defined as the distance (at palmar surface) from the base of palm to the tip of the middle finger, when hand is straight and stiff, with fingers together and extended [17]. Palm length is the distance from the base of the middle finger to the base of the palm, at the palmar surface [17]. The maximum breadth across the palm with the thumb at right angle to the long axis of the hand is known as hand breath with thumb [17]. Hand breath without thumb is measured as the maximum breath across the palm at distal ends of the metacarpal bones (where the fingers join the palm) of the index and the little [17].

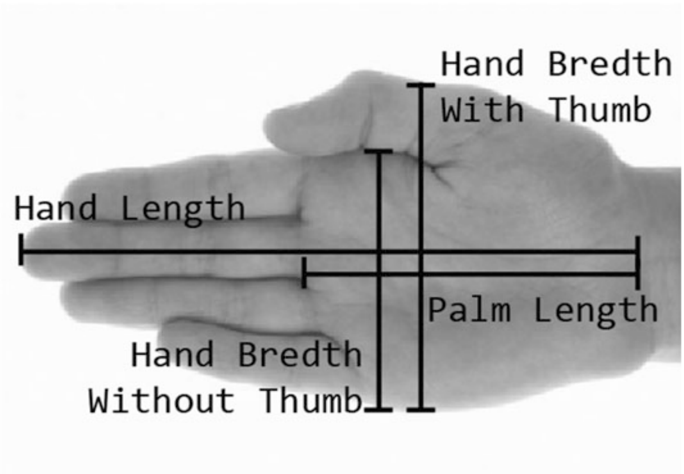

Fig. 1 Hand anthropometric dimensions measured in this study

2.4 Measurement of Handiness and Mobile Size Preference

Handiness and mobile size preferences were measured using 9 point Likert scale in which '1' is strongly disagree and '9' is strongly agree. Authors defined handiness as perception about ease of holding, ease of task execution (holding, typing, and calling) and usefulness of the physical product after use. Therefore, the handiness scale constructed of related items. Reliability of the handiness was measured by calculating the value of Cronbach's alpha from responses of 233 participants [18]. The alpha value was 0.85 which satisfied the minimum requirement of alpha value (0.70). Size preference scale was composed of two items measuring g the perceived size preference and willingness to use of phone of a particular size. Reliability of this scale was measured by calculating the Pearson's correlation coefficient (r). Calculated 'r' value was 0.79 and between item correlation was significant ($p < 0.01$). These results satisfied the minimum requirement of 'r' value 0.50 [18]. All items for handiness and size preference scales were presented in the Table 3.

2.5 Procedure

Initially, the all demographic information of users was noted and hand anthropomorphic dimensions were measures. Then the each participant was asked to use all mobile phones (Tasks were typing and calling) for at least 30 min. All users interacted with mobile phones and gained handiness experience thoroughly. After this experience, all participants were asked to rate all mobile phones on handiness and mobile preference scales. Then the statistical analysis was conducted on all collected data. Different descriptive and inferential statistics were utilized and data presented in this paper. Names of all statistics were also mentioned in an appropriate place, in the result section.

Table 3 Items of the handiness and mobile size preference scales

Measures	Items
Handiness	This phone is easy to grab
	This phone is easy to hold
	This phone is helping me to type text easily
	This phone can help me to talk continuously for long time
	I feel this phone could be easily handled
	This phone makes me feel that it is usable
Preference	I would prefer to have this phone with same dimension
	I would love to use this phone in future

3 Results

3.1 Correlations Among Hand Dimensions, Handiness and Mobile Preferences

Pearson's bivariate correlation coefficient (r) was calculated to establish relationships among hand anthropometric dimensions, handiness and mobile phone size preference. It was observed that handiness and size preferences had significant correlations with all hand dimensions considered under this study ($p < 0.05$). Correlation matrix presented as Table 4 in which it was observed that all hand dimensions were positively and significantly related to each other ($p < 0.05$). In addition, handiness scores and size preference scores were also positively and significantly related to each other ($p < 0.05$).

3.2 Variations of Handiness and Mobile Phone Preference Scores

Mobile phone sizes were calculated in terms of volumes and ranked in ascending order (small size to large size). Then dummy mobile phone dimensions (1–7) were assigned for further calculation. Mobile phone width is another important dimension to hold a mobile phone. Similar to mobile volume, mobile width wise ranking was also done and, then dummy mobile widths (1–7) were assigned. All mobile phone dimensions were presented in Table 1.

One way ANOVA was conducted four times. Once, mobile volume was considered as independent variable for handiness and preference variation study. Next time, mobile width was considered as independent variable for handiness and preference variation study.

It was observed that perceived handiness [$F(6, 232) = 23.33$; $p < 0.001$] and mobile size preference [$F(6, 232) = 25.86$; $p < 0.001$] scores were varied

Table 4 Relationships among hand dimensions, handiness and mobile preference

Parameters	HL	HBWT	HBWoT	PL	HN	MPREF
HL	1.00	–	–	–	–	–
HBWT	0.98*	1.00	–	–	–	–
HBWoT	0.98*	0.99*	1.00	–	–	–
PL	0.95*	0.95*	0.95*	1.00	–	–
HN	−0.30*	−0.32*	−0.33*	−0.31*	1.00	–
PREF	−0.32*	−0.33*	−0.33*	−0.33*	0.73*	1.00

HL Hand Length; *HBWT* Hand Breadth with Thumb; *HBWoT* Hand Breadth without Thumb; *PL* Palm Length; *HN* Handiness; *MPREF* Mobile Preference
*Significant at the level of 0.05

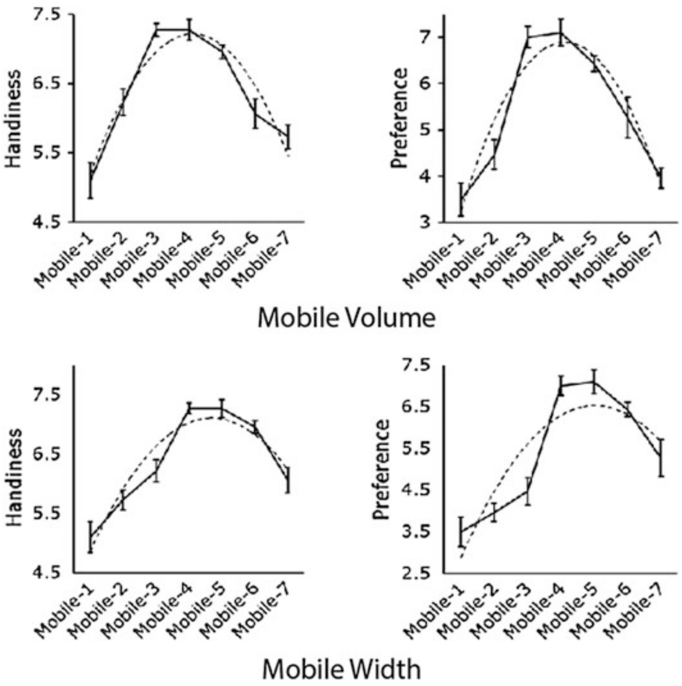

Fig. 2 Changes in handiness and mobile preference according to mobile phone dimensions

significantly due to changes in mobile size (volume). When mean values of perceived handiness and mobile size preference scores were plotted against various mobile sizes, it was revealed that perceived handiness and mobile size preference were increasing up to a certain mobile size and then it decreases. When trend lines (dotted lines in Fig. 2) were plotted on handiness and mobile size preference curves, these were appeared as inverted 'U' shaped curves.

It was evident that perceived handiness [$F(6, 232) = 23.33$; $p < 0.001$] and mobile size preference [$F(6, 232) = 25.86$; $p < 0.001$] scores were varied significantly due to changes in mobile width. When mean values of perceived handiness and mobile size preference scores were plotted against various mobile widths, it was revealed that perceived handiness and mobile size preference were increasing up to a certain mobile size and then it decreases. Similar to mobile size curves, when trend lines (dotted lines in Fig. 2) were plotted on handiness and mobile size preference curves against mobile widths, these were appeared as inverted 'U' shaped curves.

4 Discussion and Conclusion

Based on the evidences it was hypothesized that variation of mobile phone preference depends on mobile phone size and hand anthropometry. Hand length, hand breadth, palm length etc. were found to affect the users' preference of mobile handset [13]. Similar findings were observed in the present study. Perceived handiness was negatively related to hand dimensions ($p < 0.05$). It could be argued that larger the hand dimension, lesser the preference for a particular size of mobile. This phenomenon was clear from the trend curves (Fig. 2). These curves showed that mobile phones which are too big and too small were not preferred by users. Negative significant correlations ($p < 0.05$) also observed between size preferences which had with all hand dimensions. These results showed that users preferred mobile phones which are relatively bigger than their hand size. It can be inferred from correlational study results that the perceived handiness might be the basis of mobile size preference as handiness and size preference scores positively and significantly were related to each other ($p < 0.05$). Therefore, the perceptual factor (perceived handiness) was very important for user preferences towards mobile phones. Similar argument was also made by Chuang, Chang, and Hsu in the year 2001 [16].

Mean values of perceived handiness and mobile size preference varied significantly from mobile phone size (volume). This means that mobile phone size (volume) has significant effect on perceived handiness and preference. From the mean plots of perceived handiness and preference to size, revealed that small sized mobile phones which are either too small (Mobile-1: H = 90.0 mm; W = 33.0 mm; D = 15.0 mm; V = 44550.0) or too large (Mobile-7: H = 111.0 mm; W = 51.7 mm; D = 15.5 mm; V = 88949.9) were not handy and people were not preferred these mobile sizes as these are not handy. On the other side mobile phone which had medium size (Mobile-4: H = 138.0 mm; W = 70.0 mm; D = 8.0 mm; V = 77280.0) was perceived as much handy and mostly preferred by the users. Width wise plot of means of perceived handiness and mobile preference showed the similar fashion of handiness and mobile preference. Width wise handiness and preference was highest in case of Mobile having width of 70.0 mm; whereas, mobile phone with lowest width (33.0 mm) and highest width (77.2 mm) were less preferred by the users as these were comparatively less handy (please see Fig. 2).

Users preferred the mobile phone size which is relatively bigger than their hand size. However, neither too small mobile phones nor too large ones in size were preferred by the users. If we look at both the results of widthwise and volume wise variations of handiness and mobile preference, it can be concluded that Mobile-4 (H = 138.0 mm; W = 70.0 mm; D = 8.0 mm; V = 77280.0) was most preferred by the user, among the mobiles under study. This study also unveiled the pattern of mobile phone size preference based on handiness and human hand anthropometry. There were only seven mobile phone sizes were evaluated in this study. This might be one of the limitations of this study. Physical ergonomic factor such as anthropometry is not always positively related to product related experiences and product preference. However, cognitive factor like perceived handiness might have positive impact on product preference.

Scope of investigations of certain factors like phone weight and some form-based aspects (e.g. bottom curvature) are limited in the present study. However, effect of these factors could not be evaluated in future. The study also does not cover senior citizens/children whose gripping ways as well as anthropometric dimensions will differ from young adults.

In future we could also consider mobile preferences according to gender. In order to thoroughly understand mobile phone preferences of Indian users a more investigations has to be made from the point of view of socio-cultural influences, price and aspects of physical design and/or features of the interfaces.

5 Practical Implications

It is established in this study that perceived handiness is an important factor to determine the mobile size preference. It is revealed that users do not always perceive a mobile phone as handy even if it exactly fits their hand; rather, they perceived a mobile phone as more handy which is relatively bigger in size than their hand size.

Designers need to measure perceived handiness to determine the most preferred mobile phone size. Retailers might suggest to consumer to have relatively bigger mobile phones to their hand but mobile phones should not be too big or too small to the users' hands. The new scale prepared to measure perceived handiness is also beneficial for designers to measure handiness of a mobile phone.

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Ergonomic Evaluation and Customized Design of Toothbrush Handle

Vibha Bhatia, Amit Bhatia, Parveen Kalra, Jagjit Singh and Rahul Datta

Abstract Toothbrush handles available in the market are classified in adult, junior and baby sizes. As per IS 3387:2004, the length of the handle for these variants is specified. However, the width and thickness of the handle is not specified. As per the standard “The width and thickness of the handle may vary according to the individual design”. The focus of the current work is to design an ergonomic toothbrush handle based on hand anthropometry. This would improve the grip of the handle (user comfort) and enhance oral hygiene. A commercially available toothbrush was taken as reference to find out the optimal parameters of toothbrush handle. Hand anthropometric data of volunteers was collected. The comfort rating of these volunteers was related to the normalized handle sizes. The resulting regression equation was used to find out the optimal handle dimensions. Contact area was measured using both commercially available toothbrush handle and the same toothbrushes with different fabricated handle sleeves. Electromyography activity was recorded for muscle fatigue. The plaque index was also obtained before and after two weeks of using customized toothbrush handle. It was observed that the customized toothbrush handle was comparatively more purposeful. **Relevance to Industry**. From the results of this study, tooth brush designers, researchers and manufacturers can obtain guidelines for maximising grip comfort based on the hand sizes of users. The results also shows that optimal handle diameter will result in

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increasing the subjective comfort rating which will further increase the user performance and will lower the risk of muscle fatigue.

Keywords Toothbrush handle · Distal oblique grip · NHS · EMG · Grip force · Subjective comfort rating · Ergonomics · Anthropometry · Plaque index · Muscle fatigue · RPT

1 Introduction

A toothbrush is a fundamental product used to maintain the oral hygiene of an individual. If teeth are not properly cleaned, bacteria interact with the food particles present. This releases an acid and causes tooth decay. Dental Plaque is sticky transparent bacterial mass accumulated on our teeth. Built up plaque gets converted into Tartar which is difficult to remove by normal brushing.

Survey by Dental Council of India says that 89.6% of periodontal disease occurs in the age group of 35–44 years. Also, according to a recent study held in Australia, adults over 35 are prone to lose more teeth due to gum diseases than from cavities. Gingiva is a soft tissue lining surrounding the teeth which provides a seal around them. Some individuals face a problem of gingival recession (receding gums) which leads to exposure of roots of teeth due to loss in gum tissues. Gingival recession commonly occurs in individuals over 40 years of age, but it may also occur in teenagers, around the 10–12 years of age. To get rid of this problem, the pressure on the toothbrush handle must not be excessive. Excessive pressure would further lead to receding gums.

Ergonomics, a science behind making products more efficient, can be used to improve toothbrush handle design. As per IS 3387:2004, the length and size of the head of the brush is specified, but nothing is mentioned about the width and thickness of toothbrush handle. While brushing teeth some people find it difficult to grip the toothbrush properly due to the sleek design of toothbrush handle. The brush may also slip from the hand in such a case. Therefore, excessive force is required to grip the toothbrush in between the fingers resulting in hand muscle fatigue. Kong and Lowe have stated that the maximal voluntary contraction (MVC) force of finger depends on handle diameter. Therefore, the variability in handle sizes should be in accordance with hand and finger sizes [1]. The authors also suggested that for smaller handles the ring finger's contribution to grip force is higher than that of the index finger and vice versa. According to the authors, there is increase in the contribution of the middle finger when the handle diameter is increased up to 40 mm. Some researchers used electromyography and force sensors to define the optimal diameters of the cylindrical handle, considering finger forces and muscle activity [2].

In some cases, where the toothbrushes are not ergonomically designed, it may not be effective in plaque removal. Ergonomically designed toothbrush handle ensures a relaxed grip and reduces pressure on both teeth and gums enhancing plaque removal.

Though there are five methods of holding a toothbrush, distal oblique is most commonly used and is considered here for experimentation. In real world, it is very difficult to analyze the grasping of any object and is dependent on the comfort ratings of the user [3]. In this work the author has observed a strong correlation between perceived subjective comfort and user performance and has suggested incorporation of this aspect during the design phase [4]. Gregor Harih and Bojan Dolšak have suggested that developing the digital human hand model with the use of Magnetic Resonance Imaging (MRI) and subsequent 3D printing of the optimal diameter tool handle using the anthropometric data will give an anatomical shape to the tool handle [5]. This would increase the perceived level of comfort.

The focus of the current work is to find the optimal handle size that would result in increased contact area, reduced muscle fatigue and increased user comfort rating [5]. The aim is to develop an approach that would finally give optimal size for a range of hand sizes in accordance with design for human variability. The paper is organized along the following lines: Sect. 2 describes the methods used in current investigation; Results and discussion are given in Sect. 3 whereas conclusions are given in Sect. 4.

2 Methods

2.1 Subjects

The study showed that the urban population of Ludhiana is more prone to periodontitis than rural population (periodontitis is the medical terminology equivalent to gingival recession) [6], so volunteers considered for study were mostly urban. Majumdar [7] studied that in different regions of India we find different Indian population, so North Indians were focused as the target user population. Forty right handed University students volunteered in the study, twenty of both genders within the age group of 22–28 years. In the Handgrip strength test performed, the best of three trials for the grip strength for males varied between 32–62 kg and for females it was 16–26 kg. Further, these volunteers had no prior complaint to muscle fatigue. Participants were informed about the study and their willingness was recorded on the consent to participate form. The averages of their ring finger length (from hand crease), population height and hand width were 171.5 ± 20.5 mm, 1780 ± 42.0 mm and 81.5 ± 13.5 mm respectively. The study was approved by the ethics committee, COE-I & PD of PEC University of Technology, Chandigarh, India.

2.2 Equipment

Vernier caliper. Vernier calliper with least count of 1/20 mm = 0.05 mm was used to measure the hand anthropometric data of the volunteers for the design purpose. Hand length was measured from the crease of the hand to the tip of the finger considered in design.

Electromyographic measuring system. The electromyographic activity of the Extensor Digitorium (ED) muscle was acquired at a sampling frequency of 1000 Hz. EMG is used in the experimentation to detect the muscle fatigue while gripping the toothbrush. Surface electrodes, used to extract the EMG activity of muscle, were positioned over the Extensor Digitorium muscle parallel to the longitudinal axis of the muscle fibers [8].

2.3 Experimental Design

The handle shape of a commercially available toothbrush (Thermoseal) having circumference 34 mm (ring finger location) was selected as a reference for evaluation out of all the reputed brands of toothbrushes.

The other four 3D printed handle sleeves having circumferences 42, 51, 55, 59 mm were considered in study. Here standard toothbrush with same bristle length, softness, sharpness and material was used prior and after the change in circumference. This toothbrush is shown in Fig. 1 (Fig. 2).

The main aim of study is to find out the handle diameter according to individual's hand anthropometric factors considered. Procedure for experimentation is shown in Fig. 3. Before the experiments, all volunteers were asked about illnesses or injuries of their upper extremities by which the results could be affected. Brief

Fig. 1 Toothbrushes used while taking subjective ratings (*thinner one* being commercially available toothbrush)

Fig. 2 Customized toothbrushes according to hand anthropometry

purposes and procedures of the experiment were discussed with the volunteers. Experiment has been conducted in two phases as given below:

Phase 1. Five different circumferences (34, 42, 51, 55, and 59 mm) of handle at location of ring finger were used in experimentation. Each subject was asked to rate

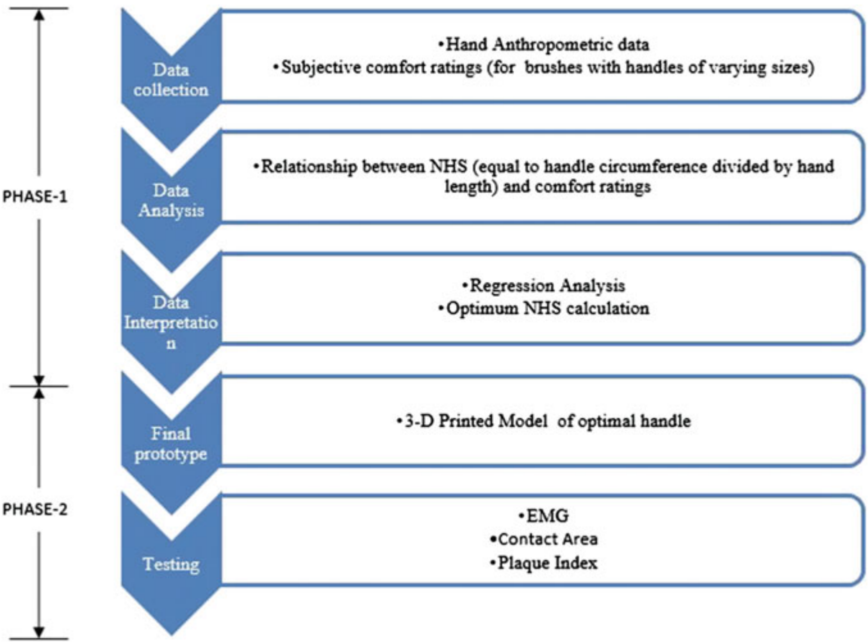

Fig. 3 Procedure of experimentation

all toothbrushes with variable circumferences on the Semantic scale of 1–7 (1—Very uncomfortable, 2—Moderately Uncomfortable, 3—Somewhat Uncomfortable, 4—Neutral, 5—Somewhat Comfortable, 6—Moderately Comfortable and 7—Very Comfortable). As the ratings for various brushes were taken in random order, therefore, it was a balanced design.

Hand Anthropometric measurements of the volunteers were assessed. All volunteers were asked to grip the toothbrush of various circumferences in their right hand and subjective comfort ratings were collected. For smaller handles, ring finger has higher contribution while gripping from index finger [1].

Phase 2. The volunteers were provided with the toothbrush of optimized handle design and were asked to grip in their hand. The EMG muscle activity was recorded and analyzed to check the muscle fatigue. In surface EMG, for the assessment of muscle fatigue, Mean Frequency (MNF) and Median Frequency (MDF) are most useful frequency domain features [9]. The optimal variables (i.e. MNF and MDF features) which are extracted from EMG are used to identify the muscle fatigue [10]. Extensor Digitorium muscle was chosen to find out the Median Frequency (MDF) of the EMG activity. These muscles stabilize the wrist during gripping motions. The stronger the grip, the stronger the muscle (extensor digitorium) gets activated.

The contact area signifies the comfort level of any object. For handles, more the contact area more will be the comfort in gripping the handle [5]. Paint was used on the handles during the experimentation and the volunteers were asked to grip the handle and trace it on the A4 size blank paper. The contact area was compared for the commercially available and the customized handle and the results were assessed.

Dental indices are used for recording oral diseases in individuals. According to Russel AL, Index of plaque is basically a defined graduated scale having upper and lower limits, with scores on the scale which correspond to specific criteria and is designed to facilitate comparison with other population. Oral Hygiene Index (OHI), developed in 1960, was used in the research work. OHI is simple and sensitive method used for assessing individual oral hygiene. Debris Index used in the study is scored between 1–3 scale, which signifies ‘0’—no debris or stain present, ‘1’—soft debris or extrinsic strains covering not more than 1/3rd the tooth surface, ‘2’—soft debris covering more than 1/3rd but not more than 2/3rd of the exposed tooth surface and ‘3’—soft debris covering more than 2/3rd of the exposed tooth surface. Rating scores for Oral Hygiene Index (OHI) indicates ‘0’ for excellent, ‘0.1–1.7’ for good, ‘1.8–3.4’ for fair, and ‘3.5–5.0’ for poor. On the basis of above theory, plaque score of all individuals were assessed, as in Eq. (1).

$$\text{Plaque Score of an individual} = \frac{Total\ Score}{Number\ of\ teeth\ examined} \tag{1}$$

The plaque index before and after the use of customized toothbrush was compared. The improvement in the plaque index will signify an improved design.

3 Results and Discussion

3.1 Experimentation—Phase 1

NHS is expressed as a function of handle size and key hand anthropometric dimensions related to the grasping. NHS is taken as the ratio of Handle Circumference (HC) at location of ring/middle finger to hand length (HL) at ring/middle finger. NHS (Normalized Handle Size) was defined in a manner similar to that given by Kong, 2001 and is calculated as:

$$NHS_{ij,k} = \left(\frac{HC_j}{HL_i}\right) * 100 \tag{2}$$

where HC is the handle circumference (mm) of handle *j*, HL is the Hand Length (mm) of volunteer *i*, *i* is the subject, *j* is the handle, *k* is the subject number, NHS_i is the Normalized Handle Size based on hand length measured at ring finger, NHS_j is the Normalized Handle Size based on hand length measured at middle finger. These parameters are shown in Fig. 4a, b.

Subjective comfort rating for the gripping task was assessed and relation between NHS and subjective comfort rating was evaluated using Minitab® 17.1.0. Software. There were total hundred experiments. The regression model was used for the relationship between NHS and the subjective comfort ratings. It was further used to derive the NHS that maximizes the subjective comfort ratings for handle.

The effect of both fingers (middle and ring finger) in gripping the handle was found out using Minitab® 17.1.0. The various types of regressions i.e. Linear Regression, Quadratic Regression and Cubic Regression were undergone. Regression data is given in Table 1.

For Linear Regression, the R^2 value was 9.60%, which is very low and hence was not considered for design purpose. Likewise, for Cubic Regression, the p values for both the fingers were 0.187 and 0.227 respectively, which were insignificant. The result was significant for Quadratic Regression with R^2 value 68.9%. Moreover, the NHS based on the ring finger shows the p value ($p < 0.014$) significant than that based on the middle finger for this regression model. This shows that while gripping the toothbrush, the ring finger contributes more as compared to middle finger. Therefore, the NHS based on ring finger was considered for the design purpose. The variation of comfort rating with NHS based on hand length measured at ring finger is shown in Fig. 4.

The relation between comfort rating and NHS works out to be:

$$\text{Subjective comfort rating} = -0.03783 * (NHS)^2 + 2.166 * (\text{NHS}) - 25.94 \tag{3}$$

The optimal value NHS obtained by first derivative of the Eq. (3) works out to be 28.63%, [NHS% = 2.166/(2 * 0.03783)]. As ring finger came out to be the most significant factor, taking ring finger hand length as a reference, handle

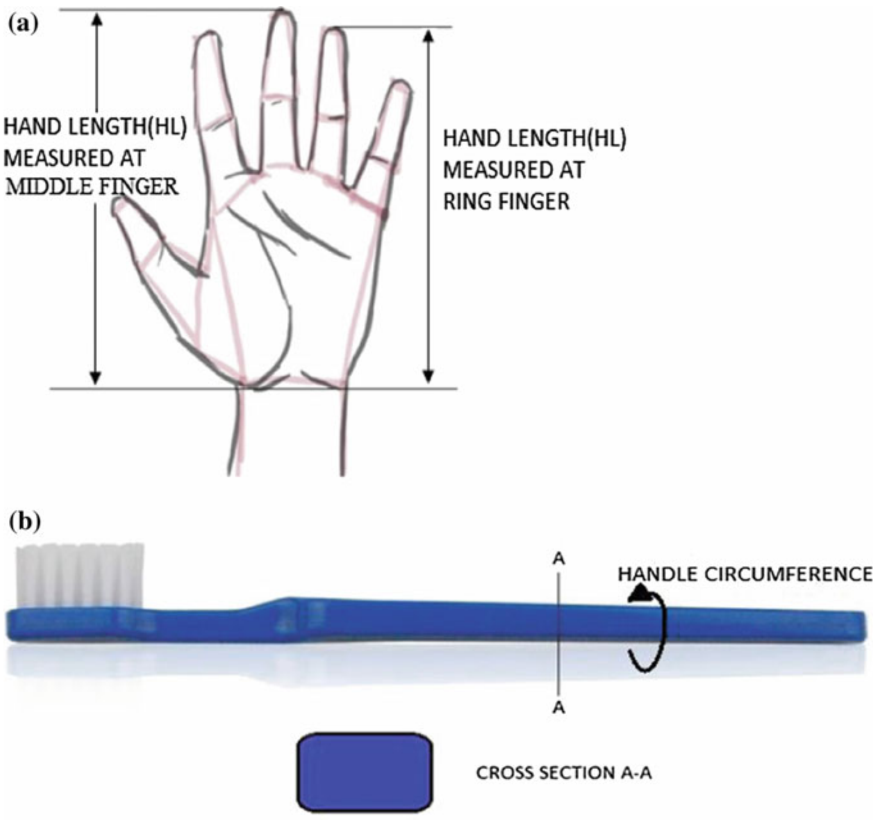

Fig. 4 **a** Hand length measurements for ring and middle finger. **b** Cross section showing handle circumference (HC) of tooth brush

Table 1 Regression analysis data

Regression	R-square (%)	p-value		Significant factor
		Ring finger	Middle finger	
Linear	9.6	0.033	0.015	–
Quadratic	68.9	0.014	0.995	Ring finger
Cubic	71.89	0.277	0.187	–

circumference(optimal) [i.e. $Handle\,Circumference_{Optimal}$ = user's hand length * $NHS_{Optimal}$] was found out for all the forty volunteers based on their ring finger hand lengths. Further, experimentation was done on four representatives out of forty. The customized handles were fabricated using Rapid Prototyping Technology (RPT) for a subset of the volunteers (Table 2).

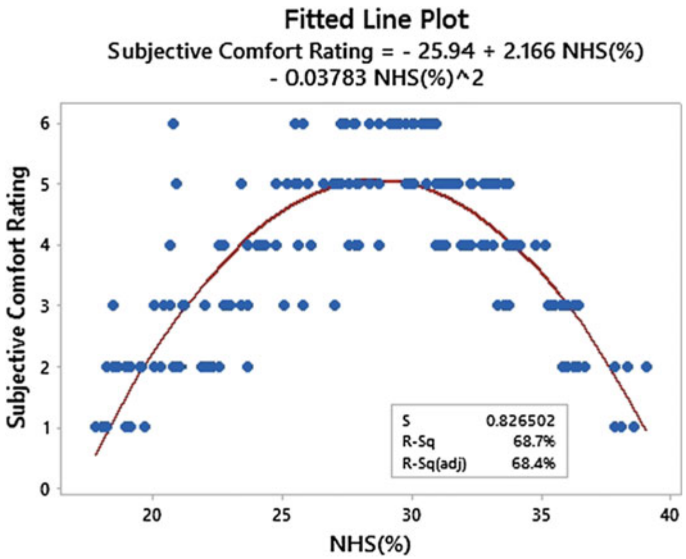

Fig. 5 The relationship between subjective comfort rating and NHS

Table 2 Recommended handle diameters of 4 representatives for maximizing subjective comfort

Volunteers	Hand length (mm)	Handle width (mm)	Handle depth (mm)	Recommended handle diameters (mm)
1	178	17.9	10.7	18.2
2	180	18.1	10.8	18.4
3	156	16.1	09.7	16.4
4	167	17.2	10.2	17.4

3.2 Experimentation—Phase 2

Plaque score was found out for 4 representatives based on the Oral Hygiene Index (OHI). The normal plaque score of all the representatives were 1.33, 1.5, 1.33 and 1.5 respectively. The representatives were provided with the optimally designed

Table 3 Plaque index scores before and after brushing with optimally designed toothbrush

Volunteers	Plaque index	
	At start of experimentation	After brushing with optimally designed toothbrush for 2 weeks
1	1.33	1.2
2	1.5	1.3
3	1.33	1.1
4	1.5	1.3

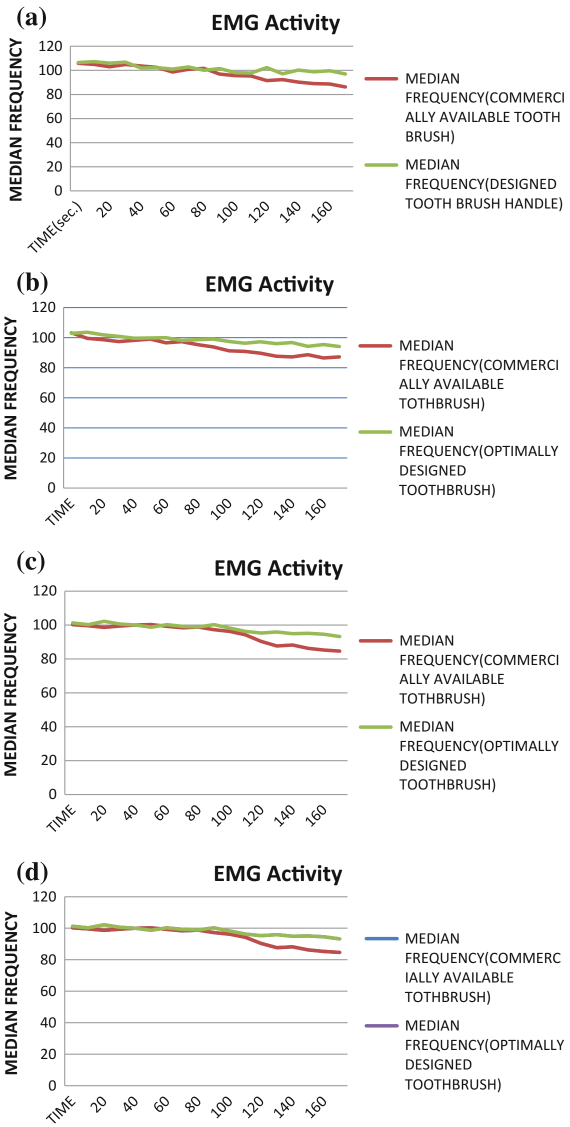

Fig. 6 **a** The graph showing the median frequencies on both the handles of volunteer 1. **b** The graph showing the median frequencies on both the handles of volunteer 2. **c** The graph showing the median frequencies on both the handles of volunteer 3. **d** The graph showing the median frequencies on both the handles of volunteer 4

toothbrush handle and were asked to use the designed toothbrush handle while brushing for two weeks. The improvement in plaque score was noticed after the use of the designed toothbrush handle by all 4 representatives. Plaque Index scores before and after brushing with optimally designed toothbrush is given in Table 3.

Fig. 7 Hand prints taken to measure contact area for both type of handles of all the four representatives

Table 4 Contacts areas of toothbrushes

Volunteers	Areas (cm^2)	
	Commercially available toothbrush	Optimally designed toothbrush
1	24.80	32.70
2	27.10	37.70
3	20.80	28.60
4	21.30	30.17

Median Frequency is considered for the assessment of muscle fatigue. Muscle fatigue was detected in static contraction as the EMG signals during short-time intervals may be assumed to be stationary. The EMG Activity during grasping of commercially available and the designed toothbrush handle were extracted and the graph between their Median Frequencies is plotted for all the 4 representatives, as shown in the Fig. 6. It was observed that the fatigue occurred earlier for the commercially available handle as compared to the designed handle for all representatives.

The contact area of both the handles was assessed. The handles were painted and the representatives were asked to grip the handles one by one. After gripping, hand impressions on blank paper for both handles were obtained. Areas were found by Meshing/Triangulation method. The results were compared for the hand impressions for both handles. It was seen that the contact area for the designed handle was more as compared to the commercially available handle. The contact areas obtained on the blank sheets for both the handles are shown in Fig. 7.

LEFT SIDE Impression—Using Commercially Available toothbrushes.
RIGHT SIDE Impression—Using Ergonomically designed toothbrushes (Table 4).

4 Conclusion

Experimentation shows that brushing with the customized handle results in increase of perceived comfort and reduction of muscle fatigue. Brushing with this toothbrush also results in reduction of plaque index. A toothbrush handle should therefore be designed on the basis of suitable hand anthropometric parameters. This would include the hand length measured at ring finger. In future, effort would be made to consider different sections and designs of toothbrush handle and inclusion of additional anthropometric parameters for evaluation of dependent design parameters.

5 Future Scope

The study is limited to manual brushes only and hence the concept of motorized brushes was kept out of scope for time being and was kept for future evaluation(as results of fatigue/plaque index in motorized brushes will depend on other parameters like motor performance, bristle movement and vibration etc.). The future study will take the survey feedback for five different types of brush holding techniques which was avoided in the current study to maintain the simplicity of the problem at initial stages of research. Also, the static EMG analysis was done as a part of initial study, so dynamic analysis and evaluation will be done in further experimentations to serve the real life problem in design. DfHv approach will be considered for designing the toothbrush handles for the ranges of hand sizes where we can design it for different segments like baby, junior sizes etc.

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Implementation of Ergonomic Design Interventions to Improve Workplace Amenities for Assam Policewomen

Shilpi Bora, Abhirup Chatterjee, Sougata Karmakar and Debkumar Chakrabarti

Abstract Womanhood issues at workplace with specific reference to basic amenities are major problem in the police duties. This paper looks into the womanhood specific issues at Police Stations. Personal interview and individual responses to a subjective assessment questionnaire were recorded from forty policewomen of different ranks posted in Guwahati, Assam (N = 40, purposive non-probability sampling) to have their views on these issues. A thorough scrutiny of the actual situation revealed critical lack of facilities and basic amenities for policewomen (pertinent to womanhood) at workplace, i.e. the general police stations. Analysis of the responses reflected policewomen to be under stress at their outdoor duties and workplace also, specifically due to the lack of privacy and conveniences facilities. This piece of work depicts the views and feelings of policewomen before and after implementation of proposed design interventions in an existing police station, there by improvement of their occupational wellbeing.

Keywords Womanhood issues in police force · Convenience facilities · Police station amenities · Occupational wellbeing

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1 Introduction

Women contributions in law enforcement have progressed tremendously during the last three decades. Globally (as stated by UN women report, 2011), a standard of just 9% of the police is women, with rates declining as low as 2% in some divisions of the globe. On average, women do not encompass more than 13% of the gross police force in any region. In nearly all developed countries, women make up to 25% of the total force. Police job have traditionally been dominated by males. However, with more and more females entering the workforce and more prominence being placed on equivalent opportunity hiring, there has been a vast increase in the number of women becoming police [1]. Barely 6.11% of the total police force in the India is initiated for Women in the Police Force as reported by CHRI [2] and recently Government of India has reserved 33% women in force.

Consequently, an effective and efficient workplace for policewomen along with safety and proper convenience facility in such police stations (previously suited the male predominant job) has become imperative for their occupational wellbeing. Occupational stress of a police is a widespread problem because of its various negative effects on individuals and on police organizations, where stress is considered as the one of the principal factors [3, 4]. The Parliamentary Committee on the 'Empowerment of Women' documented the working conditions of women in the police force (in its 2013–14 and 2014–15 reports) emphasizing the lack of facilities for women. The Committee articulated that these issues can only be tackled through focused efforts and consistent follow up by the Government along with time-bound action plans. In addition, the 6th and 7th National Conferences on Women Police ([5] and [6] respectively) reported the lack of facilities for women personnel and initial phasing in of ergonomic adjustments in workplace facilities.

The present study looked into the womanhood specific issues related to the basic amenities and privacy in their workplace. The particular stress instigate for daily living or working situations might lead to diverse health tribulations and subsequent revolutionize in job performance and above all, quality of life [7]. Hence, this study addressed the womanhood specific issues and occupational wellbeing of woman police personnel lacking the basic facilities such as rest room, separate toilet facility, crèches, privacy etc., availability of which might reduce the level of occupational stress among the women sharing common workplaces in police stations at Guwahati city, India.

2 Methodology

This cross-sectional study was conducted among policewomen from Guwahati, India. Permission through proper channel was obtained from the Institutional Committee and Police Commissionerate both. The study encompassed all levels of women employees working in the city police stations of Pan Bazaar. Individual responses to a subjective assessment questionnaire (vide Table 1), on forty policewomen (N = 40, different ranks but posted in Guwahati, Assam) as well as face-to-face personal interview (interactions) were obtained and compared with the records from the office of the Commissioner of Police, Guwahati and other relevant publications. The respondents were selected by purposive non-probability sampling. Later, after analyzing the responses of the questionnaire and interviews, some possible design interventions were shared with higher authorities with a two-dimensional (2D, drawing on paper) schematic working plan suggesting the framed interventions towards a better working condition of women in the police station.

Table 1 Participant response questionnaire for subjective assessment of workplace and on-job amenities

Part A: Exposure to occupational and environmental stress and perceived well-being	
Please use the following response scale to indicate the extent to which you agree with each statement regarding your job satisfaction. Please choose the scale that is most closely applicable for each statement for all the parts: (1) Strongly agree; (2) Agree; (3) Neither agree nor disagree; (4) Disagree and (5) Strongly disagree	
1	Law enforcement is generally regarded as a masculine profile, therefore we who are inducted in this job, felt that convenience is equally important for us
2	Consecutive shifts/intermittent repetitions of administrative work are common
3	Staff shortages cause stress
4	Lack of resources cause stress
5	In equal sharing of work responsibilities cause stress
6	Shift work causes stress for special cases like pregnancy, expecting mother, lactating mother, menstruation period
7	Traumatic events affects psychophysical health
8	Social life outside the job is impacted by duty regimen
9	Occupation-related health issues in special cases like pregnancy, expecting mother, lactating mother, menstruation period
10	Not enough time to maintain a good physical condition
11	Feelings like you are always on the job and other responsibilities are compromised
12	Working beyond working hours brings boredom
13	Noisy work area
14	Frequent interruptions brings disturbance in the work place
15	Inadequate or poor quality equipment/maintenance
16	Unfair work environment in this job
17	Lack of a modern system/apparatus on duty
18	Occupational health issues (e.g. back pain, neck pain, joint pain)
19	A good infrastructure brings satisfactions while doing work
20	Lack of resources in professional/promotional
21	Working alone at night is risky and I don’t feel good

(continued)

Table 1 (continued)

22	Prolong standing affects physical health
23	Lack of separate modular convenience/prompt service utilities in every police station
24	Basic amenities like isolated/separate restrooms and child care units are still a major requirement for women police personnel
25	Requirement of residential accommodation which is one of the major impediments faced by women in joining police force
26	While I am involved in outdoor duities such as patrolling, security duty on several occasions, touring in and outside the district where mobile utility facility is a compulsory requirement
27	Crèches/day care center in the police station for working mother will help them to take care of their children
Part B: On-job satisfaction	
1	Public attitude towards women police is awkward
2	Lack of separate utility facilities in police stations
3	Problems related to training
4	Govt accommodation for womanhood related issues
5	Difficulties faced in upbringing of children—day care center is essential
6	Need to have a better working environment in terms of infrastructure
7	Provision of separate toilet facility at all offices/outpost
8	A modular mobile convenience facility while outdoor duty an immediate need

The design of the study was descriptive in nature, wherein we attempted to assess the occupational stress imparted on the policewomen in their workplace. Individual interview method was also adapted to collect required information since responses to the questionnaire alone might not be abundant to have deeper observation from the respondents about the pulverized situation. The respondents might distinguish questions in their own way. This interview schedule helped us to explain the purpose of survey to the respondents and anticipate for gathering appropriate information.

3 Results and Discussion

A schematic layout of a model police station considering workplace comfort for women was designed, recommending most of the facilities that a police station requires for police personnel in their respective workplaces. To address the above findings, a 2D schematic design layout of a police station has been prepared, taking into consideration workplace comfort and basic amenities for both women and men. These include women's restrooms with toilet facilities; officers' rooms for both male and female police; one reporting room; one office for male police and one for female police, separate restrooms, canteen, jail, day care centres, a records room, reception, WC (toilet for visiting women) and an officers' room [8]. Womanhood specific utilities were considered in the police station for increasing their occupational well-being and working capacity. The entire Pan Bazaar Police Station was planned (Fig. 1) and all the convenience facilities were implemented as per the proposed layout.

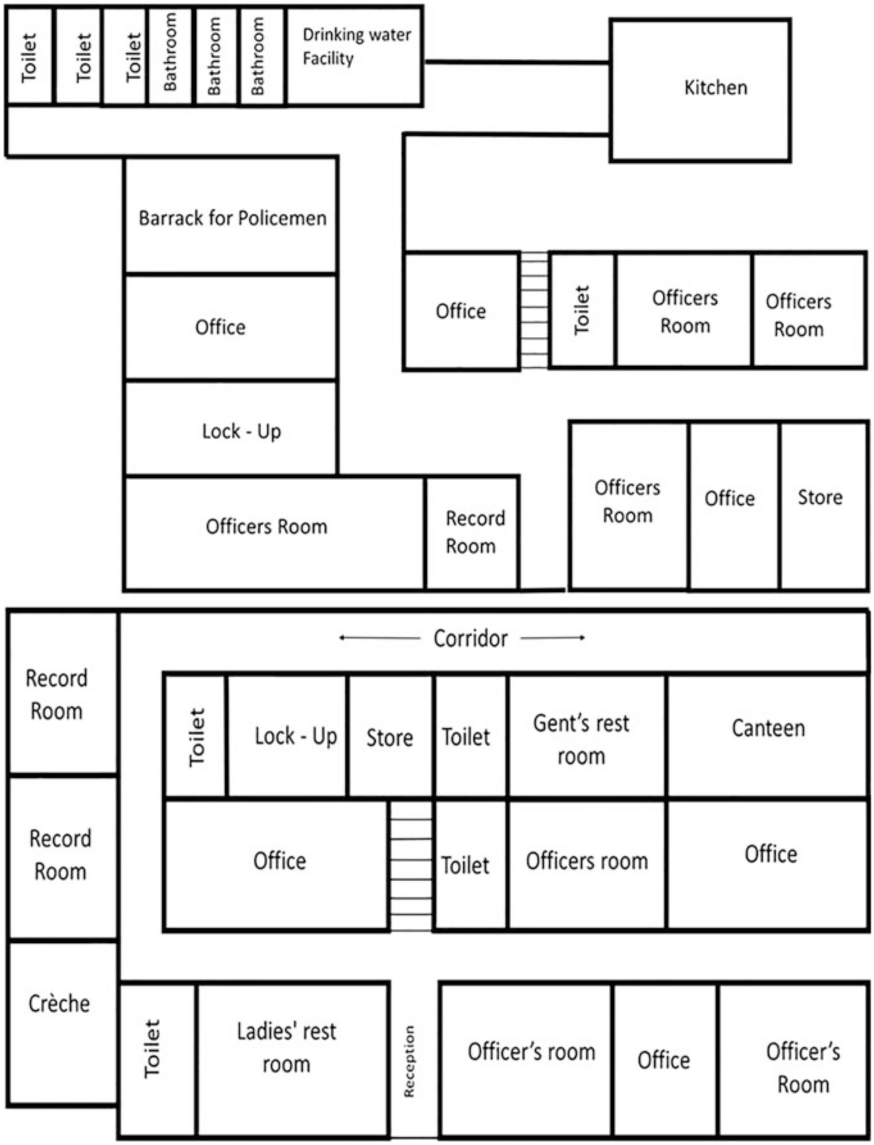

Fig. 1 Layout of the existing police station of Pan Bazar earlier (*top*) and after implementation of proposed design intervention (*bottom*)

Both the layout designs were revealed to the respondents and they anticipated that the job satisfaction will rise and with enhanced working capacity if the recommended design were implemented in the respective work places. These were the mutual needs in the work places to be addressed urgently, where ergonomic design interventions were anticipated to encompass a more hygienic, user friendly and amiable workplace, most importantly to enhance impetus for, pleasure from, and devotion to the job responsibilities.

Occupational stress in the work causes job distress. It leads to the development of negative impacts for the individual employee and the employing organization in the police station [9]. Current responses from policewomen are presented in Table 2, which expresses high exposure to occupational wellbeing of women police personnel at Police station, a questionnaire was administered to the respondents exposed and a gross varied inclination of thoughts regarding the current scenario concerning conveniences in the workplace. The government plans to induct more women into police as part of its empowerment motivation, a survey conducted among those serving has found they still grapple with lack of conveniences like toilets, want of privacy, day care center, sitting room [11]. Insufficient resources and infrastructure are the problems faced by women police, and all causes deep-rooted problems among which addressing the under-representation and conditions of women police in some ways becomes difficult. The need of these facilities subsidize to a mutual sensitivity among women police that police departments do not adequately accommodate women's particular needs.

Deprivation of general well-being as well as levels of satisfaction and obligation to the police organization has been recognized as a result of the employee undergoing occupational stress. The majority of women police personnel were subjected to stress as a result of inconveniences such as lack of adequate privacy, separate toilets, day care center, and modular utilities in the police station is one of the major causes. The female police personnel expressed that the convenience facility is the foremost requirement in each police station with specific reference to the issues of womanhood. In view of these issues nearly all the respondents suffer from work place discomfort, privacy, inefficiency and inadequacy in their workplace. A majority of women have dehydration and urinary tract infection (UTI) frequently due to lack of proper and hygienic facilities in the workplace [6]. They have also stated that the present infrastructure is not beneficial for the policewomen to work mostly during night. The respondents find it very difficult to accomplish their responsibility in this situation and thus they assumed that their performance of duty moderates for the uncomfortable environment and facilities. Correlated to this the male police also supported the issues and revealed that there should be a separate utility facility in the police station for better performance of work. (Tables 2 and 3 depicted the gross responses from 40 policewomen of Pan Bazaar Police Station, Guwahati with before (abbreviated as B in the Tables 2 and 3) and after (abbreviated as A in the Tables 2 and 3) ergonomic interventions towards the holistic occupational improvement of policewomen.)

Mobile utility van for policewomen during patrolling duty is a must due to lack of adequate facilities in the vicinity. Ideally multi-utility vans with a washroom and

Table 2 Survey results on exposure to occupational and environmental stress and perceived well-being

Questions		Strongly agree		Agree		Neutral		Disagree		Strongly disagree	
		B	A	B	A	B	A	B	A	B	A
1	Law enforcement is generally regarded as a masculine profile, therefore we who are inducted in this job, felt that convenience is equally important for us	40	40								
2	Administrative over shifting is common	40	40								
3	Staff shortages cause stress	40	40								
4	Lack of resources cause stress	40			**21**				**19**		
5	In equal sharing of work responsibilities cause stress	40	40								
6	Shift work causes stress for special cases Like pregnancy, expecting mother, lactating mother, menstruation period	20	20			12	12			8	8
7	Traumatic events affects psychophysical health	20	20	20	20						
8	Social life outside the job is impacted by duty regimen	20	20	12	12			8	8		
9	Occupation-related health issues in special cases like pregnancy, expecting mother, lactating mother, menstruation period			15	15			12	12	13	13
10	Not enough time to maintain a good physical condition	18	18	22	22						
11	Feelings like you are always on the job and other responsibilities are compromised	40	40								
12	Working beyond working hours brings boredom	40	40								
13	Noisy work area	13	13	12	12			15	15		
14	Frequent interruptions brings disturbance in the work place							40	40		
15	Inadequate or poor quality equipment/maintenance			21	21			19	19		
16	Unfair work environment in this job	40							**40**		
17	Lack of a modern system/apparatus on duty	40	40								
18	Occupational health issues (e.g. back pain, neck pain, joint pain)	20	20	10	10			10	10		
19	A good infrastructure brings satisfactions while doing work	40									**40**

(continued)

Table 2 (continued)

Questions		Strongly agree		Agree		Neutral		Disagree		Strongly disagree	
		B	A	B	A	B	A	B	A	B	A
20	Lack of resources in professional/promotional	40	40								
21	Working alone at night is risky and I don't feel good	40	40								
22	Prolong standing affects physical health	40	40								
23	Lack of separate modular convenience/prompt service utilities in every police station	40									**40**
24	Basic amenities like isolated/separate restrooms and child care units are still a major requirement for women police personnel	40									**40**
25	Requirement of residential accommodation which is one of the major impediments faced by women in joining police force	23	23	17	17						
26	While I am involved in outdoor dui ties such as patrolling, security duty on several occasions, touring in and outside the district where mobile utility facility is a compulsory requirement	30	**40**	10							
27	Crèches/day care centre in the police station for working mother will help them to take care of their children	30	**40**	10							

Table 3 Survey results on on-job satisfaction

Questions		Yes		No	
		B	A	B	A
1	Public attitude towards women police is awkward	5	35	7	36
2	Lack of separate utility facilities in police stations		40	40	
3	Problems related to training	10	30	–	–
4	Govt accommodation for womanhood related issues			40	40
5	Difficulties faced in upbringing of children—day care centre is essential			40	40
6	Need to have a better working environment in terms of infrastructure		40	40	
7	Provision of separate toilet facility at all offices/outpost		40	40	
8	A modular mobile convenience facility while outdoor duty an immediate need		40	40	

pantry, rest room, will allow cops who stand for hours together to freshen up or rest for a bit. The cops have to keep always fit and standing for prolonged hours causes difficulties—they feel exhausted, and having been forced to abstain from basic physiological necessities for a long lead to various medical problems, including kidney stones and pregnancy-related problems [10]. In the north eastern part of India, Assam is reportedly lagging behind in this regard; reports revealed that a necessary action is required for the well-being of policewomen on duty. A schematic concept of a modular mobile utility van for policewomen with interior plan was conceptualized, which might reduce their occupation hazards, increased their job satisfaction and reduce work burnout while on duty (Fig. 2a). On a special request of police personnel, a schematic interior concept of men-women combined utility van was planned to ensure better working condition of both the gender (Fig. 2b).

Table 3 illustrated the survey result of the policewomen working in the common police station; their job satisfaction index increases after implementing the design intervention for better performance of their work. An ergonomic intervention applied in their workplace reduces discomfort and inefficiency in their work life. Also, to make their workplace comfortable, safe and efficient it is important to reduce the occupational stress through design implementation.

Design possibilities considering specific areas such as separate toilet facility, rest room, privacy, and day care center have been worked out through a 2D plan. Hence the Policewomen must be provided with certain probable compensatory processes by way of better working conditions like flexible working conditions, conveniences, mobile facilities and amenities. The male counterparts in the police station encourage the changes in the police station including the specific issues of womanhood as an important concern and urge a better workplace for the police personnel. They have also recommended for an SMART police station [12] for both the genders compatible work condition.

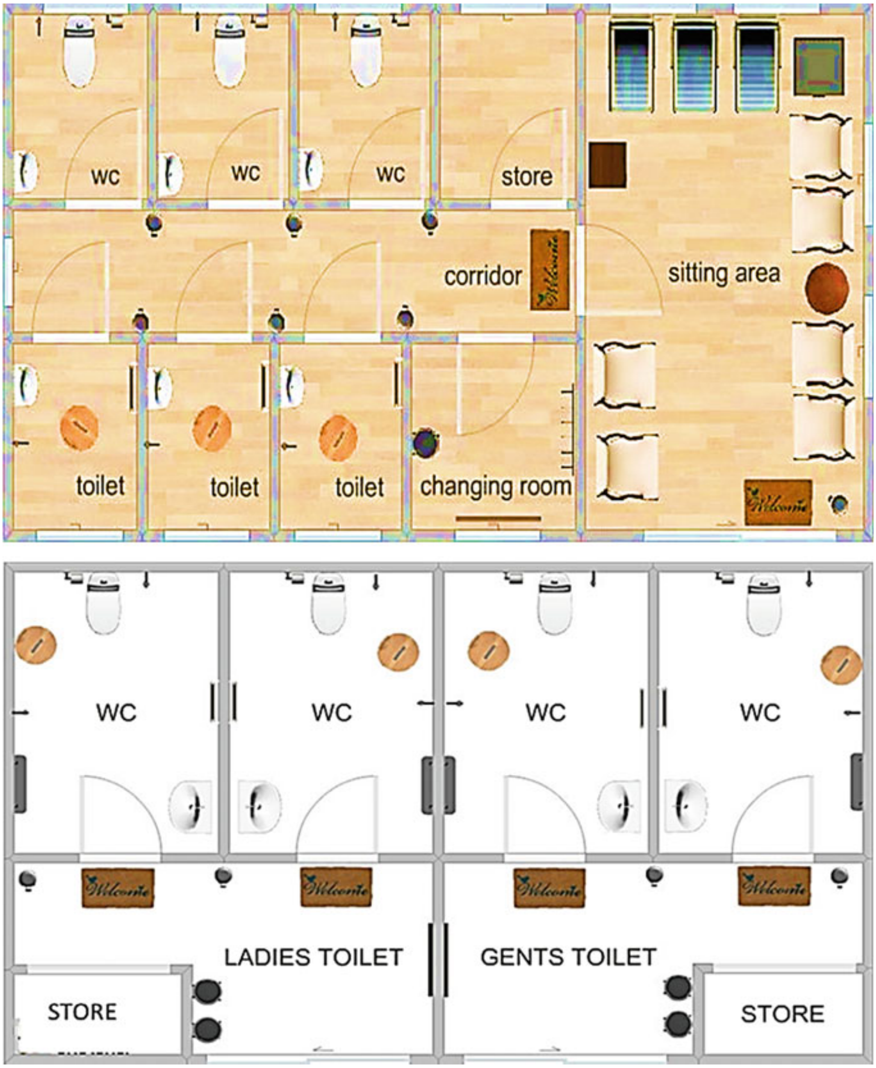

Fig. 2 Schematic interior concept of utility van for policewomen (*top*) and for common use (*bottom*)

4 Conclusion

Based on the above observation and information's collected, a recommendation to implement a set of convenience facility specific to woman-hood was made through 2D plan modification of a police station. Some of the suggestions were implemented in Pan Bazaar Police Station, Guwahati, where the feedback was very satisfactory.

The study also endeavored few prospects in police workstation concerning to occupational issues in tune to the policewomen. These changes were trailed out in consultation with higher authorities of Assam Police. It was expected to help policewomen to be comfortable against various kinds of on-job stress. It appeared that, womanhood relevant convenience facility at police station has been a major concern.

The present study was conducted on a small sample size as compared the total strength of policewomen in Assam. Further enquiries to large group considering various workplace and job demands are under process to address the women police issues at large.

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Study on User-Interface Problem-Finding Based on Flow-Line Analysis

Satoshi Kadomatsu and Yukari Nagai

Abstract A user interface is one an essential component that determines the efficacy of computer software. Therefore, evaluating and improving a user interface are crucial aspects of the software development process. User interfaces have been improved through various methods, including user testing and heuristic approaches. However, these techniques cannot be applied practically because the data provided by them may contain subjective aspects and do not reveal the developer's demands. Therefore, to develop practical methods required in this field, we interviewed the developers on site to understand their needs. With this information, we developed a technique and conducted an experiment. In the process, we successfully analysed and illustrated the problems in a user interface by using flow line analysis techniques to obtain a user's software-usage history. Finally, by applying the technique to experimental software interface and interviewing the developers, we verified that the new method provided the necessary information.

Keywords Software design · User interface · Flow-line analysis

1 Introduction

The user interface is one of the most important factors that determine the efficacy of computer software. Therefore, the evaluating and improving a user interface are crucial aspects of the software development process. Studies to improve user interfaces have used various methods. Examples of such techniques include expert review, which is a technique to discover the problem based on rules laid down by usability experts [1–5] and monitoring surveys [6–8] for the user. However, their

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use in the field of software development is limited. Because the existing approaches are too complexity to use in a practical way for software developers who design and develop the software.

Therefore, a practical approach that is more simplify and reliant on the requirements of the site needs to be developed.

1.1 Listening Survey with Software Engineers

First of all, we conducted a listening survey among software developers. The reason that a target was limited to a software developer is because they design software mainly in Japan and the voice which feels a load was heard by evaluation technique of existence.

The three major objectives of this study are:

- To find the current state of user interface evaluation at the development site
  - To clarify the problems in existing methods for improving user interfaces.
  - To find the problems associated with implementing user interface improvement methods at the software development site.
- To find the improvements required in the new technique by developers

Table 1 shows an excerpt from the result of the listening survey with software engineers.

Table 1 Excerpt of listening survey with software engineers (N = 20)

Question	Answer
Q1. Do you think software user interface is an important element?	Yes 95% (19) No 5% (1)
Q2. Are you trying to improve the user interface?	Yes 70% (14) • Asked the professional to evaluate • Listening to the opinion of the user • Doing it by experience No 30% (6) • Not enough money or time • I don't know how to do • I can't find the problem
Q3. Do you think the existing evaluation method is adequate? (Only Q2 YES)	YES 7% (1) NO 93% (13) • It is costly • Must have expert knowledge(cannot do by themselves) • I do not know the method to analyse evaluation results • We cannot continue to apply the technique

Furthermore, 10 questions are asked to developers. For example, "What is the problem of the existing methods?" "What kind of feathers do you except to new method".

Based on this listening survey, we conclude that although the developers acknowledge the existence of a problem in the user interface design along with the need to improve the user interface, the time and human resources required to evaluate the software are not sufficient. The existing methods are extremely difficult and vast quantities of data are involved, which they are not capable of analysing.

Therefore, they request an easy method, for example, one that can visualize the vast log data of the user. The new method should be suitable for implementation at a low cost in the development flow method.

In order to develop a more practical method, we conducted a study with the goal of developing a technique to meet the following requirements:

- The technique should be inexpensive and easy enough for the developer to implement it himself
- The technique should allow developers to visually comprehend a user-interface problem by using the user's operation log data
- The technique should be suitable for repeated applications in the actual work environment and incorporation into the development flow.

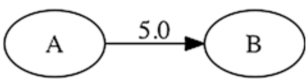
1.2 Method Development

Based on the results of the listening survey, we developed a more practical method to help developers find issues with software user interfaces.

Our method starts by logging the actions of multiple users and their access to specific software functions. This data is acquired in a production environment (an actual work environment) with user consent. Next, based on Flow Line Analysis (FLA) which visualizes a flow of users to find the problem which obstructs the expected line of flow [8–11] a flow line diagram (a weighted directed graph) is created. This displays the sequential relationship between the software functions accessed by nodes along with the access to each Edge function (primarily on-screen button clicks). In addition, edge weighs the average of the inverse downtime. (This excludes the processing time, which represents the time during which users are thinking, or lost. The unit for time is milliseconds.) The software we developed to acquire this data and draw flow line diagram can be operated easily.

For example, as shown in the flow line diagram in Fig. 1, the average downtime between accessing functions A and B is 5 s. As shown in this figure, the developer can understand and visualize the work flow of users, where users are stopping, and other unexpected patterns of errors arising during use.

Fig. 1 Sample 1



For example, when a user stops, the next function they are looking for may be in a difficult to find place from a design standpoint, making the user get lost momentarily. In addition, a user interface that leads to unexpected operations or errors in operation could be a problem.

Figure 2 shows a sample program in which buttons are pressed in the order in which they appear on screen. Each button clicks accesses a function. According to the flow line diagram, the users could access functions A through E without getting lost; it could be said that there are no problems with the user interface design in this case.

Next, Fig. 3 shows the results obtained by using the program from Fig. 2 and intentionally placing the button C in a hard-to-find place; it is a design that easily leads to errors. The flow line diagram shows that users mistakenly accessed function D after function B, or were lost during a long period of inactivity.

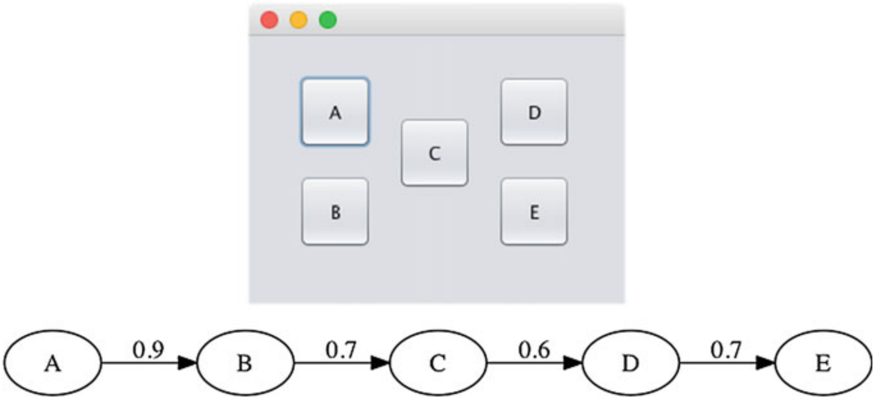


Fig. 2 Sample 2

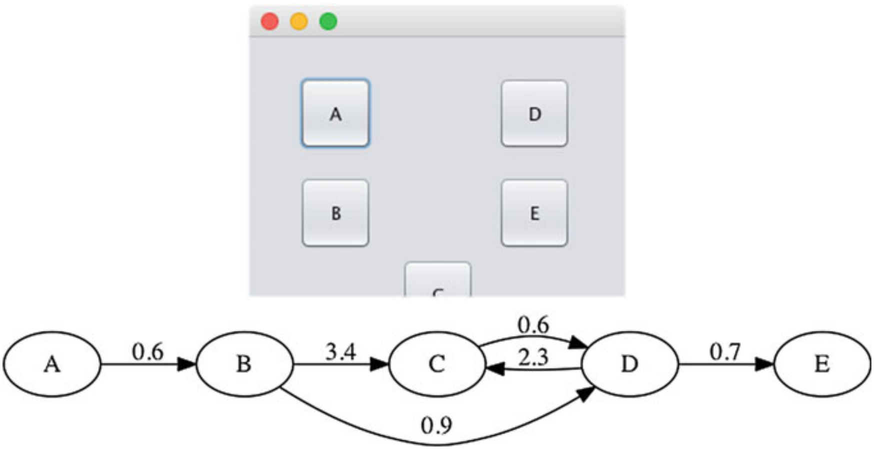


Fig. 3 Sample 3

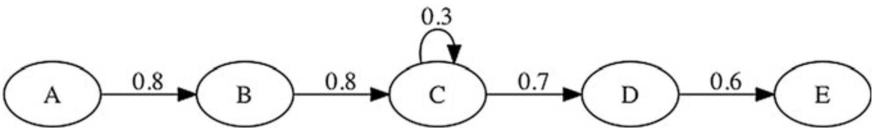


Fig. 4 Sample 4

Figure 4 shows the result of delaying the response to button C of Fig. 2. The flow line diagram shows that users repeatedly pushed button C. This is suspected to be due to users believing that they did not push button C, causing them to push it again.

In this way, our method analyses the development flow by visualising simple user actions and finds the actual cause of user interface problems.

We show 4 samples in corresponding with typical problems of the users in practically.

We consider there are many other problems in practical situation. However, these 4 types of problems are the element of other problems.

1.3 Evaluation of Technique

Tasked Experiments. In order to determine whether the newly developed technique satisfies the practical needs of the developer and whether said technique is comparatively superior to the existing techniques, evaluative experiments were carried out. For these evaluative experiments, software for the experiment shown in Fig. 5 was developed, and its user interface was analysed by survey research, one of the previously utilized techniques, and the newly developed technique, the results of which were used as a basis for evaluation. This software imitates a service login screen on an internet browser.

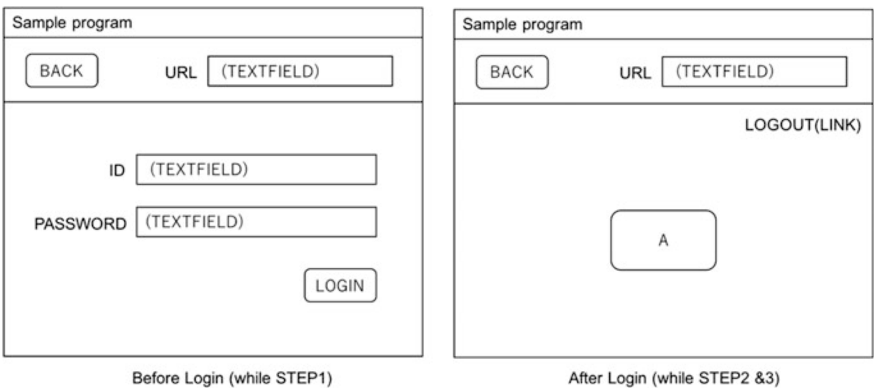


Fig. 5 Test program (excerpted)

To begin with, participants possessing an average level of computer literacy from group A (user equivalent) were presented with the following tasks to perform while operating the software mentioned above. The log of operations was then acquired.

Task 1: Enter personal ID and password (provided in advance), log into the service
Task 2: Click button "A" on the screen
Task 3: End the use of service

After operation, the users were surveyed about the points of operation that were difficult to understand.

A rendering of the flow line diagram is shown in Fig. 6.

Experiment 1 (Analysis of the flow line diagram). By using the newly developed technique, an analysis was conducted by using information from the rendered flow line diagram. The red line in the flow line diagram indicates the flow of operation that the experimental software presumably follows during development. As depicted in the flow line diagram, the users did not diverge from the predicted path of operation in tasks 1 and 2, but divergences begin to appear in task 3, and we can see that there are discrepancies in the predicted flow of operation. The discrepancy was in the "end the use of service" task, whereby the predicted path of operation expects the user to click the "log out" button on the upper left hand side of the screen, but the users clicked on the "go back" button instead, probably assuming that this action would end the service. This shows that the "end the use of service" task portion of the user interface is difficult to understand, and thereby flawed. Moreover, by implementing this newly developed technique, the problem is detected easily and displayed.

Experiment 2 (Evaluations by Developers). Subjects in group B (developers who are presently engaged in the development of software) were presented with the flow line diagram rendered using this newly developed technique to display user log information and user comments gathered from survey research. Evaluations comparing the usefulness of information gathered from each technique were then conducted.

For this evaluative comparison, the following questions were posed to the developers:

Q1. Do you think this new technique (flow line diagram) is useful for extracting information that is otherwise unobtainable from previously utilized techniques (survey research)?
Q2. Do you think this new technique (flow line diagram), could be utilized to improve user interface in your business?

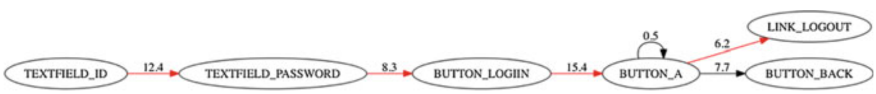


Fig. 6 Output figure of test program (excerpted)

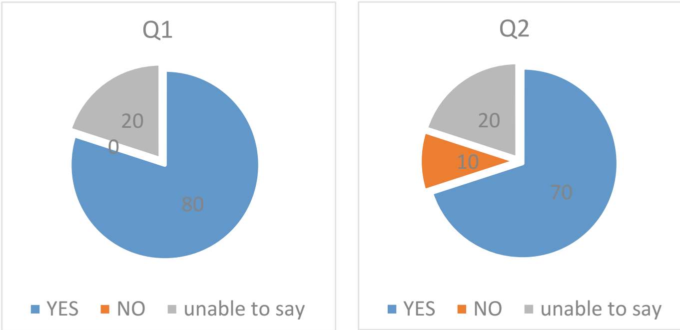


Fig. 7 Result of interviews with developers

The results are shown in Fig. 7.

According to the results, approximately 80% of developers deemed it capable of extracting information that is unobtainable from the previously utilized methods such as survey research, and approximately 70% of developers reported that it could be used to improve user interface in their businesses. Additionally, developers who reported “unable to say” in Q2 raised concerns that with more complex software, flow line diagram would also increase in complexity.

2 Summary and Future Prospects

Based on the opinion of software developers, it can be said that valuable research was conducted for developing a more practical user interface evaluation technique. These evaluative experiments showed that this newly developed technique made it easier to identify problems in user interface. In addition, software developers expressed their appreciation for this new technique. All of these findings point to the usefulness of this researched technique.

In future, comparisons with conventional techniques and evaluative experiments with more complicated software will be carried out to improve the proposed technique. We hope to demonstrate the novelty and usefulness of this technique in concert with the feedback received from developers in the field, and aim to create a more practical technique.

Acknowledgements We would like to thank many people who offered their help during our study. We are very grateful to them.

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Managing User Experience (UX) Design Practice: Approaches and Considerations

Anshuman Sharma and Aneesha Sharma

Abstract Managing design practice in an Information Technology (IT) company can be challenging as there are many factors which need to be addressed. Three main perspectives which need to be looked at are: business from a company's perspective, user experience from domain perspective and designers from personnel perspective. These three areas are interdependent of each other and need to be addressed separately. Many a times there is a conflict between business and UX practice as well as between designers and business on scope and quality of the output and deliverables. Designers have a different way of working when compared to software developers or architects and designers do not fit into an "ideal" IT resource frame or the IT way of working. Designers need independence, recognition and challenges to grow as well improve quality of design deliverables. One needs to evaluate whether a consolidated central design team across delivery verticals is beneficial or a distributed design team across delivery verticals is beneficial. There are advantages and disadvantages of both the approaches. Software product development environment and software services environment also have different focus and requirements. Designers have to follow the established processes, timelines and delivery schedules. In some cases, a designer is required to think beyond the normal and innovate to make a difference. In most cases, the scope of the deliverables is fixed and the designers need to work on the "usual" delivery. This paper explores various factors and issues related to functioning of a user experience design practice in a software development organization and the nuances of managing designers.

Keywords HCI · User experience design · Design management · Usability practice · Design roles · Practice setup · Design practice · Design process

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1 Introduction

User Experience Design (UXD) practice has become critical success factor for many Information Technology (IT) and software development companies. Since the last fifteen years, end user satisfaction levels are being tracked and there is a conscious effort from all service providers to address usability and aesthetics of applications [1]. UXD has become an important part of all software development and service organizations.

There is a lot of competition between product development companies and service providers to showcase niche skills like UXD which provide immediate and measurable value to clients and end users. Since year 2000, most design-oriented companies have transformed their approach from design as differentiation value to design as transformation value [2].

DNA newspaper published a report in India in March 2014, where UXD was identified one of the top three areas which has a huge demand for trained resources. There is a talent shortage in this area [3].

In spite of the huge demand and value for UXD resources, there are very few IT companies which are able to successfully hire and retain them. Many UXD resources change companies due to dissatisfaction towards work environment and management style of their supervisors.

1.1 History of Design Teams

Traditionally UX design which includes UI design and graphic design was a part of design agencies and advertising agencies. These design agencies also worked on aspects like branding and design for print. Due to open work culture and creative projects, design and creativity thrived and designers were happy to stick around and work for long hours.

Design is a new skill for many IT organizations, often outsourced to creative agencies or left to technologies in the systems development process. Designers support customer involvement with visualizations, usability studies and help manage customer expectations about desirability, technology feasibility and business viability [4].

The designers could come to office at a time of their convenience, wear casual dresses and change their appearance frequently, for example, by changing hair styles. Designers explored new looks and latest design trends to break the monotonous work environment. Modern IT organizations have formal dressing, strict work culture and fixed work timings. Many IT companies follow a factory model where working hours and output is measured in numbers instead of quality of output and how innovative or creative the output is.

Managers in an IT companies measure the quality and quantity of design output by metrics the same way they measure the application code. These metrics are imposed on the designers. Design is inherently a creative and person dependent process, the personality and working style of each designer needs to be respected. There is a constant tussle to “domesticate” designers who do not hesitate to speak out their mind and disagree with a sub-standard or poor design solution.

Designers want freedom to work on the projects and decide way they want to work which is quite different from a planned factory model. Managers who have design background do understand this aspect and provide limited freedom to designers. But managers who are not from design background, do not understand the needs of a designer and create typical work environment where openness and dissent is not welcome.

2 Methodology

The objective of research was to understand the issues and aspects involved in managing design teams in an IT or software development environment.

A “survey and interview” method was followed for deriving data points, factor and issues for managing a design practice. A set of questions were prepared for interview and surveys. The participants were designers and non-designers as well as managers who were from design and non-design background. Parameters like personality, work culture, design work and design process were considered to get similarities and differences in the way of working of designers and non-designers.

Interview was conducted for 30 managers of design teams which included 15 managers from design background and 15 managers from application development or project management backgrounds. The experience range of the design managers was between 10–25 years. The managers were selected to represent small, medium and large IT organizations in major Indian IT companies.

2.1 Designers Versus Non-designers

Differences, uniqueness and similarities in designers versus non designers were probed from design and project management perspective. Designers ideate by exploring the solution space, whereas engineers work in a space of problems to be solved [5].

2.2 Context and Stage of Design Intervention

The context and stage of design intervention by designers was probed. Context and type of work was understood. User centered design process (UCD) consists of three stages: analysis, design and evaluation. Effort was made to understand if the steps

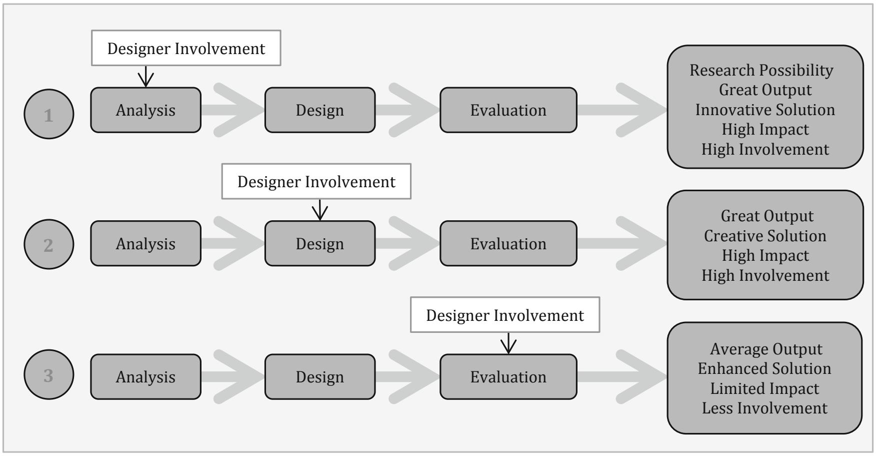

Fig. 1 Designer's intervention at different stages of UCD process and its impact on design output

and process of working of a designer changed with the stage of the design process at which the designer was involved (Fig. 1).

Designer's intervention at the initial stages of knowledge acquisition and concept evaluation gives a higher ability to designer to influence the final design [6].

2.3 Personality Differences

There are differences in work styles of designers. Some designers are extroverts and some designers are introverts. Some designers need handholding and some designers need full freedom to perform well.

3 Factors for Managing Design Teams

Six major factors were identified from the interviews which affects management of design teams.

3.1 Practice Divide: Usability, Visual Design & Interaction Design

It is quite easy to manage a UX practice from a business perspective. But to manage a UX practice from perspective of Centre of Excellence is a different ball game. We

Table 1 Design roles in a UXD practice and creative team

The UXD team	The creative team
Interaction designer	Branding consultant
Usability specialist	Market analysis specialist
Visual designer	Graphic designer (for print collaterals, logos)
Front-end engineer	Website/UI designer

need to encourage a culture of research, creativity and innovation to achieve more. This cannot be done unless we optimize the contribution from the individuals who make up the UX team. Managing a team of designers can be difficult at times due to different individual aspirations and personalities. Typically there are four major roles in UXD practice (Table 1). These roles are different from design roles of Creative team from a design agency.

A visual designer a creative person. He is more like an artist who introspects frequently and comes up with user-friendly and appealing designs. He is usually an introvert and sensitive personality. Such people work best when they are left alone in their comfort zone after providing them detailed requirements, constraints and timelines.

Proficient visual designers generally do not need hand holding once they understand what is required. They are extremely creative of the lot. One needs to be careful to deal with them as they get annoyed easily with repetitive work and subjective review comments from non-designers.

The resource-based view offers another path for design strategy, one that is better for designers [2]. Interaction design can be seen as a more recent alternative to interface design, or as a development [7].

Many times a non-technical or a "non-designer" manager reviews highly creative work of visual designers. This may create issues as the management review and creative review are two different things. The designers produce design to please the end-customer whereas the management target business without looking at the end customer.

3.2 Educational Qualification

Visual designers are the creative lot who create the visual design for an application. A formal degree in arts or design is preferred for visual designers. There are some designers who do not come with a formal degree in design but they have a knack of creating compelling interfaces. Such designers are believed to be born to be graphic designers. IT companies in India look out for generalists as well as specialists.

Usability analysts and front-end engineers typically come with an engineering background. They have analytical thinking, higher functional and problem solving capabilities. It is difficult for designers from engineering background to get trained in graphic designs skills. Engineers may need to unlearn their engineering training in order to creative designers.

3.3 Work Experience

Depending on the educational background, most designers are ready to work on critical projects at an experience level of 3–5 years. Senior designers are fast and polished and they demand special attention and freedom to work the way they want.

Many graphic designers may have worked in print media and may have shifted to web and IT. Such designers need time to learn and adjust to constraints of web and mobile platforms and follow guidelines and standards of web and mobile channels.

3.4 Project Management

Most visual designers prefer not to take responsibilities of project management, scheduling and status reporting. The reason comes from the structure of the design teams where they were driven by the project managers and the business analysts. In many cases, UX is a part of the larger delivery team where the UX designer would be consulted at initial design phases and then the design will be implemented by the rest of the development team.

There are limited projects where UX delivery is independent of the software development and delivery.

3.5 Client Interaction

Most designers learn the project management skills and the client handling skills on the job. Communication and presentation skills are often an issue with many designers as may not be exposed to clients directly. When a designer is expected to lead a project and handle the client requirements directly, the designer faces several self-imposed barriers like “it is not my job” or “the client is not clear on what he wants”.

It is only after a few projects, that a designer learns how to interact with the client and get the design requirements and proposals approved. Extrovert designers like Usability Specialist and Interaction designers have better client handling and requirement gathering skills, whereas introvert visual designers have limited client handling skills.

3.6 Creative Work Versus Repetitive Work

Designers work for satisfaction of working on challenging and creative projects. Repetitive work gives little possibility to reinvent oneself and does not interest most designers. The design manager needs to constantly rotate designers into different projects where the requirement and the challenges are different.

4 Design Management Interview Findings

Design managers need to understand the dynamics of designers and handle creative ideas generation during the design process and maintain quality of the design output. Here are some findings and issues identified from the survey and interviews.

4.1 Interview Findings

The findings from the interviews can help a manger to align his management style with the technical and design teams. Major findings are summarized below.

- Knowledge management—which was the focus in the initial analysis phase of design process.
- The research conducted by designers at the analysis stage is different from non-designers who found it difficult to the take the research ahead and convert the research into design opportunity.
- Workflow during design and analysis stage was done differently by designers.
- Design evaluation can be conducted by non-designers much faster than designers.
- Designers look for freedom, non-status based meetings, less stringent deadlines, less stress, more motivation and high level direction from the stake holders.
- A manager should not apply the same management or evaluation style for technical members and design members and he need to change his style to get the best output from both technical and design teams.

4.2 Aspects Identified

The flowing aspects were identified from the interview and surveys.

- Ego: When a designer has spent a considerable amount of time designing, they do not like to take criticism and have restricted ability to learn from junior associates. This needs to be handled sensitively by senior designers.

- New Concepts: Many senior designers find it difficult to adapt to thinking on newer concepts and different ways of representation.
- Customer Orientation: Many designers find it difficult to connect with clients and defend new concepts and ideas.
- New Tools and techniques.
- Cut the process: Many designers skip the peer review process and directly jump to design solutions. This may lead to loss many functional and UI aspects.
- Target low-hanging fruits: Many designers want to work for quick wins and try to avoid research and come up with innovative solutions.
- Forget due-diligence: Due to pressure of timelines and constraints of the development platforms, many designers forget to follow the design process and discussions with business analysts and subject matter experts for design refinement.
- Individual versus team player: Depending on the personality of the designer and the project requirement, a suitable designer should be identified.
- Thinker versus doer.
- Control—My way is the right way: There are designers who have very strong opinion about things. They are suitable to be identified for design defense.

5 Tips for Design Managers

Design managers need to understand the dynamics of designers and handle the design delivery. Based on the survey and interviews, the designer managers have reported the following tips and approaches to handle a diversified design team:

- Spend more time on understanding the project requirements and expectations. This will help understand scope and deliverables.
- Have discussions with the project teams who are delivery owners of the project. Have similar discussions to within the UX team to thrash out any gaps in understanding the direction of design progression. Based on the time constraints and the project requirements, the target needs to be identified with either transformative and out of the box solutions or quick fix enhancements.
- Pick the best suited resource to handle the UX part of the project. This will help in quick turn-around time and fewer gaps with the deliverable and the requirement. Typically, the usability analyst will conduct UX audit or usability testing; interaction designers will own wireframes and visual designers will create the graphics for an application.
- In case the UX team is not able to place the best resource available for the project; a panel of multiple UX resources may be constituted for best results. One candidate may actually work on the project with support of one expert from the visual design, interaction design or usability depending on the nature of the project at hand. The third resource can be a person who is good at providing independent feedback. The UX resource panel of three associates can be interchanged for different projects with one resource handling a project and can be a reviewer for another project.

- Brainstorming at the beginning of the project with critical review of any available designs or data followed by a brain storming session to thrash out possibilities and constraints. Mandatory peer review to at the final design stage to eliminate any eye sores from the proposed design. With this process, a designer begins to understand another designer's perspective and starts adding lot of logical and creative aspects into the design at creation stage. This process works for designs where interaction design and usability has more importance. For projects where one needs to think out of the box, the designer in charge of the project needs to have the final say even if other designers think otherwise. This sometimes helps a designer prove a point. Whether to take the feedback from review panel or not should be left to the discretion of the designer. But this should not mean that the brainstorming and review process holds no value and can be skipped.
- Once a project is completed, the designer should be asked to create a case study which may be shared with the rest of the team members. If the designs or the execution is best in class, it needs to be appreciated and shared. This will set a benchmark for other designers and set a target for them to achieve and even do better in their own project.
- One senior designer or preferably a manger should be a part of all the discussions. This is important as many times, the discussions get derailed and go off-track. One of the most critical things is that even if a senior person is chairing a discussion, he should be non-intrusive, silent and a non-influential spectator. The chair person will give due importance each and every comment based on their merit and not let the discussion go ugly or person-centric. The discussion needs to go logically while maintaining focus on creative content of each recommendation. The discussion sessions are important to bring the team on the same page but at the same time the chair-person needs to act like the king of a kingdom and keep his nobles happy and avoid them going on war.

6 Conclusions

Managing a UX practice is not easy. It is difficult to manage a practice which thrives on the diversity of its members. Designers are a diverse lot. They have varied skill levels and personality types. An easy scenario would have been to hire generalized resources who have been baptized into the IT way of working [8]. But such resources work best in a factory model where repetitive work gets more appreciation than out of the box solutions. Design managers and design teams should consider design as a core competency or as a sustainable competitive advantage [2].

In order to get innovative UX solutions, one needs to carry whims and fancies of a team of specialists who may not be ready to change their way of working to suit the standard and established ways of working of IT companies. Noisy discussions, literary challenges and fights are required for specialist designers to fee their minds of the usual solutions and deliver something which is innovative and different from the established standards of design output.

Many senior managers have been heard saying, “I want the Wow factor! Get me something different which would impress my clients. I have only few minutes to make an impression.” For such scenarios, the designers need to think out of the box. A designer needs to be handheld to understand what the application is all about and what the end users may like. Once the context and business requirements are understood, the designer should be left to work on his own without any reviews and discussions.

A simple non-status based discussion may be required at specific stages and milestones to speed-up the design creation process. Design managers need to shift from a project-based view to a process-and-knowledge view [2].

We have seen design management from the traditional management styles, where one puts deadlines, constraints and get designers to work on very specific and focused solutions in short span of time. This typically fails when highly creative and innovative solutions are expected out of the UX team.

There are UX teams where designers have felt miserable and left out due to management style of the design manager. A real design manager needs to get the right deliverable out the designers by creating favorable working and thinking environment.

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Constraints for Gamification of Data Intensive and Analytics Applications: A Case Study

Anshuman Sharma

Abstract Data intensive applications are backbone for sectors like—banking, insurance and retail industry. Data representation and workflow are two most important aspects of such applications. Although, data representation is catching-up with the latest trends, but for traditional sectors like Banking, Finance, Securities and Insurance (BFSI), any new technology or design trend takes a while before it is integrated into the applications. Such sectors try to minimize risk caused due to new technology environment. There is a wait and watch attitude towards new technology and new user experience. These sectors are the last to adopt the latest design trends. Back-office and mid-office applications have not changed much over the last 10–15 years. Some large banks from North America, Europe and Nordic regions are using applications which are more than 50 years old. Design trends like gamification are rarely used in banking sector. BFSI retail sector is changing fast with advent of new technology and better customer experience. New channels like mobility and tablet; touch enabled platforms like iOS and Android are changing the face of application design and behavior. Users expect similar behavior from the traditional and data intensive applications as well. These new platforms not only use the latest technologies and user experience but also make use of latest design trends which includes gamification. This paper looks at design trends which are shaping the digital media and their impact on traditional and data intensive sectors like banking, finance and insurance.

Keywords HCI · User experience design · Gamification · Game design · Design trends · Usability · Banking · Insurance · BFSI · Design process

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1 Introduction

Application design has emerged as one of the most sought after capabilities by software product organizations and software service organizations. The technology and applications in most BFSI and other organizations are more than a decade old. There are efforts to transform and upgrade the legacy applications into modern applications which are intuitive, user friendly and are based on the latest technology platforms. Before UX and design intervention, the sales team sold applications on the basis of rich functionality. But many organizations in banking sector like Credit Swiss are emphasizing usability of their products with the expectation that "clients will pay for a good experience" [1].

The main reason why these organizations are looking for application transformation is due to maintenance issues. In addition, there are new players in the market which boast of modern applications which have high customization capability and users like to work on these applications for long hours without getting tired or bored.

1.1 History of Back-Office Application Design

The retail part of application design which serves the end customer has been addressed and lot of effort is being made to keep it up to date with the latest trends in UX and technology. The back-office application platform which is used by the back-office users are often ignored. There are many reasons for this. One is there is no cost benefit in revamping the back-office applications. This effort is a cost to the organization. Second, the business logic has not changed over many decades. Third, the users working on these applications are so used to the good and bad aspects of the application that they are not ready to accept a newer and better application interface. In light of all these aspects, the back-office application group in most organization is neglected and is the last group to be looked at for any modernization bid.

Design is a new capability for many organizations which has been often outsourced to creative agencies or owned by technical teams from the systems development process. Designers support customer involvement with visualizations, usability studies and help manage customer expectations about desirability, technology feasibility and business viability [1].

From year 2010 onwards, IT departments of several large BFSI sector based organizations have started focusing on legacy modernization by transforming the age old back-office application in to modern, sleek, fast and user-friendly applications. Gamification concepts started picking up importance during this period. Gamification as a term originated in the digital media industry. The first documented uses dates back to 2008, but gamification only entered widespread adoption in the second half of 2010, when several industry players and conferences popularized it [2].

Designers who are engaged on designing the back-office legacy applications have to look at multiple areas of application design. One of the areas to be looked at is study the user profile and design applications which they will like to use. Technology and hardware is driving the user interface features. Based on the latest design trends, designers have to match the user requirements with best in class trends and features which will help the organization save money, increase productivity and have better user engagement levels with the applications.

Back-office work is boring and monotonous. The back-office application users need to work on repetitive work, go thru a sequence of steps (workflow) and complete assigned tasks or work on a pool of open items by self-assigning. Traditionally the back-office application interface was neglected and not too much attention to detail was given to design it. The back-office application interface and workflow was strictly designed as a functional flow which had very formal and serious design outlook. Due to the poor focus on back office application design, one of the trends selected by designers for designing back-office applications these days is gamification, which tries to bring fun into the application usage. It motivates the users and tries to keep them engaged.

2 What Is Gamification?

Gamification was one of the top five trends in the web and mobile space in 2012. The penetration of gamification in year 2012 was 45% in the entertainment sector as compared to 4% in the financial sector (BFSI). The penetration of gamification in financial sector is expected to grow to 8% by 2017.

2.1 Definition of Gamification

"Gamification" is an informal umbrella term for the use of video game elements in non-gaming systems, services and applications to improve user experience and user engagement (Fig. 1). Gamification is the use of game design elements in non-game contexts [2].

2.2 Need and Importance of Gamification

Gamification aims at integrating game dynamics into a business service in order to drive participation and engagement by changing people's behavior. Game design is a valuable approach for making non-game products, services, or applications, more enjoyable, motivating, and/or engaging to use [2].

Fig. 1 Gamification

Goal of gamification is to engage with consumers and get them to participate, share and interact in an activity to achieve business goals. Gamification is a potential means to create engaging workplaces or facilitate mass-collaboration [3].

People's daily lives have become increasingly sedentary, with extended periods of time being spent in front of a host of electronic screens for learning, work, and entertainment [4]. The recent introduction of 'gamified' applications to large audiences promises new additions to the existing rich and diverse research on the heuristics, design patterns and dynamics of games and the positive UX they provide [2].

One of the key requirements to target high value customer problems is to address customer experience and solve the problems through design and customer insights [1].

2.3 *Gamification Aspects*

Several vendors now offer gamification as a service layer of reward and reputation systems with points, badges, levels and leader boards [2]. It is recommended that gamification term should not be limited to specific usage contexts, purposes, or scenarios, while noting that joy of use, engagement, or more generally improving the user experience currently serve as popular usage contexts [2].

Games are characterized by rules, and competition or strife towards specified, discrete outcomes or goals by human participants [5]. From the perspective of the achievement system, an achievement appears as a challenge consisting of a signifying element, rewards and completion logics whose fulfilment conditions are defined through events in other systems (usually games) [6].

Table 1 Achievement framework

Achievement framework	
Signifier Name Visual (badge) Description	
Completion Logic Trigger Condition Pre-requirement	Multiplier
Reward In game Out game Achievement game	

The signifying elements in all cases consisted of a name, a visual badge and a description that elaborates the operational rules and rewards. One achievement can have many completion logics, which are distinguished by separate triggers, pre-requirements or condition [6]. Achievement framework can be looked at to refine workflow in an application (Table 1).

Both name and visual part complement each other and convey theme of the achievement (Table 1). Description attempts to capture what is required from the player to complete the achievement (the completion logic) and what will result from completing it. It also includes consequences of completing an achievement. Action/event or a trigger defines what a player has to do. Conditional requirements determine whether the action or the event will be counted towards a given achievement. Multiplier refers to the amount of times the compositions of the three previous components have to satisfy the defined requirements [6].

Some industry studies have found that games with achievements generate more revenue and receive better critical reception [6]. Badges and achievements as a game design pattern bear close resemblance to marketing tools, such as loyalty stamp cards, where people accumulate stamps or badges. This notion also could explain why studies have found achievements boosting game rating and revenues.

3 Approach

The methodology for analysis was of theory-driven and bottom-up in nature, where we gathered data by reviewing several achievement systems, conducting participatory observation and interviewing experts as well as players. This data was then validated and combined with game research literature on game design.

The approach included study of gamification concepts and study of issues and design opportunities in back-office data intensive applications. After understanding both the areas, a study was conducted along with interviews from business analysts, end users and product managers to understand challenges and possibilities in implementing gamification for application design.

3.1 Can Gamification Be Used for Data Intensive Application Design?

Once the concept of gamification is understood, once needs to evaluate whether gamification can be used to improve the fun quotient of an application and lead to higher end user motivation and engagement levels. One needs to look at the following questions to proceed:

- What are data intensive applications? What do we do with them? Why they are required?
- What is the traditional way of designing data intensive applications?
- Why there was no focus on designing back-office applications till now?
- Why change is required now? What kinds of changes are required?
  - Can we save cost on training
  - Can we save cost on modifications of UI
  - Can we address the different roles of end users
- For back office users, was it boring/difficult to work for long hours on traditional data applications. Can the application be designed in way that will improve the user's productivity and motivation level?

3.2 Challenges for Use of Gamification for Data Intensive Application Design

During the study of back-office applications, several parameters and issues were identified. These challenges, issues and aspects need to be addressed before applying gamification concepts in application design.

- Pressure, targets and leaderboards may work against the user if they get depressed for not achieving a target.
- The back-office and data-intensive applications have a lot of dependence on the database, internet and performance of the application. Any addition of fancy/fun elements are never looked at with seriousness. There will also be impact on the system/application performance as the system will have to remember the steps, the sequence of steps, the number of times similar task was accomplished, how much time and number of clicks did it take, how many tasks did a person complete last day, last week and last month.
- This kind of reward/achievement system has to be built on top of any existing application so that there is no disturbance to the stability of the existing application.

- If a new application is being built, then we can take care of such innovative solutions by providing handlers, preferences, counts and displays based on the user login.
- A user's history has to be maintained for him to be motivated.
- A detailed set of rules has to be prepared for the ideal workflow and speedy resolution of assigned tasks.
- For applications, where a user login is not maintained or it is not important, it is difficult to keep the historical data specific to a user. One can only show and display data which is either best in class in the what is the average or what is not acceptable and whether the person who is working on the system falls into that category or not.
- Many games have optional achievements where a user can turn them down or disable them. It should be available to the user at levels and whether the user wants his work to be measured against a set of pre-defined rules and evaluated with ratings.
- A user should have the option to be measured but not evaluated. This works for users who are still not at their best, would have a number to compare their own performance with the previous performance. System would not remember how they performed but each user has to remember how he is performing.
- Achievements help a user to work better and learn faster. There is motivation and rewards in the system in the form of badges. The user looks at description and an ideal way and steps to complete a task and tries to follow a similar path. This has immense impact on the training of a user and his ability to improve himself.
- This is a challenge for the business analyst (BA) and documentation team as they have to define an ideal and faster way to complete the tasks and the logic behind it.
- From usability perspective, it is easier to design a system or an application as the designers know what is expected out of the workflow.
- The managers can also have a look at the workflow management and work distribution/load distribution across teams. If a particular user is able to close more pending tasks/work items without any issues, he can be rewarded by the system as being the star of the day and others can be informed about it.
- Introduction of gamification in a system also improves collaboration as each user contact and speak with the winner/leader to understand how he did it and what it would take for him to work on a speedy resolution.
- Many organizations do not believe in the rewards/gamification system as they believe that many users will find out faster ways to complete the task without giving enough attention and performing all the necessary tasks, checks and balances. They believe there should be no distraction to this serious work and the users should be left alone to work on the way they want and the speed at which they want to work.
- Critical applications like trading and treasury have not seen a lot change over the last 10–15 years. One of the change we see in these applications is that they now support analysis of huge transactional data and have a way to represent the

possible outcome of an action for faster and accurate decision making. For example, if a broker wants to buy or sell a share/security at a particular amount the data analytics can show how much profit one is likely to make.

4 Findings and Design Solution

After studying gamification concepts and evaluating back-office applications for possibilities and issues, the following areas and recommendations were identified.

4.1 Gamification Introduction into Application Design

Gamification can bring the following aspects into back-office application design:

- What new additional things gamification brings on the table?
  - Rewards and recognitions
  - Tasks and completion status
  - Status of a workflow
  - Who is the villain
  - Smileys and sad faces for missed targets
- What's the battery status (work time, is it the time for tea?)
- Is there another way around the target
- Motivational and personal messages
- Errors with some technical and personal details
- Treating work as fun
- How to recall certain task or status from past experience

4.2 Adaption of Achievement Framework to Workflow Based Application Design

In addition to introduction of gamification aspects to introduce "fun" element in an application, the following aspects of achievement framework can be adapted to further refine the workflow of an application (Table 2).

Based on the Gamification aspects identified (Sect. 4.1) and the achievement framework adaption (Sect. 4.2), multiple design and work flow options were created designed and evaluated (Fig. 2). These gamifications aspects and workflow options were introduced to multiple applications to identify if there was any value addition.

Table 2 Adaption of achievement framework to workflow based application design

Achievement framework		Adaption of achievement framework to workflow based application design		
Signifier Name Visual (badge) Description		*Work item/Task list* Contextual information (transaction number, user details) Criticality (deadline) Current status		Multiple assigned work items to be closed per sitting/day
Completion logic Trigger Condition Pre-requirement	Multiplier	*Workflow* Sequence of steps based on state and type of transaction Maker and checker model	Multiple actions on one Work Item to change its Status	
Reward In game Out game Achievement game		*Completion status/Task list* Task completion status Percentage completion		

4.3 Case Studies Where Gamification Failed

A proprietary ticket analysis platform (Fig. 3) analyzes tickets and enhancements related data, in order to generate analysis charts on a dashboard. This dashboard with its array of charts gives insights into problem areas, or areas in which the business users demand maximum features.

The business, analytics and the design team introduced many gamification features, but were used by the business users. The main reason was the changing

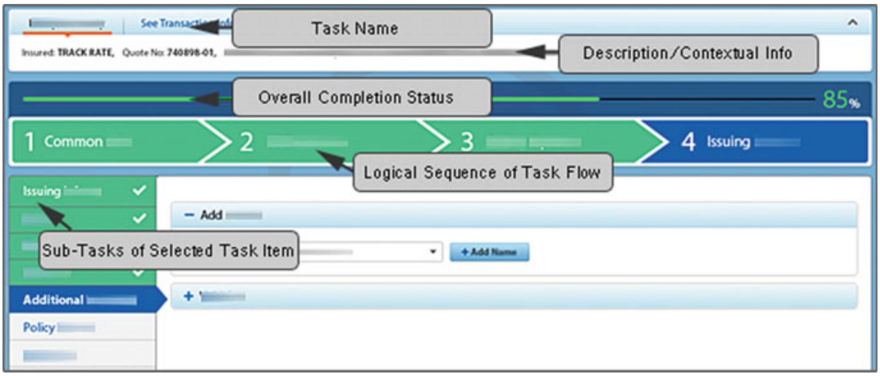

Fig. 2 Implementation of achievement framework (gamification) for workflow design in an application

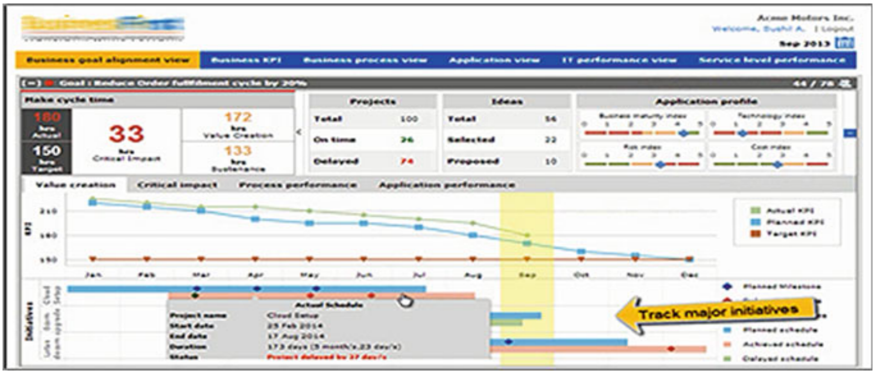

Fig. 3 Ticket analysis and enhancement application

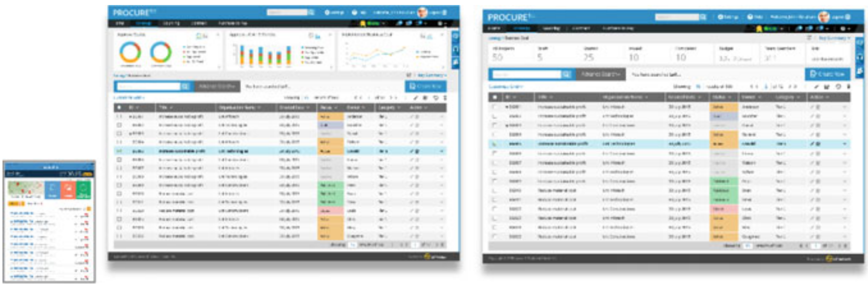

Fig. 4 Order management system

baseline and time based data which rendered the gamification related representation useless.

Similar results were also received for Order Management application (Fig. 4) where the concepts of gamification did not enhance the customer experience as the data was huge and there was no possibility of benchmarking it due to huge variation in resolution timings.

5 Conclusions

Application design for data intensive back-office platforms of BFSI has been neglected and not much attention has been given to it. Gamification has brought a new lease of life for the boring, monotonous, tiring and sedentary world of back office application usage. Trends in gaming are also preparing users of back office applications to accept and agree to bring “fun” in to their way of working.

Designers had tough time designing back-office applications as there was little scope of improvement coupled with budget constraints and reluctance of users to learn and shift to newer and faster application UI and workflow. Gamification has helped designers introduce elements slowly into the application design which improve motivation levels of the users and organizations use of gamification to improve employee engagement and effectiveness [7].

Adapting achievement models from gamification concepts help the self-esteem of users working on applications (Table 2). Elements like badges, visual cues and scores at work completion, breaks the work in to modules with intermittent levels and targets that users can strive to achieve. This also builds the need of a user to be able to work longer and faster to achieve targets set by system or by users themselves (Fig. 1).

Many legacy applications from segments like ERM, SCM and data management from BFSI are being looked at and there are application transformation initiatives being planned. Design trends like gamification are helping the product managers and designers adopt new concepts to introduce elements which help an end user improve his productivity levels and improve his overall work satisfactions levels.

However, with more flexibility, rule based reporting and workflow management, introduction of generic and fit for all gamification elements is not easy. Designers and functional analysts need to work together to make meaningful inclusion of gamification elements.

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Risk Factors for the Development of Pressure Sores Among People with Spinal Cord Injury: Results of a Case Study

Priyanka Rawal and Gaur G. Ray

Abstract This case study was conducted to understand the risk factors for the pressure sore development post rehabilitation among Indian veterans with Spinal Cord Injury (SCI). Development of pressure sore is common among people with SCI. Rehabilitation centers help people with SCI to understand the SCI better and teaches them to deal with its secondary problem like Pressure Sore. The veterans of Post Rehabilitation Center are quadriplegic and paraplegic and have reported the development of pressure sore post rehabilitation. Most common areas of development of pressure are Sacrum, Ischia, R/L Trochanters. Veterans with complete SCI are more at risk of development of Pressure sore. The paper provides the potential risk factors due to which veterans with SCI develop pressure sore post rehabilitation.

Keywords Pressure sores · Risk factors · Spinal cord injury · Post rehabilitation

1 Introduction

Many studies have been conducted on Pressure Sore on People with Spinal Cord Injury (SCI). This is a study conducted in Post Rehabilitation Center India, on SCI Veterans. This study was conducted to find out the reason of pressure sore among Post Rehabilitation Center veterans post rehabilitation. Veterans stay in Post Rehabilitation Center after rehabilitation and were taught how to live with Paraplegia or Quadriplegia depending on the level of injury. The rehabilitation duration is minimum 1 year and maximum 2.5 years for treatment and later for

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rehabilitation. As per the availability of beds and choice of veteran then can stay in Post Rehabilitation Center, if they have difficulty staying in their home, usually for those areas where facilities are not available for them to live a better life post SCI.

2 Literature Review

Pressure Sores can be defined as lesions, which commonly caused by unrelieved excessive pressure over bony prominences and resulting into damage to the underlying tissues, and are classified as stages on the basis of the degree of tissue damage [1–3]. Pressure, friction, shear, moisture are extrinsic factors that contribute to the pressure sores development [1, 2]. Other factors include poor nutrition, immobility and psychosocial factors and non-compliance with acknowledged preventive behaviors and insufficient financial resources [1, 2, 4]. The basic aspects of pressure sore development are duration and intensity of pressure and tissue tolerance to the pressure [2, 3]. Pressure relief is needed to increase tissue oxygen [2, 5].

Pressure sores continue to be a health concern and are serious and frequently occurring, life-long secondary complication of SCI and have a notable impact on quality of life [1, 2, 6]. As a health care problem, pressure sores also have impact on the society [2, 7, 8]. Every year in USA, more than 40,000 SCI patients develop new pressure sores, and management of these sores can require long and complex treatment [2, 9, 10].

In literature, its been reported that 17% of the sample of 633 non ambulatory participants with SCI of 5 or more years had at least 1 new pressure sore every two years, 9% had at least 1 new pressure sore every year and 4% had pressure sores almost constantly [11]. Many of the recurring sores require surgical management, which often results in costly procedures, lengthy hospital stay, expensive dressing and time away from family, work and leisure activities. Which reduce the quality of life for these people [12–17]. Rate of recurrence have ranged from 6 to 61%, whether surgical or medical management treatment involved or not [18–23]. Recurrence of pressure sore can be result of socioeconomic factors, lack of social support, and inadequate pressure sore prevention knowledge [22, 24, 25, 26, 27].

3 Setting and Methodology

A qualitative study conducted on pressure sore in Post Rehabilitation Center veterans. Semi-structured interviews were used to conduct the research. 33 veterans were interviewed out of 80 veterans in Post Rehabilitation Center. All the surveys and interviews were conducted in Hindi and the interviews were digitally recorded and transcribed for analysis. Participants in the study were instructed that they could refuse to take the interview at any time (1 respondents opted not to be interviewed and 1 did not wish to share the demographic information).

The respondents are randomly chosen among the 80 veterans, the only criterion was the veteran should be staying in Post Rehabilitation Center and had received his rehabilitation. All Veterans staying in Post Rehabilitation Center are male.

Field notes served as an additional aid during the process of analysis where all observational data (verbal and non verbal) was recorded by the researcher. The process of interpretation was taken from the researcher's analytical insights that emerged from the interview process. The consistency and trustworthiness of the data was achieved by asking each participant to verify the researcher's interpretation during and after the research process. It was ensured that the themes and "constituents" are clearly evident in each participant's interview data. The interview data was compared with field notes taken during or following the interview.

4 Results

4.1 Demographic and SCI-Specific Characteristics

Participant's age, marital status, and level of education were obtained by Semi Structure interview as shown in Table 1.

Table 1 Characteristics of the sample (participant veterans, n = 33)

Variable	Number	Percentage
SCI level		
Tetraplegia	11	33.33
Paraplegia	22	66.66
SCI cause		
Traumatic injury		
Road accident	26	78.78
Fall from height	3	09.09
Gun shot	1	03.03
Sports injury	2	06.06
Non traumatic injury	1	03.03
Marital status		
Not Married	12	36.36
Married	21	63.63
Caretaker		
Spouse	7	21.21
Attendant	12	36.36
None	14	42.42
Location of pressure sore		
Sacrum/Coccyx	9	27.27
Ischia	12	36.36
R/L Trochanters	5	15.15
R/L Feet/Ankle	1	03.03
None	6	18.18

Table 2 Means and ranges of the study variables for the total sample (in years)

Variable	Mean	Range
Age (years)	46	32–69
Age at onset of SCI (years)	25.36	20–34
Duration of SCI (years)	21	06–38
Number of sores	5.8	0–15

Table 3 Life of the supporting surface (in years)

Variable	Mean	Range
Bed mattress (year)	11	10–12
Cushion of wheelchair (year)	05	04–06
Cushion ring (year)	01	01–02
Rubber sheet (year)	01	01–02

SCI descriptors such as level and completeness of injury, age at onset, and time since onset shown in Table 2.

Every product has life, to which it performs best; using just the recommended mattress is not sufficient. Using it for duration till when it retains its strength to do its job best is right. Mattress and other supporting surfaces used by SCI veterans have life during which it can serve the best, which is mention by the manufactures. In Table 3, duration of use of supporting surfaces is given, the duration for which veterans approximately use these products.

5 Discussion

The pressure sores is one of the most common long-term secondary complication for a person with SCI [27]. There are many risk factors for which it should be considered to prevent the development of the pressure sore.

Gender: It has been found that the males are more prone to pressure sores than the female. As this study is conducted considering only the male veterans, so gender is not a point of discussion.

Age: The Significance of age in the development of pressure sore is doubtful in literature. Few studies have reported that with increase in age the risk of pressure sore increase whereas few other studies refuse this statement. In this study significant relationship between age and development of pressure sore is not found.

Marital Status: In Post Rehabilitation Center, SCI veterans stay with and without family. There is no direct connection found that those who stay with family or whose caregiver are spouse or family member don't develop pressure sore. The results are not so distinct to make any statement in favor or against.

Education: A study by Garber reported that participants with SCI who received a structured, individualized pressure ulcer prevention and treatment education program during hospitalization for pressure sore repair, improved their pressure sore knowledge more than persons who did not receive the enhanced education [28].

These all veterans staying in Post Rehabilitation Center had undergone rehabilitation for minimum 1–2.5 years. They received same education program and are well aware of the reason and prevention of Pressure sore. Also they know how to identify the Pressure sore, so that they are able to find and cure the pressure sore in right manner as taught in treatment education program.

As viewing whole body is not possible to them, for whole body check up they use mirrors and in those cases where they cannot use mirror, they take help of caretaker to do daily body check up. This helps them to identify the pressure sore in very early stages. That’s the reason they are able to cure these pressure sore themselves with out reporting to doctors or hospitals.

They use white bed sheet underneath, so that when they find blood drop on the bed sheet due to pressure sore they would know that there is starting of pressure sore. These are the precaution method they use. Changing of position in every 2 h is usually followed by every veteran as assistant regularly take care to do so. But in few cases as shown in Table 6, where the veteran stay in home and spouse take care of them or in cases where they don’t need assistant to change position, the veterans sleep on one side for long time as they don’t want to disturb others sleep or are too lazy to change the position. In those cases, they take care that next time when they sleep they will not sleep on the same side as they did before to relieve that side. So knowledge about pressure sore is not an issue among these veterans.

Level of Injury: As the quadriplegic/tetraplegia veterans are dependent on attendant or spouse, the attendant has follow a schedule to position them in every 2 h without fail. So chances of development of pressure sore reduce, but when they need to position themselves, they do get careless due to laziness as shown in Table 6. But the finding of the study is not making a clear statement in favor or against the relationship between pressure sore and level of injury.

Completeness of the Injury: As completeness of the SCI affects the level of activity, mobility, and degree of sensory. Respondents with incomplete injury (which comes in ASIA B, C, D, i.e. total 48.49% of respondents) reported that they have very less or no mobility but some feel the burning sensation, when they sit or sleep on same position for long time. This sensation of heat and burning make them uncomfortable, hence in that situation they need to change their position to relief from this uncomfortable feeling. This study shows the evidence that more complete SCI lesion (those fall in the category of American Spinal Injury Association A (ASIA A) i.e. 51.51% of respondents) is associated with an increased risk of pressure sores.

The participants with incomplete SCI face uneasy sensation that’s make them to change their potions time to time, so the veterans with incomplete injury have a lesser risk of pressure sore than the one having complete injury.

In case of complete SCI veterans, situation is more critical as they don’t get the feeling of discomfort when they sleep on one side for long, they themselves or caretaker have to change their position consciously. As moisture is not good for the skin of SCI people, they need to keep the surface dry, which come in contact with their skin. They make the habit of changing their bed-sheet at least once in a week or whenever needed in between week. They use catheter and also chances of urine leakage is more in nights, while they are asleep. In such situations, they prefer to use rubber sheet to avoid ruining mattress. Such urine or water spill accident cannot be predicted. They use the mattress as per the specification of the hospital i.e. 40-density kg/m^3 form (Form based mattress are mostly preferred) and of 6″ height. For wheelchair cushion it's the same material with 40-density kg/m^3 form and 4″ height.

So if we see the habits and schedule of these SCI veterans in Post Rehabilitation Center, we can say that they follow the standards, which are set for SCI people. They develop their own habits like sleeping on one side for long and next time they will sleep on another side. Even though they reported that they often develop pressure sore, they understand the severity of pressure sore and what to do when pressure sore develop. That's why these pressure sore are usually detected in initial stage and don't need hospital help to cure them.

Support Surfaces: We took a step further and ask them about the support surfaces they are using support surfaces like Mattress, Rubber Sheets, Wheelchair Cushions and Rubber Rings for sitting on wheel chair. The reported pressure sore location indicates that the issue could be from the support surfaces, due to pressure. Question related to support surfaces were asked to understand when, how, for how long they use these products.

a. Bed Mattress: Generally manufactures and chiropractors recommend replacing the mattress in every 6–8 years. Form mattress companies recommend using these mattresses for 6–8 years [29] and then changing the mattress. Similar recommendations are given for the cushion, as material is same.

The Post Rehabilitation Center veterans follow almost the same schedule daily, as recommended to them by hospital. There time can be divided into time on bed and time on wheelchair. Generally bed hours of these SCI veterans range from 12 to 14 h. Morning 6 A.M.–12 noon, they spend their time on wheel chair and then 12 noon–5 P.M. on bed, then 5–9 P.M. on wheel chair and 9 P.M.–6 A.M. on bed. Bed rest in regular interval is recommended to them to relax the buttock area to avoid pressure sore.

And generally a normal person spends 8–10 h on bed, hence these SCI Post Rehabilitation Center veterans spending around 4 h extra on bed, means they are using the mattress for longer time. Hence the life of these mattresses would be less compared to the one used by a normal person. It is reported by the respondents that they use the mattress for 10–12 years before changing it. This is already more than the time recommended by the manufactures of the mattress and chiropractors i.e. 6–8 years, it should have been even less than 6–8 years, as they stay longer on bed as shown in Table 6.

Probably this could be one of the reasons that these respondents develop pressure sore so often, even after following the recommended practices. There use of mattress is more and the accidental urine leakage on mattress is also not good for life of mattress.

b. Wheelchair Cushion: These SCI veterans use the same material cushion as of mattress i.e. Form base mattress 40-density kg/m^3. They spend 6–11 h in wheelchair daily depending upon the injury level. But in the case of cushion its height is

4″ and they change the cushions in 4–6 years, depends upon the use of the cushion as shown in Table 3.

c. Rubber Ring cushion: SCI people use donut shape rubber ring, to relief the spine area while sitting. It is recommended to those who have lost their muscles in buttock area. Its price is ₹500 and its life is only 1 year or less, depending upon the rubber quality and usage. The SCI veterans find out a cheaper alternative i.e. Honda Activa tire tube which cost less, but the it is harder and create pressure in those areas where it gets into contact with the body as shown in Tables 3, and 5.

d. Water Mattress: Only one complete quadriplegic veteran out of 80 veterans use water mattress, he has no movement and sensory and is completely dependent on the attendant. The cost of water mattress is more and life is small, chances of puncture is quite high as water needs to be changed in every 3 months and during this process the mattress can puncture accidently. That is the biggest reason veterans with SCI in Post Rehabilitation Center don't use water mattress except for one as shown in Tables 3, and 4.

e. Rubber Sheet: Accidental urination or motion is very common, as they cannot run to washrooms. So to protect the mattress and to increase its life the veterans use rubber sheets in between mattress and bed sheet. They don't want to use the rubber sheet as it creates heating and burning sensation in the skin in veterans with incomplete injury. Hence they use a small size rubber sheet under buttock area only, so that they would not feel discomfort in other parts. But there is a disadvantage of that small rubber sheet. Sometimes during positioning it get folds or wrinkled and lying on those folds or wrinkles for long time creates uneven pressure on contact areas and increase the chances of developing pressure sore.

In complete injury cases, sleeping on the rubber sheet does not create discomfort, as they don't have any senses. Lying on rubber sheets for longer time harms their skin without causing the feeling of discomfort. Hence Rubber sheet is only good for mattress and not for the people with SCI. Even though the skin is not in direct contact with the rubber sheet as bed sheet is in between, still rubber can cause heating or burning sensation, as rubber is a bad conductor of heat.

Financial Reason: As these veterans have to use the support surface to avoid the pressure sore as recommended to them by the hospitals, as mentioned above. But still these veterans find out similar products that are cheaper so as to reduce their expense as the recommended support surfaces are not affordable to them and if they do use the recommended they keep on using the expire product as shown in Tables 4, and 5.

Water Bed cost less compare to Form base mattress but its life is only 1 year as reported by the one veteran (only one use water mattress for daily use). As water mattress punctured more often while changing water as water needed to be change in every 6 months (Recommended time by manufacture to change water is

Table 4 Type of mattress used by SCI veterans (with cost)

Type of mattress	No. of veterans
Water mattress (₹1800)	1
Form mattress (₹3150)	12
Local market mattress (₹700)	20

Table 5 Type of rubber ring used by SCI veterans (with cost)

Type of rubber ring	No. of veterans
Medical ring (₹500)	16
Tube of Activa Honda (₹150)	12
None	05

Table 6 Reported careless/lazy behavior by SCI veterans

Careless/lazy behavior	No. of veterans
Sleep on one side for more than 2 h (some time 5 h)	27
Sitting for long time in chair without rest	15
Sleeping in wet bed	4
Over use of supporting surfaces then recommended time (see Table 3)	29

3 months). So over all Water mattresses are costly if consider the life of the product. And few respondents reported that its not suits to them or they never used water mattress. Mattress manufactures recommend the use of product for 6–8 years for normal use. So to save money they use it for 10–12 years or use local cheap mattress. Veterans know that they should change the mattress in every 7 years (hospital recommended).

Similarly with Rubber Ring, recommended medical ring will cost them ₹500 and Activa Honda tube ₹150. Material is rubber but Activa Honda tube is hard and little small the standard medical ring. So hard rubber cause harm to skin as its not made for the same as shown in Tables 3, and 5.

Careless/lazy behavior:

Following a schedule without fail is not easy. During interview, when researcher asked about the reason why they develop the pressure sore, often they (those who developed pressure sore post rehabilitation i.e. 81.81%) use the word carelessness as the reason behind the development of the pressure sore.

The SCI veterans actually pin point their act of careless behavior, as they don't rest time to time as recommended, which could be the reason of development of the pressure sore as shown in Table 6.

6 Conclusion

This study indicates many areas, which could be the risk factors for development of pressure sore among these veterans. The four main contributions and/or conclusions that this study provides are as follows. First, it provides the information of condition of pressure sore among veterans in Post Rehabilitation Center. Second, Veterans with complete SCI are more likely to develop pressure sore than with incomplete SCI. Third, the study suggests that lack of financial resources could be one of the reasons in development of pressure sore, where design interventions can help to solve some issues. And lastly, the ignorant and careless behavior of SCI veterans i.e. they perform activities that could be harmful and can leads to development of pressure sore and even though they know the consequences, they tend to ignore it.

This study broadly covers many aspects about development of Pressure sore, which can be the base of further designing of the services or products like supporting surfaces. The condition of these veterans is good but as most of them are not working and live on their pension, managing all expenses is difficult for them and hence they follow the practice of using the supporting surfaces even after their expiry. There are mattress in market but either they are costly or not suitable for person with SCI.

The study shows that the duration of use of mattress for more than the recommended time could be one of the reasons behind the development of the pressure sore. As every mattress has a usage life, using it for more than that does not give any benefit. Infect that may harm the skin.

The results of this study strongly points towards the demand of consideration of design intervention to avoid development of pressure sore due to products they use. Redesigning the existing supporting surfaces, which could be more appropriate for their needs and yet should be cheap and long lasting. Developing the design guidelines for the uses by manufacturing company and for the inspection of the supporting surfaces. This would allow veterans to replace the mattress when they no longer serve the purpose. Design of additional covers or aids to maintain the supporting surfaces life can be one of the aspects since now rubber sheets are being used but these are not comfortable.

7 Future Scope

Based on the results of the study future research can be done in more detail level with civilians as well. Further, standards can be developed for the duration of use of the mattress and other supporting surface in different set-ups like with rubber sheet. New alternative supporting surfaces can be designing especially considering the need of these veterans with SCI.

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Exploring Visual Response on Form Features of the Autorickshaw

Susmita Sharma and B.K. Chakravarthy

Abstract Styling plays an important role in automotive appearances to attract visual attention. Features such as the headlights and windscreen become the prime carriers of style that can evoke visual interest. These features involve major to fine refinements in form as well as their compositional arrangements while designing. The feature that evokes high visual interest in isolation, or whether the combinations of features sustain visual interest for a long time, can be valuable knowledge for the designer and stakeholder teams to make visual decisions on form especially during early stages of designing. Present study deals with feature level observations of Autorickshaw concepts as Areas of Interest (AOI) to assess attention distribution towards the form features during concept development stage. The data is obtained as visual response of Product Designers (PD), Automobile Designers (AD), Autorickshaw Drivers (DR), and Passengers (PS) through eye tracking. The investigation analyzes how visual attention can be driven by features in isolation or in combination within larger units for four concept representations of the Autorickshaw. The effect of variations in visual-formal characteristics of the designed form is analyzed conjointly with by assessing the dwell time (DT) on each feature through a demarcation of specific AOIs, as well as a gridded analysis of the spatial distribution of visual attention on specific features. The findings indicate that the concept with curved features that are arranged in proximity, evoke high visual interest; instead of a concept, that supports sharp angular non-proximal features, implying that proximity and curved features can have strong combining effect to evoke and sustain visual interest in Autorickshaw styling. Overall, it was observed that the spatial distribution of attention converges, getting focused on the Cowl and the Headlights during style scrutiny. Increase in proximity of features results in an increased dwell time, thereby causing an active visual scrutiny that sustains visual interest. A combination of strategically placed proximal features, accentuates visual interest and the perception of style in observers. When available at the early stages

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of designing such inferential visual response feedback as objective knowledge can help the designers to anticipate sustained visual interest in a designed object, and help predict product acceptance, thereby curtailing potential market risks.

Keywords Visual response · Visual attention · Visual feature analysis

1 Introduction

Design features define the characteristics of a designed object. The 'feature' of an object is largely in multidisciplinary studies, inclusive of attributes like color or texture in isolation, or an element of form, like a line or an edge. Features are understood as a set that depends on the integration of several elements or even sensory quality of objects [13]. In our research study, a feature of a designed object, like the autorickshaw, is its visual semantic unit. Headlights, windscreen and Cowl are considered as the features, which are variables of manipulation through stylization. These are the sub-units that constitute the holistic form in their compositional arrangement.

The study for visual evaluation for autorickshaw restyling has been carried out on a live industrial consultation project commissioned in a design institute. The project required re-styling of the front of the auto rickshaw for an automotive company. The research study is done at concept development stage of the design project, where life-like renderings are used to evaluate design and styling of a product. The stimuli thus acquired are the four concepts under consideration for evaluation, including rendering of the existing Autorickshaw design.

2 Background

Attneave stresses the importance towards systematizing and validating formal and relational factors regarding form perception. This idea believed in systematic, meaningful and specified variation with and within form features, so that a degree of differentiation and impact can be understood. For example, the curvedness and angularity are experimented in symmetrical and asymmetrical arrangements [1]. Though these studies have immensely contributed to the knowledge of form and relational aspects with and within organization of form and its elements; they also strongly believed in controlled sample experimentation, so that the differences are specifically attributable [2]. While the outcome of these studies can be generalized widely, these aspects have to be contextually experimented in order to assess specific combinations in a product.

Drawing attention to a product can be a starting point to influence aesthetic appraisal. The object-perception has been observed to be led by the aesthetical appreciation that manifests itself through visual choices. These studies also help understand interpretation of Form as it influences the success of products [4]. Form aesthetics, is an important factor that is broadly portrayed by appearance of the designed to assess the aesthetic perception in design [11]. Product physical language is also explored that entails its form, style, function, aesthetics, cultural value, affordance and personality along with associations that may be formed with the formal elements of a product [8]. Additionally, in a methodology for computer-supported design for aesthetics, three main characteristics are proposed to study form—shape, composition and physical attributes that can be used as an expression for high-level characteristics like style or taste [10]. These ideas have led to identification of various sub-factors that explain both, at a macro and micro level influences of the physical aspect of the designed object form. Studies also qualify the aesthetic preference of form by determining utility functions [11]. "Sensory pleasure and delight" is how Hekkert and Leder [7] interpret forms, as the objects fundamental to the profession of product design that elicit aesthetic response.'

Product appearance and similarity on basis of geometrical arrangements, and feature proportion, with interrelationship to overall form have been given importance [5]. While studying the influence of Symmetry and complexity on form preference; trend for high symmetry and low complexity preference have also been reported [9]. These findings coincide with Barlyne's arousal-complexity theory, where complexity may evoke interest from experts [6]. A positive relationship between complexity and preference has also been reported [12]. But, excess of use of some visual aspects like unity or symmetry may also create redundancy and boredom in orderly arrangement of elements and may repel the visual interest according to Berlyne [3]. A designer in such situation needs to know how relevant can the features be or stylization in isolation and in congruence; to place the design of their proposed form concept appropriately. These studies can be regarded as benchmarks for conventions that need to be objectively complemented with design research on visual exploration of form.

3 Methodology

In product design, especially at early stages, one of the important factor is the ability of a designed object to evoke attention towards its form. Additionally, the ability of its form and features to sustain visual interest for longer time, as it may also be a starting point for generating visual interest towards the product. This in turn can become an implicit capacity of features of a designed concept to evoke and sustain visual interest. This understanding can be achieved by examining the duration of fixations on each area of interest. However, there needs to be triangulation to validate if larger share of attention may have been a result of an evoked visual confusion.

Present scheme of analysis decodes the visual attention pattern, and attention distribution by analyzing how visual attention could be driven by features in isolation or an organizational composition. And weather visual attention behaves differently within larger units for each concept. This is examined by inspecting the role of features in each design concept, to determine the ability of individual features, and elements to sustain visual interest in the design concepts for the autorickshaw.

3.1 Stimulus

Autorickshaw—The form is distinctively consisting of large Continuous surface, with meaningful features, as additional identifiable semantic units. It can be noticed that overall shape is not altered much; features are altered or differently placed for each concept. For the given stimulus, there were varied stylizations made to certain parts only. These are shown in the Fig. 1.

3.2 Material

The study uses iView X RED system; it is a Remote Eye Tracking Device; that automatically compensates for head movement noise data. It is a dark pupil eye tracking system, which uses Infra-Red (IR) illumination and computer based image processing. A 9-point calibration was done with x and y positioning tolerance level at 99%. The system Laptop with 60 Hz refreshing rate was used, and the stimulus was displayed on a dual monitor, 96 dpi, 17″ LCD monitor. The display monitor resolution was 1280 × 1024 pixels, in a 32-bit color mode. The physical stimulus size was 24.5 × 22.5 cm. The subject-screen distance was 720 mm.

3.3 Procedure

After calibration, for Free viewing (FV) condition, the four concept images were exposed to the subjects for 10 s each. Each stimulus image was followed by a gap of empty grey slide to provide a visual break to minimize any visual biases. After completing one session, the entire session was repeated for the same user with a random viewing order change in displaying concepts, with a question spoken, ‘do you find this autorickshaw stylish’, as the Motivational View (MV) condition. A calibration was repeated with change in viewing condition; implying that every 4 exposures there was a re-calibration.

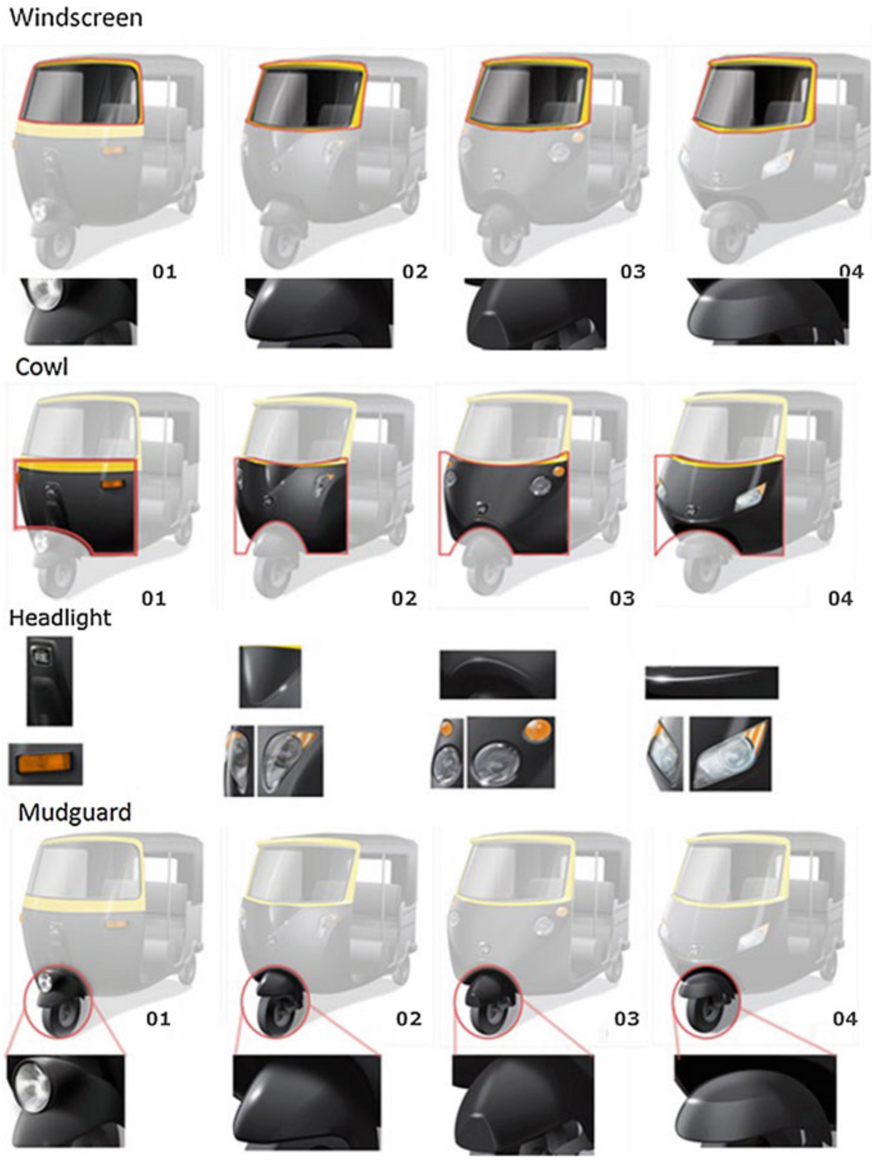

Fig. 1 Windscreen design varies only for 01. 02, 03, and 04 design concepts have same windscreen design. The Cowl of each design concept had varied features and stylizations. Variations in mudguard are also shown, with 01 mudguard featuring the single headlight unit

3.4 Subjects

Eye movement data was recorded for 20 respondents ($N = 20$, 6 F/14 M, *Mean* Age: 34.8; *SD*: 12.1). The respondent groups comprised of—Product Designers (PD), Automobile Designers (AD), Drivers (DR), and the Passengers (PS).

3.5 Detection Parameters

Detection for events, refer to a gaze point being turned into a fixation. The detecting parameter for a fixation threshold was minimum duration of 80 ms and maximum dispersion of 2°. This is the low speed event detection. This becomes the minimum fixation duration window; fixations smaller than this are not caught.

4 Analysis Scheme

4.1 Distribution of Visual Attention on Form Features (AOI)

The effect of variations is considered in visual-formal characteristics of the designed form, with high visual interest by assessing dwell time (DT) on each feature through demarcation of specific AOIs as well as gridded study for spatial distribution of visual attention. Areas of Interest (AOI) have been kept as marked by the designing team of the product concept. As the design team specifically worked on focus features like the

No	AOI	CODE
1	Windscreen	W
2	Cowl	C
3	Headlight	H
4	Intersection	I
5	Mudguard	M
6	Rear	R
7	Top	T
8	Front Wheel	F
9	Back Wheel	B
10	Outside/BG	X

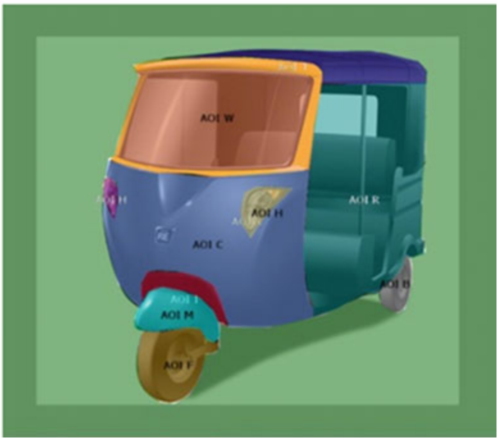

Fig. 2 Windscreen design varies only for concept 01. 02, 03, and 04 design concepts have same windscreen design

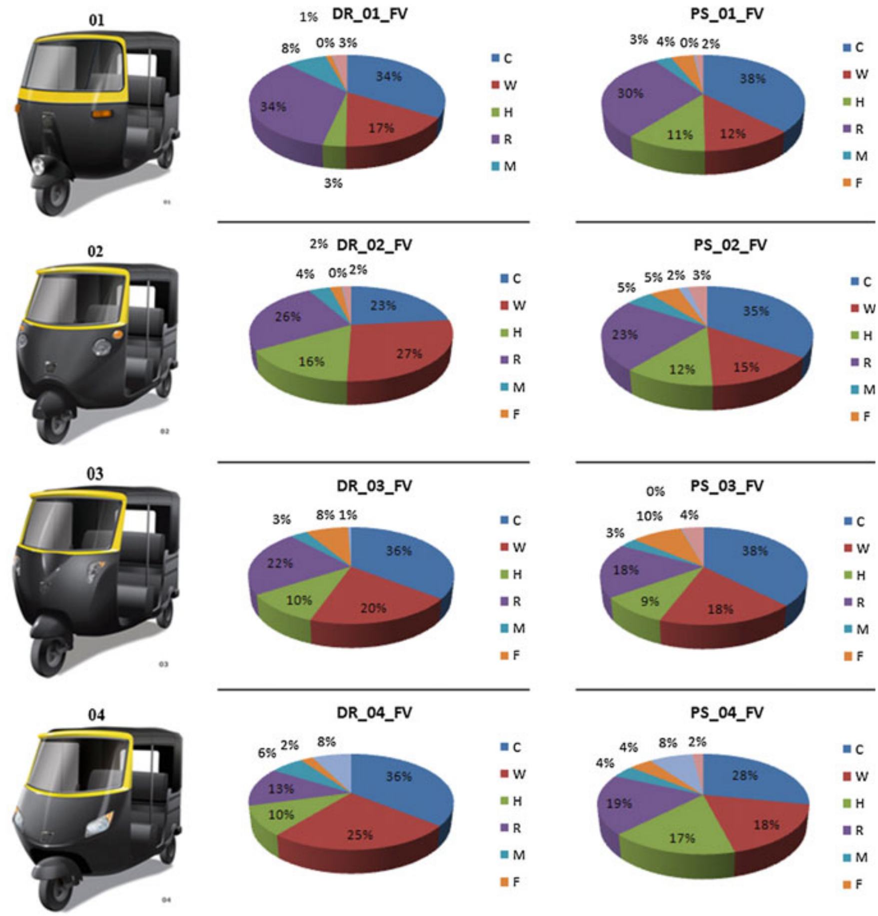

Fig. 3 Dwell time percentages for each AOI for DR (Drivers) and PS(Passengers) in FV (Freeview) for each concept

Windscreen, Cowl (with design variations in headlights with indicators, and additional nose features) and the mudguard. No other change had been made to other parts, therefore these main areas of stylistic variations were regarded as AOIs for the study. Conjoint analysis is done by analyzing *AOI feature* data and by *applying gridded* heat map. We explain each method in the following sections.

4.2 Allocation of Visual Attention on AOI

For AOI feature data, outlining of each AOI is demarcated and coded as a unique alphabetical code and dwell time on each feature is retrieved. This demarcation is done according to shape of the AOI feature as shown in Fig. 2. Each Area of

Interest is defined as a unique alphabet; we use the starting alphabet of each AOI. For example, the ‘AOI W’ is coding for Windscreen, ‘AOI H’ for Headlight; ‘AOI C’ for Cowl as shown in Fig. 3.

4.3 Gridded Heat Map Analysis

A heat map projects the intensity of visual attention, from low to high with demonstrating the dwell time on an area of interest as color code and dwell time gaze rate. The gridded heat map allows to analyze the dwell time (DT) range superimposed on the stimulus for a comprehensive visual analysis with a combination of both numerical and spatial data visualized as a heat map.

For visual analysis the heat map is transferred as a grid along with the dwell time allocations to the stimulus image that is superimposed with 8 × 8 grid (64) of 3.2 cm × 2.6 cm each (Fig. 4).

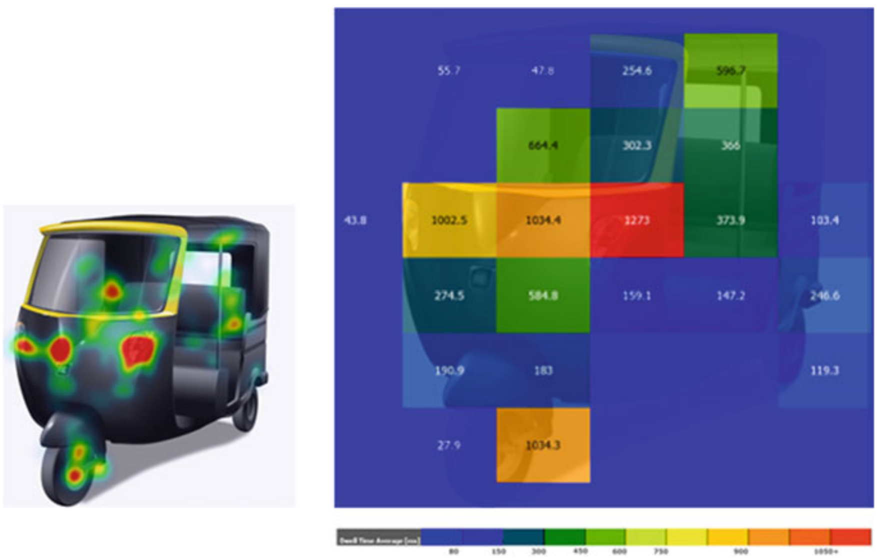

Fig. 4 Gridded heat map. The intensity of attention is determined with intensity of gaze. A heat map is a graphical representation of gaze data where the individual values contained in a matrix are represented as *colors*. The default lowest values are suggested towards *blue* and highest values towards *red*, shown with a *scale*

5 Results and Discussion

Design Concepts 01 and 03, evoke and sustain visual interest despite viewing condition, due to proximity, augmented by added feature of nose-shaped suggestion in Cowl. However, 03 exceed sustaining visual interest due to an additional inclusion of a suggestive cowl curvature highlighting the headlights. For concept 01, conversely there is disengaged visual interest with placement of indicators, and a singular headlight placed at the mudguard allowing the gaze to wander.

Overall, spatial Distribution of Attention converges, focalizes at Cowl and Headlights while scrutinizing for style in Motivational viewing (MV). Perception of style is characterized by Cowl and Headlights for PD. For AD, along with Cowl and Headlights, rear and logo spaces are relevant. For DR, headlight Cowl rear and Windscreen hold visual relevance to assess style, while for PS, Headlight, Cowl and logo space are more relevant. For AD it is Cowl Logo and Headlight that create relevance.

For 03, overall results reveal a decreased spatial distribution of visual attention despite motivational task; as the features are able to sustain and direct attention in a more focused way; for concept 04, its only true for free viewing condition. The decreased spatial distribution of visual attention attributes to an efficient and streamlined acquisition of information from select features through sequential guidance, in sustaining visual attention. A combination of strategically placed proximal features accentuates the concept 03 to evoke and sustain visual interest and reinforce perception of style in the subjects. We observe that visual distribution of attention varies from FV (Freeview) to MV (Motivational View) as there is an effect of motivation on visual distribution of attention to AOIs.

For the abundant visual information, the visual exploration relies on the mechanisms of selection and rejection of visual information. Selection of certain features depict the visual priority through a sustained and prolonged visual interest by observers in the visual form features and their organization. We explored how attention is distributed spatially to AOIs.

It is clear in the study that despite having a similarity in spatial distribution of attention, there can be switch or shift in visual intensity areas, due to motivation, indicating a switch from stimulus-driven (bottom up) to task driven (top down) influences. Task-driven (Top-down) and Stimulus-driven (bottom up) may implore a conjoint effect towards visual spatial distribution of attention. Also, increase in proximity results in an increased dwell time in proximate features forming an active visual scrutiny that sustains visual interest. Thus, for designing vehicles with an arrangement of features especially such as the autorickshaw in present case, the study proposes that while the features may hold attention for information processing, however, the arrangement of the features holds the key to sustaining visual attention. Present case is a pilot study and thus more exhaustive research needs to be done on these factors to understand concrete evidence of sustained attention on feature arrangements, in more controlled experiments. While concept development stage is crucial to obtain visual assessment, this stage provides mainly the 2D, or graphic representation of the product as stimulus. A study with 3D models could verify if the visual attention pattern brings about similar insights. The drawback of a ready prototype stage however could be, that the number of concepts decrease towards final stages in a live project.

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Effect of Orientation and Position of Impact on the Lower Extremity Injuries During Car Pedestrian Crashes

Raghu V. Prakash and Harikumar Payyur

Abstract Pedestrians belong to one of the most vulnerable group of road users. During a car pedestrian impact, injuries may happen to the head, which may be fatal enough to cause death, or to the lower extremity which is non fatal. Lower extremities are the first region in the human body to come in contact with the vehicle. During a car pedestrian impact, lower extremity injuries which occurs due to the bumper contact can either be a bone fracture or knee ligament injury. Car pedestrian impact is studied from the lateral direction. A real world car pedestrian impact can occur from any orientation to the lower extremity. The present study investigates the variation in the lower extremity injuries with the variation in impact orientation. Total Human Model for Safety (THUMS), the standard finite element human model developed by Toyota central R&D labs, was modified with failure values to the knee ligaments and bones to evaluate the lower extremity injuries during an impact.

Keyword Lower extremity injuries · Pedestrian impact · Impact orientation · Position of impact

1 Introduction

Crash analysis has been one of the most challenging areas of research. Crashworthiness can be defined as the capability of the structure to undergo plastic deformation and yet maintain a survivable space for the occupants in crashes. The objective of crashworthiness is to develop a vehicle structure to absorb the maximum possible impact energy so that the residual energy is tolerable by the

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occupants. Crashworthiness assessment is dependent on the injury risks of the occupants and pedestrians which in turn, is dependent on the deceleration tolerance limits of the human body. Several organizations are working for the protection of pedestrians from vehicles. Pedestrian Crash Data Study (PCDS) [1] reports suggests that during a car pedestrian impact, the impact mostly occurred from the lateral direction (68%), while 17% of the impacts occurred from the front and 10% impact occurred from the rear indicating the pedestrians facing away from the vehicle. This accentuates the importance of the present study.

2 Literature Survey

The literatures available in the field of impact biomechanics is enormous. One of the first and foremost study is the bending response of the long bones by Yamada [2]. The study presents results of an extensive investigation about the response of the bones of human and animals in quasi static and dynamic loading. Kajzer and Bosch [3, 4] provided experimental details about the response of the lower extremity during a high speed (40 kmph) and low speed (20 kmph) lateral knee impact in shearing and bending loading. Kerrigan et al. [5] have done an investigation on the response of knee joint during bending and shearing loading by isolating the knee joint from the lower extremity of cadavers. The failure bending moment of the joint was estimated by the experimental investigation. Chawla et al. [6] has done the numerical validation of THUMS. The kinematics response of the model was validated with the experimental study [3, 4, 5]. Matsui [7] had studied the lower extremity injuries considering the impact velocity and the position of the impactor. The study came up with the fact that the variation of these parameters results in bone fracture or ligament injury in the lower extremity. Later, Soni et al. [8–10] expanded the investigation to the effect of muscle activation in the injury of the lower extremity and carried out an extensive study on the lower extremity in a full scale car to pedestrian impact in the normal walking posture both in low speed and high speed impact conditions. The stiffness of the impactor which influenced the injury of the lower extremity was studied by Yasuki [11]. The study did the investigation of the variation in the response of the lower extremity with the variation in the stiffness of the impactor. Kuwahara et al. [12] investigated a real world car pedestrian impact condition and the influence of lower energy absorber in the lower extremity injury. Arnoux et al. [13, 14] studied the strain experienced in the knee ligaments with the variation in the velocity of impact and also implemented injury criteria to analyze the standard impact conditions. Till then, all the standard finite element human models developed were in the standing posture. The real pedestrian may be in some random position during the impact condition which may vary the injury. Jani et al. [15, 16] developed a methodology to reposition the human body to various out of positions. The study compares the results of repositioning using the methodology developed to the repositioning using FE simulations. The study by Nakane et al. [17] focused on the evaluation of the lower extremity injuries from the bending moment diagrams with a comparison between finite element model and multi-body model. Nagasaka et al. [18] investigated the effect of position of the impactor on the kinematics of the lower extremity. It also studied the effect of impactor stiffness and the impact at various orientations. Mo et al. [19] had incorporated the failure parameters into the knee ligaments of the finite element human model which observed that the ultimate strain incorporated into the model in the element level is different from the global strain level that is obtained as the output and hence should be iteratively obtained. Though Nagasaka [18] had studied about the various impact angle orientations, the lower extremity injuries during various impact conditions at different impact positions were not studied in detail. In the current study, the effect of impact orientation at various positions of impact are studied. Failure parameters are incorporated into the finite element model to understand the injury possibility in the knee ligaments and the lower extremity bones during various impact conditions.

3 Model Validation Study

THUMS, the standard finite element human model, is available in various sizes including average size adult male (AM50%ile), small size adult female (AF05%ile) and a large size adult male (AM95%ile). The present study utilized the AM50%ile model in the standing posture representing a pedestrian. The first step towards the analysis of car pedestrian impact is the validation of the standard Finite Element model. The study done by [2] was used as the reference for the validation study. Femur and tibia bones extracted from the standard Finite Element model were supported on both ends and constrained in the posterior direction. A cylindrical impactor was allowed to impact at the middle region of the bones with a velocity of 10 mm/s such that the loading occurs in the anterio-posterior direction (Fig. 1). The force deflection characteristic of the long bones posterior was estimated from the numerical simulation to compare with the experimental results.

Figure 2 illustrates the comparison of the response of the experimental study (shown in Fig. 2a) with that of the numerical study (Fig. 2b); it can be seen that there is a similar trend between numerical and experimental results for femur and

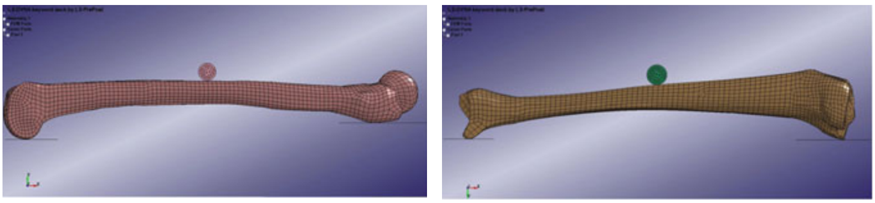

Fig. 1 FE model of quasi-static loading of femur (*left*) and tibia (*right*) in the anterio-posterior direction

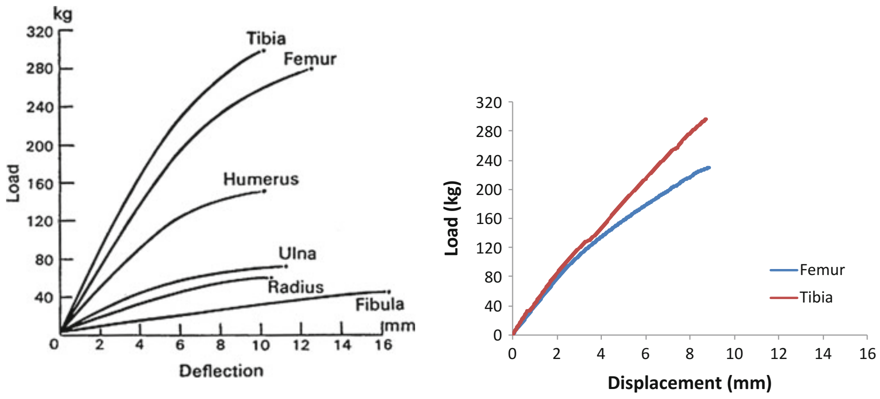

Fig. 2 Force-displacement response from the experimental results [2] (*left*) and from the numerical study (*right*)

tibia. The error in force values at a fixed displacement of 4 mm and 8 mm is about ±8%.

The kinematics of the model has been validated with the experiment study [3, 4]. Figure 3 represents the experimental setup followed by Kajzer and Bosch [3, 4]. The study investigated the shearing and the bending loading effects on the lower extremity in two different velocities. The lower extremity was preloaded with a load of 400 N in order to include the effect of upper body mass. The distal and the proximal region of the femur was constrained in the lateral direction. In the experiment study, target points were marked in the femur and tibia [3] to predict the displacement of the lower extremity of the cadaver. The target points, shown in Fig. 3, has been used to compare the kinematics of the finite element human model with the experimental results.

The lower extremity has been extracted from the finite element human as shown in Fig. 4. The numerical study has constrained the top portion of the sacrum. In order to replicate the boundary conditions simulating the experimental study, the proximal and the distal regions of the femur were laterally constrained. The results

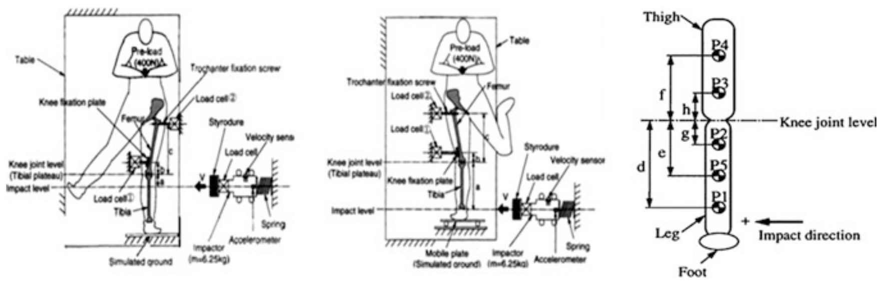

Fig. 3 Test set up for shearing and bending tests [3, 4]

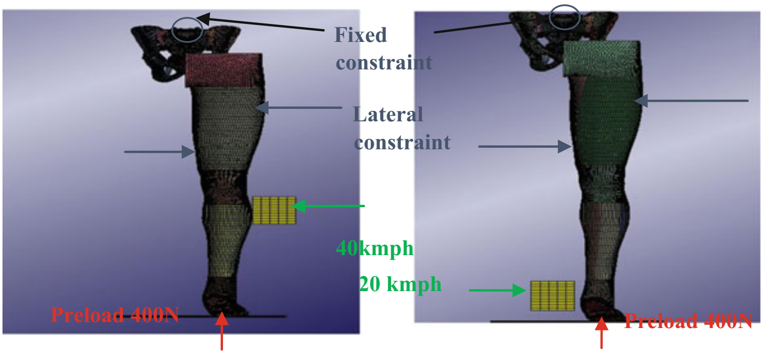

Fig. 4 Finite Element model of lower extremity with lateral constraints and loading

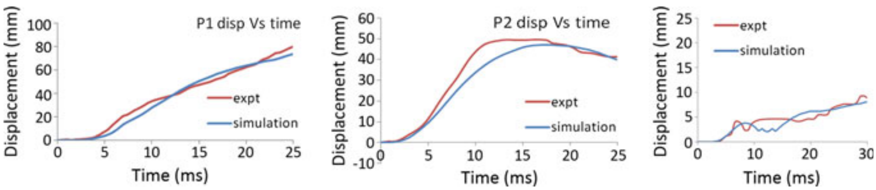

Fig. 5 Comparison of displacement versus time history of numerical study to the experimental results [3, 4] in shearing (40 kmph) and bending (20 kmph) loading conditions

from the numerical study was compared with the experimental results [3, 4] and the same is illustrated in Fig. 5. It is observed that the deviation in the displacement response of the finite element human model in the numerical study has been within the acceptable limits of the experimental study.

4 Numerical Evaluation

The lateral constraint boundary condition used in the validation study does not represent a real car pedestrian impact condition. Further numerical evaluation considered the case of removed lateral constraint of the femur. The position of impact which represents the height of bumper is one major factor influencing the lower extremity injuries. For the numerical study, a foam impactor of 6.25 kg was used. The impactor was allowed to impact at the lower extremity with a velocity of 40 kmph. Figure 6 explains the various impact configurations considered in the study.

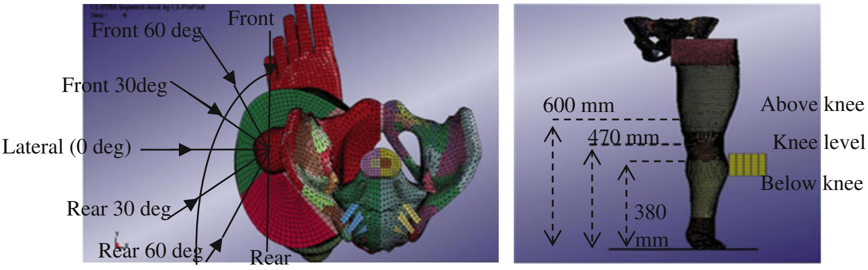

Fig. 6 Orientation and position of impact on the lower extremity

5 Results and Discussion

Failure values were input into the finite element human model as maximum strain for ligaments and maximum stress for bones. As per previous literature [13], ultimate strain of 22 and 28% has been assigned as failure strain to the cruciate and collateral ligaments respectively. The fracture of cortical and cancellous bones were obtained through the element deletion with a failure value 150 and 50 MPa respectively [14]. The failure criteria was incorporated in the human model using *MAT_ADD_EROSION card in LS Dyna.

In the lateral below-knee impact, the impactor compresses the fibula and pushes towards the medial direction. This resulted in the relative shearing between the tibia and femur during the first 10 ms. The inertia of the femur tends to rotate the upper portion of the knee about the tibia condyle. The compressive force exerted by the impactor on the leg produces a valgus motion of the knee. The Anterior Cruciate Ligament (ACL) and Medial Collateral Ligament (MCL) experienced more strain during the relative shearing phase. It is observed that the ACL rupture occurred during the initial relative shearing phase. The failure of ACL resulted in a sudden increase in the strain on the other ligaments, especially MCL which continued till the end of relative shearing period. The rotation of the femur about the tibia condyle results in an increase in the MCL strain but was below the failure strain. The posterior and lateral ligament experience a reduction in the strain as a result of the lateral rotation of the femur. Maximum strain distribution and von Mises stress distribution during the lateral below-knee impact is shown in the Fig. 7. The compressive force exerted by the impactor resulted in the peak stress in the impacted region of fibula. Ultimate failure stress was reached and fracture of bone occurred at around 11 ms.

Frontal below-knee impact, illustrated in Fig. 8, resulted in a lower duration of relative shearing than the lateral impact. Unlike the lateral impact, no bone fracture was experienced during frontal below-knee impact. von Mises stress experienced

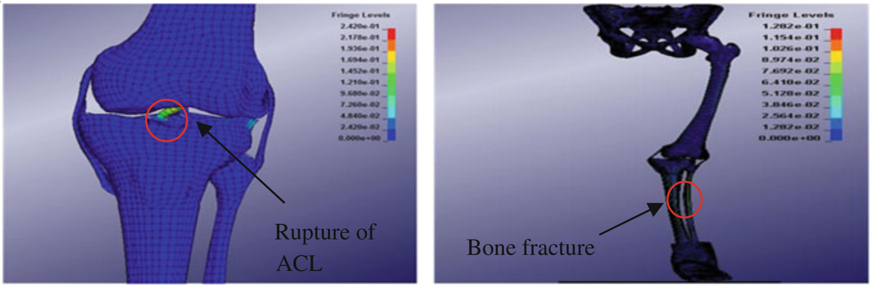

Fig. 7 Max strain (*left*) and von Mises stress (*right*) distribution at the onset of failure during lateral below knee impact

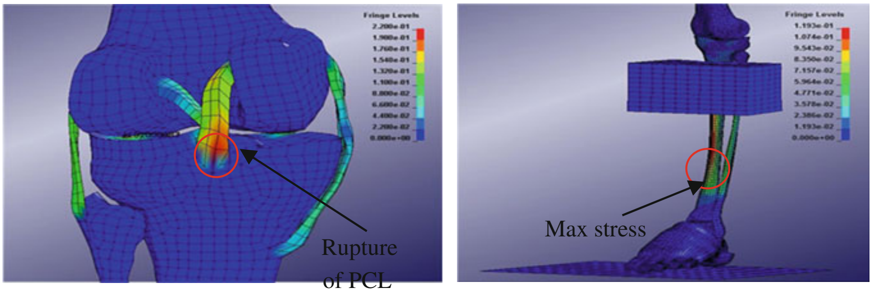

Fig. 8 Max strain (*left*) and von Mises stress (*right*) distribution during frontal below knee impact

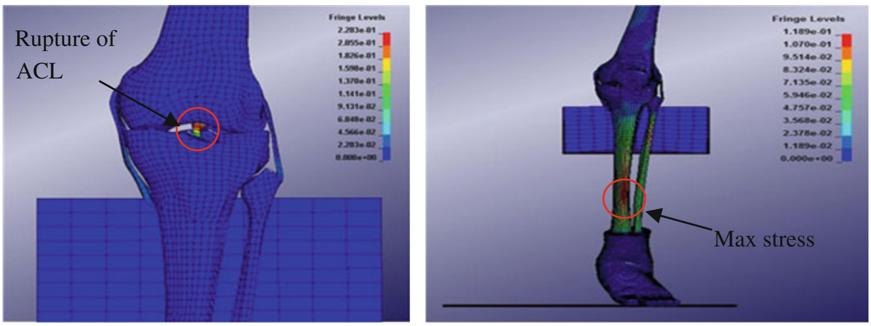

Fig. 9 Max strain (*left*) and von Mises stress (*right*) distribution during rear below knee impact

was higher in the anterior region of tibia near the distal third portion due to the lower cross section area [20] in the distal third region. Similarly, during the rear impact also von Mises stress was higher near the distal third region of tibia as shown in Fig. 9. ACL experienced a failure during the relative shearing phase.

5.1 Ligament Strain Comparison During Oblique Impacts

Figure 10 illustrates strain time history plot of the ligaments during oblique below-knee impacts. It shows that ACL is ruptured in all the oblique below-knee impact orientations. The rupture of ACL occurred during the relative shearing phase of the impact. The strain experienced by LCL showed a steady increase during the relative shearing phase period. A gradual reduction in the strain afterwards can be attributed to the rotation phase of the lower extremity about the knee joint. During oblique rear below-knee impacts, a steep reduction in the strain was observed due to the rotation of the region above knee joint towards the flexion direction. MCL experienced high strain during an oblique impact orientation. A steady increase in the strain is visible in the frontal oblique impacts. PCL rupture was visible only during frontal 60° impact since it resulted in the hyper-extension of knee similar to a normal frontal impact.

Figure 11 shows the comparison of ligament strains during oblique knee level impact. Ligament ruptures were less than the below knee impact. This could be due to the shorter relative shearing phase in a knee level impact. The strain experienced by MCL was found to be higher in oblique knee level impacts which could be due to the bending effect as a result of the direct impact on the knee joint.

As shown in Fig. 12, oblique impacts at above knee level resulted in more ligament rupture than other two positions. Relative shearing phase existed in the oblique above-knee impact. A variation in the slope after 8–10 ms shows the beginning of rotation phase. Frontal 60° impact resulted in the rupture of three ligaments namely ACL, PCL and MCL.

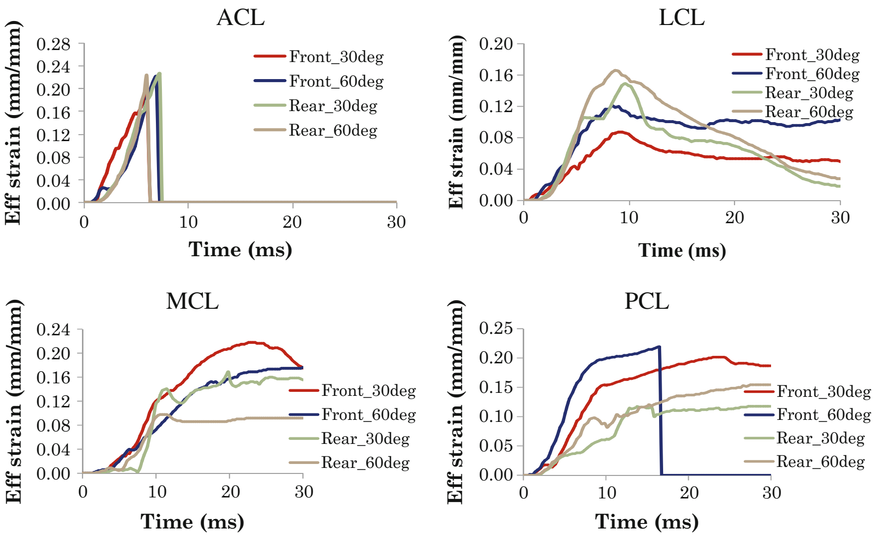

Fig. 10 Ligament strain variation during oblique below knee impact

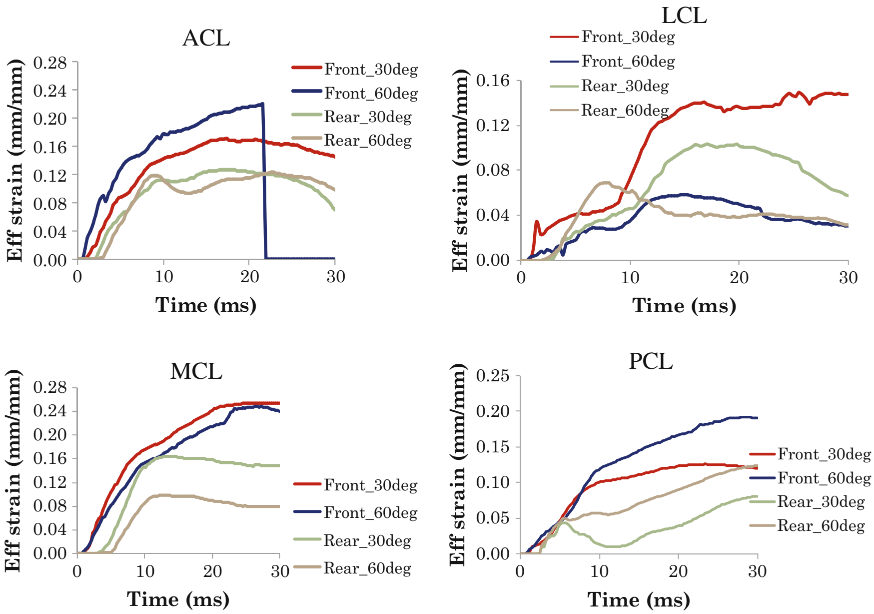

Fig. 11 Ligament strain variation during oblique knee impact

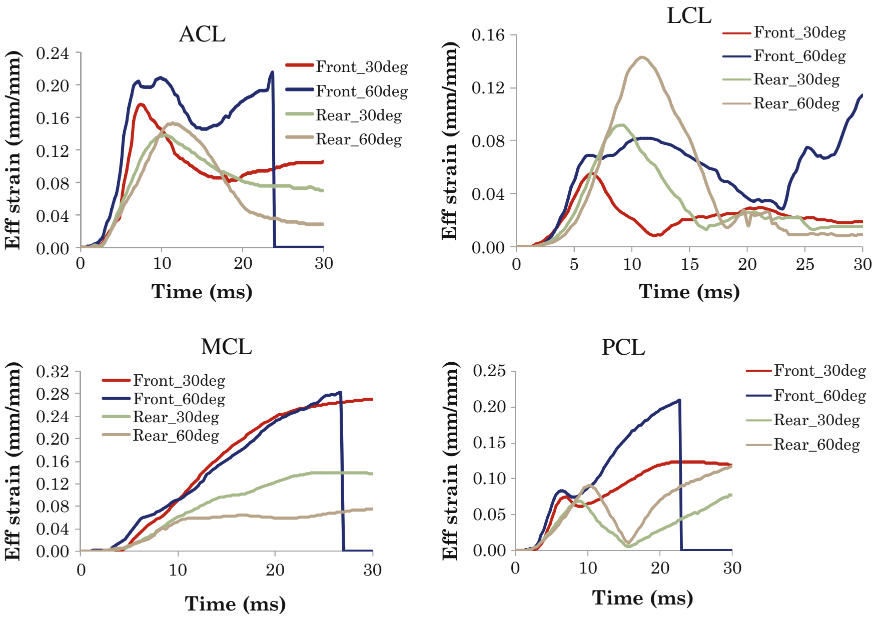

Fig. 12 Ligament strain variation during oblique above knee impact

6 Conclusion

THUMS had been extensively used to study about the injury mechanisms associated with occupants and pedestrians during impact. In the current study, only the lower extremity was used to investigate the influence of impact orientation and position on lower extremity injuries representing an AM50%ile pedestrian. The model incorporating the failure values for the bones and the knee ligaments is proposed. The numerical study had the hourglass energy below 10% of the internal energy which is acceptable. The study explains that the lower extremity injuries were dependent on the impact orientation. The lateral below-knee impact were having a rupture of knee ligament as well as a fibula fracture at the region of impact. The rupture of ligament was the first injury to occur. The frontal below-knee impact was more vulnerable to the ligaments. The rotation phase resulted in the rupture of knee ligament (PCL) followed by an immediate rupture of ACL. During a rear impact, the initial shearing phase between femur and tibia resulted in the rupture of ACL. No bone fracture was observed in the frontal and rear below-knee impact. From the study, frontal 60° above knee impact resulted in more ligament injuries than any other impact orientation. But the possibility of bone fracture was not observed.

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Inclusive Personlization of User Interfaces

Pradipta Biswas, Ankit Halder, Khushboo Maheshwary and Somnath Arjun

Abstract This paper presents a user modelling system that facilitates developing and using interfaces for people with wide range of abilities. It consists of a simulator that helps designers to understand, visualize and measure effect of physical impairment on user interfaces. The modelling system also consists of a web service to customize static features (like font size, colour contrast) of an interface and a pointing facilitation module that predicts users' intended target. The paper highlights applications of the system in product design and developing a web based geo-tagging application for reporting civic, healthcare issues and disaster warning messages by elderly users themselves.

Keywords User modelling · Inclusive design · Target prediction · Human computer interaction

1 Introduction

A huge part of social communication now takes place through electronic media though lot of it remains inaccessible to the growing elderly population. Many existing user interfaces often work for 'average' user and does not cater the need of the growing population of elderly users. The World Health Organization also says that 15% of the world's population is disabled in some form, the world's largest minority. This number is growing every day due to increased medical advancements and an aging population.

How can we design inclusive intelligent interface or interaction? Say for example you have decided to launch a new tablet which will be easier to use than

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existing devices by people with disabilities and elderly users and thus will conquer a wider market segment than competitors. How can you achieve that? One possibility is to enlighten the development team about the problems faced by people with different range of abilities with existing devices and ask them to develop a solution which does not have such problems. Another possibility will be to take an existing tablet, load it with a few profiles tuned for different range of abilities—like profile for low vision, colour blindness, Parkinson's Disease and so on and ask end users to activate an appropriate profile after buying the tablet. The third possibility is more ambitious—we can have an online intelligent agent observing human machine interaction as part of the operating system of the tablet and adapting the user interfaces as users kept on using their devices.

This paper presents the Inclusive User Model that supports all these possibilities. It has a simulator which can help designers to visualize, understand and measure effect of physical impairment on designers. A part of the model is published as a web service which can be used to create an online user profile which can adapt user interface irrespective of device and application. A part of the user profile is standardized by publishing through an ITU-T report [16]. We have investigated eye gaze, hand and finger movements of users and developed a few models using neural network, linear regression and Bayesian logic that can predict users' pointing target in a graphical user interface and can significantly reduce pointing and selection times.

2 Literature Survey

Inclusive Framework: The Global Public Inclusive Infrastructure [14] in USA and its EU counterparts like Cloud4All [9] and Prosperty4All [21] projects took an initiative to develop an inclusive infrastructure for developing, publishing and searching appropriate inclusive systems for people with different range of abilities. These projects did a commendable job in specifying the scopes and objectives of a large scale inclusive infrastructure but implementation-wise the projects are still at preliminary stage and only developed a few technology demonstrators, which are yet to leverage the whole framework. More specifically, these projects do not have any objective mapping between users' range of abilities and interface parameters and works mainly based on users' explicitly stated preferences. The use of the well-validated simulation of users' performance in the proposed framework will help to cover a wider range of users than existing systems and facilitate the interface personalization process for people with wide range of abilities.

Interface personalization is mainly explored in the domain of content personalization and developing intelligent information filtering or recommendation systems based on user profiles. In most of those systems content (or information) is represented in a graph like structure (e.g. ontology or semantic network) and filtering or recommendation is generated by storing and analyzing users' interaction patterns. Little research work has been done beyond content personalization. A few representative and significant projects on interface personalization are the SUPPLE project at University of Washington [13], and AVANTI project [24] for people with disabilities. The SUPPLE project personalizes interfaces mainly by changing layout and font size for people with visual and motor impairment and also for ubiquitous devices. However, the user models do not consider visual and motor impairment in detail and thus work for only loss of visual acuity and a few types of motor impairment. The AVANTI project provides a multimedia web browser for people with light, or severe motor disabilities, and blind people. It distinguishes personalization into two classes—static adaptation which is personalization based on user profile and dynamic adaptation that is personalization following the interaction pattern (e.g. calculating error rate, user idle time etc. from usage log) with the system. The lack of a generalized framework for personalization of users with a wide range of abilities affects the scalability of products as the existing systems work only for a small segment of the user population. For example, there are numerous guidelines and systems for developing accessible websites but they are not always adequate to provide accessibility. Moreover, designers often do not conform to the guidelines while developing new systems and design non-inclusive applications. It is also difficult to change existing systems to meet the guidelines. There are a few systems (e.g.: IBM Web Adaptation Technology, AVANTI Web browser which offer features to make web sites accessible but either they serve a very special type of user (motor-impaired for AVANTI) or there is no way to relate the inclusive features with the particular need of users. A detailed literature survey on user model can be found in separate papers [3, 6, 7].

Indian Context: In India, research on human computer interaction made significant contribution on developing multi-lingual systems for Indian languages. Regarding new modalities of interaction, researchers in India already investigated eye-gaze tracking based interfaces for text typing [15, 23], eye gaze patterns of elderly people during web searching, voice based interactive systems for illiterate or neo-literate users and so on. Indian projects like Text-Free UIs [19] or VideoKheti [10] at Microsoft Research and eAgri or eHealth projects [1] at RTBI, IIT Madras pointed out not only different new interaction techniques like iconic interface, voice input and spoken output systems but also developed technologies beyond desktop computing environment and for low-cost mobile phones suitable for farmers and rural health workers. RTBI's eAgri system sets up a low-cost mobile phone based agricultural advisory system that allows farmers take photographs of damaged crop, send it to experts and get feedback over their phone. The software on the low-cost phone can personalize font size and colour contrast based on range of visual ability of its users.

Important effort was made in developing useful games for differently abled children. Sharma and colleagues [25] proposed a gaming system to improve shared attention and communication with peers for autistic children while Qiao and colleagues [22] proposed a kinematic sensor based game to improve the natural gesturing capability of children with cerebral palsy.

However, most of the above mentioned research projects lack a unified user modelling framework even though they tried to address a diverse range of abilities of users. Hence many project ended up with rather useful design recommendations but not a framework to facilitate development of inclusive systems. Although, considerable progress has been made in development of multilingual and text free interactive systems, but a personalization framework can go beyond only choosing appropriate language for end users. Additionally, a lot of projects aimed for neo-literate people, but there are not many systems developed for literate or well-educated elderly population, who did not grow up with electronic technology but otherwise successful in their respective professions. Prabahakar and colleagues [20] have noted that "Maintenance and Welfare of Parents and Senior Citizens Act, 2007, aimed at serving the elderly live in self-respect and peace. The elderly requires a range of assistive technologies that can improve the quality of their lives". The Inclusive User Model aimed to take a unified inclusive approach for personalizing interfaces for end users ranging from severely disabled children to middle-aged and elderly computer-novice users.

3 The Simulator

The Inclusive User Model more accurately represents human psychology and physiology than GOMS or application specific models while covers wider range of abilities of users than the Cognitive Architectures like SOAR or ACT-R [7]. The user model will itself be easy to use as it will be implemented through a desktop application and a web service. The desktop component is a virtual user simulator modelling human machine interaction and consists of the following three components:

The Environment model contains a representation of an application and context of use. It consists of:

- **The Application model** containing a representation of interface layout and application states.
- **The Task model** representing the current task undertaken by a user that will be simulated by breaking it up into a set of simple atomic tasks following the KLM model.
- **The Context model** representing the context of use like background noise, illumination and so on.

The Device model decides the type of input and output devices to be used by a particular user and sets parameters for an interface.

The User model simulates the interaction patterns of users for undertaking a task analysed by the task model under the configuration set by the interface model. It uses the sequence of phases defined by Model Human Processor [17].

- The perception model simulates the visual and auditory perception of interface objects. It is based on the theories of visual attention and speech perception.

- The cognitive model determines an action to accomplish the current task. It is more detailed than the GOMS model [17] but not as complex as other cognitive architectures.
- The motor behaviour model predicts the completion time and possible interaction patterns for performing that action. It is based on statistical analysis of screen navigation paths of disabled users.

The details about users are store in xml format in the user profile following the EU VUMS (Virtual User Modelling and Simulation) cluster [11], which is also recently published in an ITU-T report [16]. The user profile stores demographic detail of users like age and sex and divide the functional abilities in perception, cognition and motor action. The perception, cognitive and motor behaviour models takes input from the respective functional abilities of users.

Example of Using Simulation in Product Design

The following example demonstrates how designers can decide whether a particular brand of product can be confused with other similar brands by people having mild Macular Degeneration and Red-Green colour blindness. We start with the following target product shown in Fig. 1 and compared it with three similar brands. Figure 2 shows the simulation of Red-Green colour blindness and early stage of Macular degeneration on the target product and three other similar brands. The change in colour and blurred images will help designers to visualize the issues with people with visual impairment.

However, we conducted more detailed analysis and Fig. 3 and Table 1 shows the similarity in colour and shape features of these products for people with and without visual impairment. We assume a 2-D grid of products as they are arranged in a supermarket or online shopping webpage. We measured the colour histogram (an algorithm comparing colour features in two images [6]) and shape context (an algorithm compares shapes of two images [6]) coefficients in a scale of 0–1 between our target product (marked with a red circle in Fig. 3) with other similar brands. We have put a set of captions below each brand which all starts with the letters 'c' and 'o'. The captions are place holders for pricing information as it appeared below product pictures. In Table 1, the target brand is coloured red brads those are

Fig. 1 Target brand

Fig. 2 Simulation of colour blindness and early stage of macular degeneration

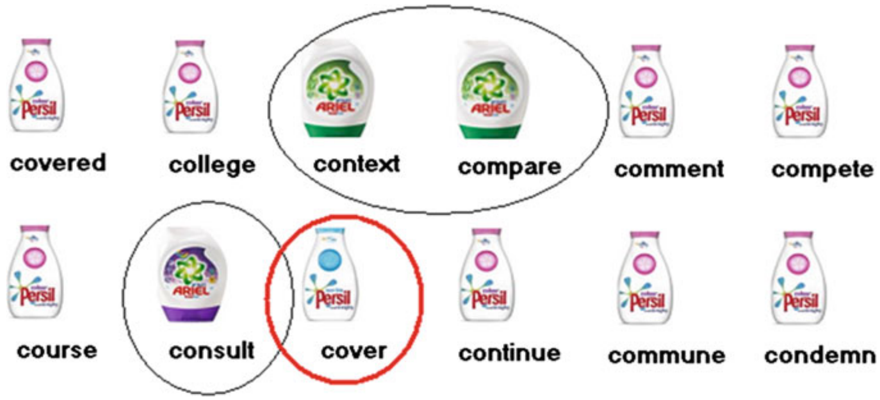

Fig. 3 A grid of different products

different in both colour and shape, are bold-faced. The table also shows there is no significant difference between people with no visual impairment and red-green colour blind users for these particular brands. However, for people with Macular Degeneration both colour histogram and shape context coefficients reduced and in particular the colour histogram coefficients become similar between the target brand and another similar brand due to blurred and distorted vision. So the simulation suggests that the target brand should have more distinctive colour to cover people with blurred and distorted vision. The analysis can be extended to pinpoint colour and shape features that can make a target brand looking similar to other brands for people with different range of abilities.

Table 1 Colour histogram and shape context coefficients

	No visual impairment		Colour blindness		Macular degeneration	
	Colour histogram	Shape context	Colour histogram	Shape context	Colour histogram	Shape context
1	0.91	0.71	0.89	0.72	0.87	0.40
2	0.91	0.71	0.89	0.72	0.88	0.41
3	0.80	0.57	0.81	0.57	0.79	0.26
4	0.79	0.57	0.81	0.57	0.79	0.27
5	0.91	0.71	0.88	0.72	0.87	0.39
6	0.91	0.71	0.89	0.72	0.87	0.40
7	0.92	0.71	0.90	0.72	0.88	0.40
8	0.82	0.57	0.83	0.57	0.81	0.23
9	0.96	0.78	0.95	0.78	0.89	0.65
10	0.91	0.71	0.89	0.72	0.88	0.40
11	0.91	0.71	0.88	0.72	0.87	0.38
12	0.91	0.71	0.88	0.72	0.88	0.38

4 User Modelling Web Service—Static Adaptation

We have used the simulator to develop a user modelling web service that can automatically adjust font size, colour contrast, line and button spacing of interfaces based on visual acuity, type of colour blindness, grip strength, active range of motion of wrist and static tremor of users. The user modelling web service

- follows a standardized user profile format specified by a EU cluster [11] and published by International Telecommunication Union [16].
- does not propose to change content of an interface rather specifies layout parameters, so it is easily integrated to different applications.
- can automatically convert interface parameters (like font size or button spacing) for multiple devices (e.g. TV, computer, laptop, mobile phone and so on) by assuming a viewing distance for different devices and taking the screen resolution as input parameter [6].
- has investigated details of visual, auditory and motor functions of humans and is developed through extensive user trials to relate human factors to interface parameters [1–7].

Our user survey [3] generated the range of visual acuity, colour blindness grip strength and ROMW of users. This range of values is used in Monte Carlo simulation to predict a set of rules relating users' range of abilities with interface parameters like font size, colour contrast, line spacing, default zooming level and so on. The rule based system along with user, device and application profiles are stored in a cloud based server.

The framework is integrated to applications using a client application. The client application reads data from the user model and sensor network and changes the font size, font colour, line spacing, default zooming level and so on by either selecting an appropriate pre-defined stylesheet or changing parameters for each individual webpage or standalone application. Once a user Signs Up to our user modelling web service, he can get personalized user interfaces irrespective of device or application. Our user study [1] confirmed that elderly users could undertake representative pointing and selection tasks faster with the adapted interface than its non-adapted counterpart.

5 Pointing Facilitation System—Dynamic Adaptation

The user modelling web service discussed above customizes static features of an interface. We have further developed a pointing facilitation system for persons having difficulty in using standard pointing devices like mouse or touchpad that reads instantaneous cursor movements and expands on-screen target based on that. Following Langdon and Godsill's earlier work on smoothing cursor trajectory of motor-impaired users [18] and Wobbrock and colleagues work on Angle-Mouse [26], our pointing facilitation system has the following two steps

1. Smoothing cursor trajectory based on a polynomial algorithm
2. Scoring a value for each on-screen target and expanding on-screen targets in proportion to their probability of being selected

The following sections explain these steps in further details

Smoothing Algorithm

Our previous analysis [2, 7] of cursor trajectories of people with hand impairment showed that a cursor movement consists of many sub-movements. The number of sub-movements increases near the target when users try to stop the cursor movement. The presence of sub-movements introduces random jitter in cursor movement. So we have used a quartic equation to smooth cursor movements. A least squares method is used in order to get an equation of the form $y = a_0 + a_1x^1 + a_2x^2 \cdots + a_nx^n$, where n is the *degree* of the polynomial, and the parameters a_0, $a_1 \ldots a_n$ are constants. In our case, we stored up to a certain number of previous mouse movements, and then did least squares fit of the last mouse movements to create the smoothed trajectory (Fig. 4).

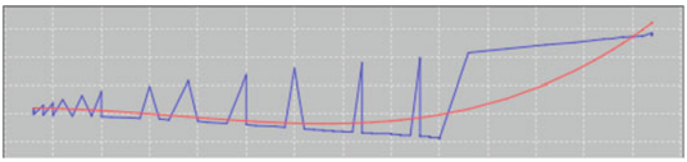

Fig. 4 An example of polynomial smoothing on a jerky pointing movement. The *red line* is the smoothed line, and the *blue line* is the original movement

Custom code was added in order to smooth mostly vertical movements, as the algorithm essentially stopped working if enough movements were made with no change in the X value. A classifier was added which classified movements as vertical movements after a certain threshold of recent mouse movements with no change in X value was passed. This code approximated the movements as a straight vertical line.

Target Expansion Algorithm

After smoothing the cursor trajectory, the Pointing facilitation system attempts to predict whether the user is in the ballistic or homing phase of movement [12] based on instantaneous acceleration of cursor movement and then uses either of the below methods to calculate the probabilities of selection of targets.

If the cursor movement is in ballistic phase, we assign a score to each target based on bearing of the movement. Upon every mouse movement, the angle between the mouse's direction vector and the target's centre are considered, and this angle in radians is added to an array of scores for that target. The direction vector is obtained by interpolating the last 3 smoothed mouse movements. We only considered movements towards the centre of the target. However, it may be prudent to add code to deal with users moving towards an edge of a target in a system where larger buttons are used. During the homing phase, the score is purely based on the distance to the target in the direction of the cursor, with closer distances having lower scores. When the cursor first reaches a target, its score is reduced to zero, and after that every mouse movement over the target adds a constant value to the score. Finally, we expanded the most probable target 40% bigger than its original size at 7 Hz based on the output of the target scoring algorithm. More detail on the system has been described in a separate paper [8] and our user study [1, 8] confirmed that the adapted interface gave an average improvement of 13.5% in target selection times, in a 10 person study involving users with different ranges of motor-impairment.

6 Adaptive Geo Tagging and Visualization

The following application has combined both static and dynamic adaptation systems. This application (Fig. 5) offers tagging exact location on the Google Maps with custom labels. The tagged data can be shared among other users to access the tagged information with the exact longitude and latitude. The web app also offers user adaptive visualization which allows our specially-able user to have a custom view of the web app. For example, a person with color blindness will have no problem to access information from the webpage as it will adapt according to their abilities to see differently. For a person having spasm or tremor in hand, the intended target will automatically be expanded reducing pointing and selection time (please note the Current Weather button on the bottom-left and Stop Tagging button on the bottom right picture of Fig. 5).

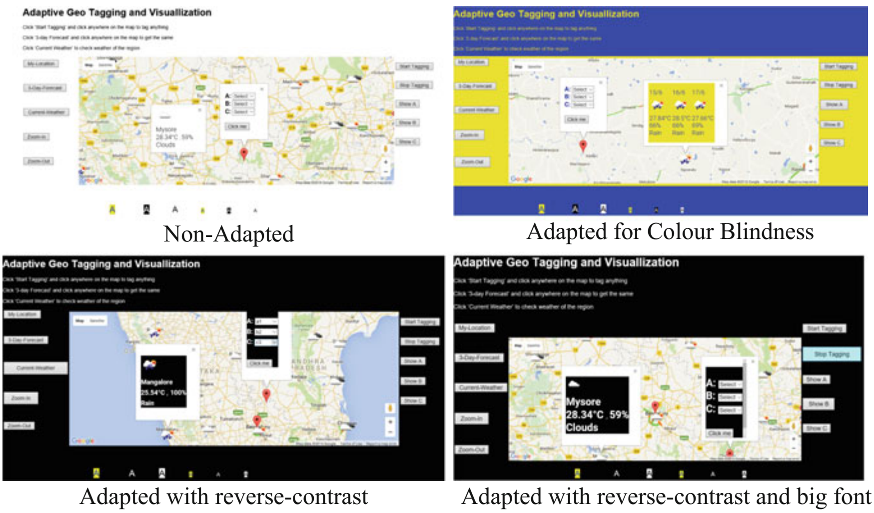

Fig. 5 Adapted geo-tagging and geo-visualization application

The map also shows current and next three days weather forecast, and the traffic layer on zooming at a point. We may also consider to add more data to the google map interface allowing a plethora of possible use cases. For example, a travel website which will allow different users to tag various locations (like ATMs, Places to Visit, Medical Center). These tagged information can be view by other users. Another use case can Disaster Reporting Tool for users as well as the concerned authority. User affected by the disaster (like type of Disaster, Severity) or user who can see the possibility of a disaster (like growing cracks before landslide, rising water level) can tag exact location on the map. This information can be accessed by other user which will help them maintain their safety, and the local authority which can set suitable precaution to reduce the casualties. Similar applications are designed for reporting civic and healthcare issues for quick identification of serious problems. The geo-spatial and temporal clustering of information provided by elderly users will be useful for quick identification and resolution of critical civic and healthcare problems.

7 Conclusions

Computers offer valuable assistance to people with physical disabilities. However designing human-computer interfaces for these users is complicated. The range of abilities is more diverse than for able-bodied users, which makes analytical modelling harder. We have taken a novel approach to designing and evaluating inclusive systems by modelling the performance of users with a wide range of abilities.

Previous work has explored this principle for able-bodied users; however performance modelling of people with a diverse range of abilities remains a challenge. We have investigated how physical capabilities of users with a wide range of abilities are reflected in their interactions with digital devices. Our inclusive user model helps designers to improve designs of user interfaces for people with wide range of abilities and helps end users to adapt user interfaces based on their range of abilities. The user model also follows standardized format to store the profile so that it can be easily integrated to multiple applications developed by different development teams. Our case studies demonstrate how a simulator can be used to improve design and the user studies confirm that systems adapted by the user modelling system are preferred by users and it also statistically significantly reduces task completion times.

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Part III
Design for X (Safety, Manufacture & Assembly, Cost, Reliability etc.)

A Research and Design Initiative for the Informal Sector of Street Food Vending in India

Vaishnavi Walvekar

Abstract Street food vending in developing countries, like India, provides convenient, inexpensive, and diverse cuisine to locals and tourists alike, while providing employment to millions of urban poor. However, despite street food's significant role in the urban food supply, it continues to be perceived as unhygienic and a hindrance to modernization. In many cases it exists as an illegal informal market, with migrant vendors working daily on the edges of busy roadways. The study investigated the nature and operations of street food vendors influencing hygienic practices. The author's research was conducted through direct and indirect interaction with these vendors, the creation and implementation of questionnaires, and continued investigative collaboration with stakeholders. The findings offered a number of impediments that led to poor hygienic practices. The resulting design solution allows street food vendors to overcome shortcomings, which not only benefits their business but also improve the experience of their customers.

Keywords Street food vending · Informal sector · Urban poor · Hygiene · Affordable · Upgradeable · Self sufficient · Pedal power · Social impact

1 Introduction

India as we know it, is seeing one of the most substantial migration patterns from rural to urban areas in modern history. Arriving in search of promising opportunities, these migrants end up living in poverty, struggling to survive in the urban environment as an ad hoc informal sector. The lack of recognition is the primary reason the vendors fall under the informal sector of revenue generating businesses that are not registered with the local government [1]. This includes individual establishments such as small-scale traders, vendors, and service providers that perform activities on their own accord. Studies on these workers show that they

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work long hours under trying conditions, though their earnings are highly disproportionate to the efforts invested [2].

This hunger to survive in the urban settings has given birth to radical and entrepreneurial modes of survival and enterprise. The most prominent place to witness this is the streets. They're colorful, they're vibrant and they're busy—what's an Indian street without street food.

Asking why India needs street food misses the essential role street food plays in the Indian diet. Statistics show that changing urban lifestyles have resulted in changing eating habits [3]. There are currently ten million street vendors in India, out of which five million are street food vendors. This number is set to double in the coming years; with more women working, they in turn have less time to prepare meals, and commuters in sprawling cities eat on the run. This increased demand for street food also increases the scope of the public health issue. Major sources contributing to contamination through the food cycle are found in preparation, utensils used for cooking and serving, raw materials, and the personal hygiene of vendors. This expanding market for quick, inexpensive, and hygienic food creates abundant opportunity for design intervention.

2 Approach

A review of the literature on street food vending indicated that until recently, the mainstream economists in India ignored the profession of street vending because of the lack of understanding of their contributions, problems, etc. [4]. Following the review, the author approached National Association of Street Vendors of India (NASVI), with a research proposal. NASVI was a valuable asset as it was a Non Governmental Organization that worked closely with the Government and the vendors. The author conducted two years of research in three major cities of India: New Delhi, Mumbai and Pune; focusing on New Delhi, where a large concentration of street food vendors live and work. Three vantages were taken by the author to conduct fieldwork: as a customer, as a NASVI employee, and as a distant bystander. The project aimed at examining the current situation in street food vending, encompassing both its importance to the modern Indian cityscape and increasing concerns over hygiene, in order to identify opportunities to empower vendors and improve customer experience with design intervention.

3 Research

3.1 Methodology

Using both quantitative and qualitative methods the author collected data in three prominent markets of New Delhi; Sarojini Nagar, South Extension, and Karol Bagh markets. Observational research and surveys were conducted in Mumbai and Pune.

Methods used to research involved the following; contextual inquiry, ethnographic research, interviews, surveys, observational research, follow-up interviews, visual audits, stakeholder meetings, focus group meetings. Documentation and presentation involved analyzed research insights, fieldwork images, and illustrations to understand and map need finding.

Participating vendors belonged to different vending types, selling different types of foods. Questionnaires to these vendors covered necessary information regarding their vending operations. The quantitative data presented in the findings is based on the findings after synthesizing the questionnaires and surveys. Follow up interviews were conducted with target users to further understand their challenges. Consumers from different cities were interviewed to find out their perceptions of street vendors.

3.2 Findings

The data gathered was critically analyzed to identify limitations and constraints facing vendors ability to deliver hygienic food. Research clearly indicated a unifying factor resulting in poor environmental and personal hygiene: A lack of structural and infrastructural facilities at the site of vending. This lack of onsite infrastructure is compounded by lengthy commutes made daily by the vendors. A survey conducted with 132 vendors in Sarojini Nagar showed almost 51% of vendors travelled more than 10 km per day. Among which, very few (13) could afford (a) paying shopkeepers a certain amount monthly to store their goods in their shop or (b) travelling by Rickshaw with their heavy goods. The vast majority of vendors interviewed commuted on foot, bicycle, or cart.

Once onsite, with no dedicated workspace for him/her, the vendors resorted to makeshift vending set-ups, the easiest being the ground. The majority of vendor participants cooked at 0–30 cm from ground level, while the World Health Organization recommends a minimum height of 45 cm.

Additionally, no provisions existed at the vending site for proper waste disposal, washing of hands, raw materials, and utensils. All of which were major factors in contributing to contamination. Focus group meetings with vendors indicated a strong need, even a willingness to pay, for basic provisions at the site of vending.

> Training camps teach us to wash our hands and clean our surfaces, utensils, and equipment but how am I to when there is no supply of water around me?
>
> —Radha Devi, Sarojini Nagar Market

> We need water to maintain cleanliness
>
> —Suneel Kumar Mishra, Coordinator, Karol Bagh Market, New Delhi.

> It is our job to keep it clean, I believe in cleanliness. If I had some basic facilities, and I served them well, I'm bound to get more customers, but if my dustbin and my utensils are confiscated by officials, how do I ensure my space?
>
> —Malti Devi, Sarojini Nagar Market

Water is required at almost every step of vending. Contaminated water is a risk to public health and a well-known vehicle for the entry of pathogens. Case studies in Kolkata reported that the water used for drinking, cooking, washing of fruits and vegetables, dishwashing, and hand washing came from pipes or hand operated tube wells supplied to different localities by the Municipal Corporation of Kolkata. 47% of samples analyzed were found to be contaminated. It should be noted that the water was safe coming from the source, but became contaminated through poor handling practices during collection, transportation, storage and usage [5]. In order to understand this cycle of contamination, it was imperative to study the current practices in water handling. In New Delhi, four water sources were used by vendors; 1. New Delhi Municipal Council/ Municipal Corporation of Delhi 2. Home 3. Contract basis 4. Tin water agency. Water was collected and stored in various makeshift containers and taken to the vending site. Handling methods included dipping a glass to transfer water from the bucket/container to utensil/food, which created unnecessary touch points for water to become contaminated.

Vendors repeatedly expressed the "need of the hour" to be a dedicated workspace with onsite facilities that enable them to practice proper hygiene in their daily operations. This need paved the way for the design process to be vendor focused towards creating self-sufficient solutions.

4 Design Process

The challenge: Street food, although nutritious, easily accessible, and inexpensive, is fraught with unhygienic conditions. How can we bridge the gap that exists in providing hygienic food, keeping in mind vendor-side self-sufficiency and affordability?

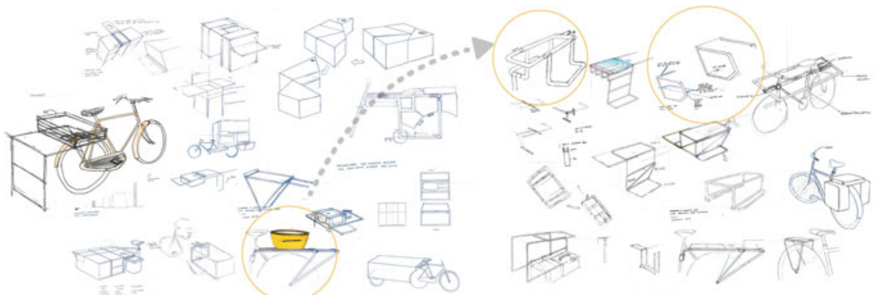
Target Audience: Vendors with no or small set-ups serving small to medium meals with no infrastructural support. In other words, the make shifts: vendors using ledges, pavements, bicycles, temporary structures, and other platforms for their vending setup.

While previous initiatives taken by the government show that there is no problem getting the vendors to accept the concept of hygiene, implementation remained low. A Hygiene Assessment Test was conducted to examine the result of NASVI and FSSAI's initiative to provide Safety Kits consisting of aprons, hairnets, and gloves indicated the following: very few vendors (6%) used the kit on a daily basis; aprons weren't washed regularly; plastic hairnets weren't worn due to the heat; and plastic gloves could not be worn for Indian cooking, due to the handling of heated equipment. The conclusion: topical solutions cannot answer the systemic problem of hygiene in street food vending. A reimagining of the way in which food is transported, prepared, and served is required.

4.1 Preliminary and Secondary Concept Development

Initial concepts included a variety of ideas to boost hygiene. Some tackled the problem at ground level; some introduced proven technology. The use of UV light, utensils that needed less contact, or raised surfaces with storage were among the many preliminary solutions. After a loop of stakeholder feedback and testing, results showed that the solutions encountered cost and acceptance issues; what vendors would be able relate to with respect to practicing hygiene was a challenge. Trying to interject modern and innovative solutions into the humble street vendor's life would encounter cultural resistance. The design parameters then, were to encourage and facilitate incremental behavioral change easily relatable to vendors.

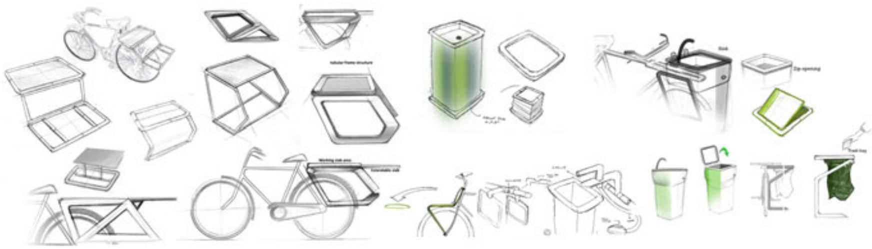
After the secondary design iterations, further concepts were iterated to find cost effective solutions. The target group's vending set up posed a primary challenge of how to get them off the ground. Handcarts were expensive and rare among the users, and while they provided a raised surface and wheels, they offered no solution to the lack of facilities. During the next stage of iterations the author leveraged an existing resource, common to users: the all steel Indian Roadster bicycle. The height, the meager cost of a secondhand bicycle (in the absence of owning one), and the weight it could support were all contributing attributes that drove the author to explore ideas in this direction. Available literature suggests that bicycles have a significant potential in increasing income by providing increased mobility, increased access to services, and increased carrying capacity [6].



4.2 Final Design and Concept Refinement

Reimagining the use of a commonly used asset paved the way for an innovation that would not only solve a plethora of user problems, but also attract customers as a symbol of the vendor's passion and dedication to providing safe food to their customers. Leveraging existing resources, such as the bicycle, would provide a central nervous system for their business. A foundation they could use, and build upon as their business grew.

The concept developed by exploring the bicycle and its form. The author used the systematic design approach of DfX (Design for excellence) focusing on design for cost and flexibility. With over 300 varieties of street foods in India, the design would need to cater to a vast target audience requiring a variety of vending operations and facilities. Designs were explored for flexibility, while optimizing operations within cost. Concept refinement included detailed material study in components, and improvisations in form and functionality.



The final design is a holistic, retro fit, upgradeable system that compliments the readily available Indian roadster bicycle, facilitating incremental improvements in user hygiene.

The design proposes a frame mounted onto the bicycle's preexisting components, in the front and back to accommodate the following: a cooking platform with the option of extension, a foldaway frame for a collapsible sink, and an enclosed water supply system connected to the sink with foot pump activation. Finally, the concept also proposed a pedal power blender for making chutneys/juices/drinks.

The foundation acts as a platform for innovation allowing for further enhancement with the flexibility to be incrementally built up on for vendor-specific needs. This concept can also be applied to street vendors selling commodities across developing countries facing similar challenges in the marginalized informal sector.

5 Conclusion

In India, as in numerous other developing nations, street food is a lifeline for both vendors and customers alike. Though it takes the form of a humble 'pop-up', the story behind it is quite complex. What goes unseen are the long hours, the grueling commutes, all to arrive at a jobsite that lacks structural and infrastructural support. These challenges come before the vendor delivers a single dish to customers. The persistent efforts to train and educate vendors on hygienic practices are not enough. Without facilities to carry out the teachings the vendors are helpless. Removing barriers to self-sufficiency by way of design intervention will help actualize the core goal that unites vendors and customers alike: nutritious, inexpensive, accessible, and safe food.

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Simulation of Roll Over Protective Structure Testing of Earth Moving Equipment Cabin

A. Gomathinayagam, P. Antony Stephen, K. Prabhakaran and R. Suresh

Abstract Roll over of heavy equipment operating in the construction, mining and agricultural sectors is a major cause of accidents. Safety frames called ROPS (roll over protective structures) have been used to protect the operators during rollover accidents. A ROPS cabin should withstand the loads and consume energy during roll over. At present, ROPS standards require full scale destructive testing to assess its adequacy which can be expensive and time consuming. The use of analytical methods to assess the performance is prohibited by them due to lack of fundamental research information on the nonlinear inelastic response of the structures. However, a non-linear finite element analysis has been used to simulate the ROPS testing. The FEA results have been compared with that of experimental testing and the FEA methodology has been improved to get a good correlation. In future this FEA approach will be used to finalize the ROPS design prior to full scale testing to minimize the number of prototype and thereby reduces the development cost and time.

Keywords Roll over protective structure · Cabin · Finite element analysis · Safety

1 Introduction

Earth moving equipment are primarily used for tasks in earthwork, compaction and re-handling. They operate in various environmental conditions both above ground (construction and agricultural machines) and underground (mining machines). Roll

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over during work is a major cause of accidents that result in death or severe injury to the operators. Hence a protective cabin is an inseparable part of the machine in order to ensure the safety and ergonomics of the operator [1, 2].

Safety frames called ROPS have been used to protect the operator during roll-over accidents. A ROPS cabin should fulfill dual criteria of withstanding the loads as well as absorbing the impact energy during the rollover [3]. At present, Indian Earth moving equipment manufactures follow ISO 3471, EN 13510:2004 which insists full scale destructive testing to assess the adequacy of the ROPS cabin which can be expensive and time consuming [4]. The use of analytical methods to assess the performance is prohibited by this standard due to lack of fundamental research information on the nonlinear inelastic response of the structures [4, 5]. However, different finite element analysis approaches have been followed by various authors to simulate the ROPS testing [6–8]. Though it is difficult to get the closer correlation, these methods have been used prior to destructive testing in order to minimize the number of prototypes.

In this work, an effort has been made to simulate the ROPS testing using a non-linear finite element analysis with ANSYS software. The ROPS cabin for a front end loader was fabricated and tested experimentally according to the standard. The FEA results have been compared with that of experimental testing and the FEA methodology has been improved to get a good correlation. In future this FEA approach will be used to finalize the ROPS design prior to full scale testing. It helps to minimize the number of prototype testing and thereby reduces the development cost and time.

2 ROPS Testing Procedure According to ISO 3471

2.1 Definitions

2.1.1 ROPS

System of structural members whose primary purpose is to reduce the possibility of a seat-belted operator being crushed should the machine rollover. It includes any sub-frame, bracket, mounting socket, bolt, pin, suspension or flexible shock absorber used to secure the system to the machine frame, but exclude mounting provisions that are integral with the machine frame.

2.1.2 Machine Frame

Main chassis or main load bearing member(s) of the machine which extend(s) over a major portion of the machine and upon which the ROPS is directly mounted.

2.1.3 DLV

Orthogonal approximation of a large, seated, male operator wearing normal clothing and a hard hat (reference standard ISO 3164:1995).

2.1.4 LAP

Load application point is a point on the ROPS where the test load force is applied. LAP is also the point where the displacements are measured.

2.2 Procedure

All load application points shall be identified and marked on the structure before any loading is applied. The loading sequence is lateral, vertical and then longitudinal (Fig. 1). When loading the ROPS in lateral direction a certain energy level also needs to be reached. The load values and the energy to be absorbed depend on the machine weight. No straightening or repair is permitted during or between the loading phases. A load distribution device is used to prevent localized penetration. It shall not impede rotation of the ROPS. The load distributor is basically a plate and may distribute the force over a length of maximum 80% of the ROPS length. The loading of the cab is a quasi-static which is performed with one or more hydraulic cylinder(s). The rate of deflection at the load application point shall not exceed 5 mm/s. At deflection increments no greater than 15 mm (at the point of application of the resultant load), the values of forces and deflection is recorded. Further, the systems used to measure mass, force and deflection shall be capable of meeting the requirements of another standard, ISO 9248, except that force and deflection measurement capability shall be within ±1 and ±0.5% respectively of maximum values.

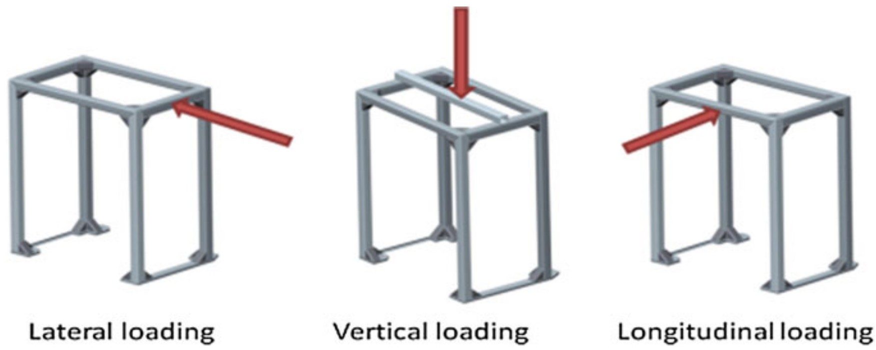

Fig. 1 ROPS testing loading sequence

2.2.1 Lateral Loading

The side (lateral) load shall give the most severe deflections on the ROPS/machine frame assembly. The initial direction of the loading shall be horizontal and perpendicular to a vertical plane through the machine longitudinal centreline. During the loading, deformations may cause the direction of loading to change, which is permissible. The position of the LAP is defined on the basis of the DLV location. The loading shall continue until the force and energy levels have been reached. The energy is calculated as the area under the force-displacement curve obtained at the cylinder(s).

2.2.2 Vertical Loading

After the removal of the lateral load, the vertical load is applied to the top of the ROPS. The centre of the vertical load shall be applied in the same vertical plane, perpendicular to the longitudinal centreline of the ROPS, as the lateral load. The loading is continued until the ROPS has achieved the force requirement. The structure shall support this load for a period of 5 min or until any deformation has ceased, whichever is shorter.

2.2.3 Longitudinal Loading

After the vertical loading, a longitudinal load is applied to the ROPS. This load shall be applied along the longitudinal centreline of the ROPS, at a load point defined by the intersecting planes of the front and top surfaces. A load distributor may distribute the load over a length no greater than 80% of the width. The loading is to continue until the force level specified has been reached.

2.2.4 Acceptance Criteria

The specific lateral force and energy, vertical load and the longitudinal force requirements shall be met or exceeded in the testing of a single representative specimen. No part of the ROPS shall enter the DLV at any time during the lateral, vertical or longitudinal loading phases of the test.

The force and energy requirement need not be attainable simultaneously. One may be exceeded before the other is attained. If the force is attained before the energy, the force is increased further until the energy also is met or exceeded.

3 Experimental Work

The Cab used in Front end loader of 10T class is tested for ROPS. Figure 2 shows a portion of the experimental testing set up (lateral loading). Table 1 shows the force and energy requirements for the different loadings of ROPS.

ROPS cabin along with the DLV was mounted to the floor plate which in turn mounted over the machine frame. M24 bolts of Grade 10.9 were used to connect these structures. A special fixture was developed to test the ROPS. As stated in the procedure, the LAPs were marked on the ROPS. The loads were applied using hydraulic cylinders and displacement due to the load was measured using linear potentiometer. These measuring instruments adhered to the standards as per the procedure.

The loads were applied according to the standard and displacement values along with loads were recorded using DAQ system. In case of lateral load, the force

Fig. 2 ROPS test (lateral load)

Table 1 Force and energy requirements

Description	Formula	Machine specific values
Machine mass (M) in kg	$10000 < M \leq 128600$	11,500
Lateral load force (F) in N	$60000\ (M/10000)^{1.2}$	70,956
Lateral load energy (U) in J	$12500\ (M/10000)^{1.25}$	14,886
Vertical load force (F) in N	$19.61\ M$	225,515
Longitudinal load force (F) in N	$48000\ (M/10000)^{1.2}$	56,765

Table 2 Force and energy met by ROPS cabin

Description	Achieved (requirement)
Lateral load force in N	87,278 (70,956)
Lateral displacement in mm	222.8 (NA)
Lateral load energy in J	14,887 (14,886)
Vertical loading force in N	225,515 (225,515)
Longitudinal loading force in N	56,765 (56,765)

values were attained before the energy values. In order to achieve the energy requirements, the loads were increased further till the energy values were met. Table 2 shows the load applied and energy met during the ROPS testing.

4 Finite Element Analysis

4.1 Initial Analysis

A non-linear finite element analysis using ANSYS software is used to simulate the ROPS testing of the cabin. The actual 3D model of the ROPS cabin along with the floor plate and the chassis mount is considered for the analysis. The 3D model from CREO software is imported to the ANSYS software without any data loss. The structural components i.e. ROPS, floor plate and the chassis mount are connected by 4 numbers of bolts. Figure 3 shows the FE model of the ROPS testing set up (DLV shown for demonstrative purpose only). Table 3 shows the element details of the model.

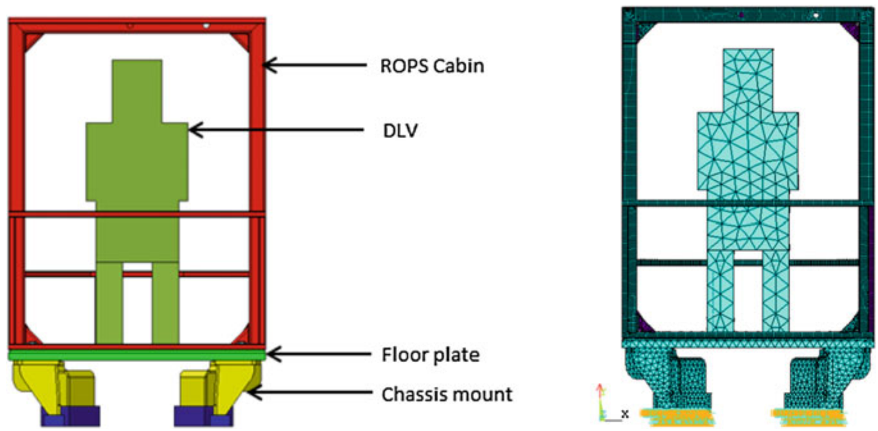

Fig. 3 Finite element model of ROPS set up

Table 3 Element and material details of the initial model

Description	Element type	Material property
ROPS cabin	SOLID 187	Elastic modulus (210 GPa), Poisson ratio (0.3), Density (7800 kg/m^3), Yield strength (310, 250, 350 MPa respectively), Tangent modulus (63000 MPa) with the assumption of bilinear kinematic hardening
Floor plate		
Chassis mount		
Bolt	BEAM 4	Elastic modulus (210 GPa), Poisson ratio (0.3)

Initial analysis was made with assumption of bilinear kinematic hardening for the materials as the test data of true stress-strain curve were not available. The bottom face of the chassis mount was rigidly arrested for all degrees of freedom according to the standard and the loads are applied in 6 load steps as below:

i. Lateral loading
ii. Lateral unloading
iii. Vertical loading
iv. Vertical unloading
v. Longitudinal loading
vi. Longitudinal unloading

It was observed that even for a lateral load of 100 kN, the lateral energy requirement was not met in FEA while it satisfied the vertical and longitudinal loading. Figure 4 shows the load versus deflection curve comparison between the initial FEA and Testing for lateral loading. FEA results are not in correlation with experimental results.

4.2 Improved Method

In the initial analysis, the energy requirement was not reached because of the lesser lateral displacement for the given load. This may be due to the reason that the ROPS was modeled as a solid element which may not be more suitable. Since ROPS is a tubular structure with less thickness, it is decided to model it as the shell element based on better practices suggested by ANSYS. Even after modeling the ROPS as shell element, the results were not in sync with experimental results.

It was decided to get the true stress-strain curve by testing the material. Based on the test data, materials were modeled as Multi-linear kinematic hardening. Even in this approach too, after multiple iterations, it was learnt that the first point of the true stress-strain curve in ANSYS Software should be the elastic modulus point and stress-strain values were entered from that point onwards. The geometry was solved with SHELL 93 element for ROPS structure and Multi-linear kinematic hardening material model.

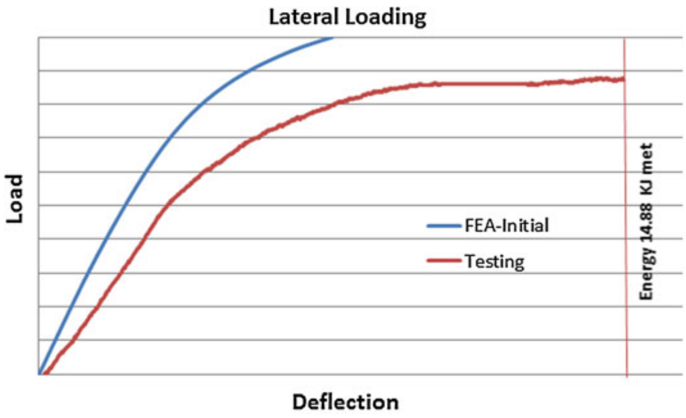

Fig. 4 Comparison of load versus deflection curves for initial analysis

The FEA deformation plots and results of the improved method are shown in Fig. 5 and Table 4. Figure 6 shows the load versus deflection curve comparison between the improved FEA and Testing for lateral loading. The improved FEA

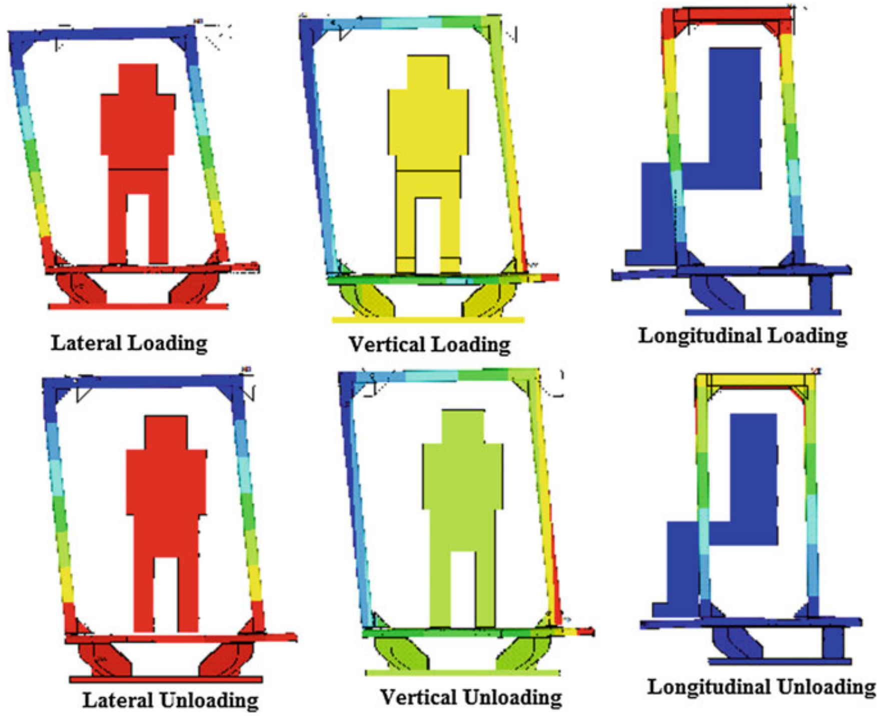

Fig. 5 FEA results—deformation plot

Table 4 Results of improved method

Description	Requirement	Experimental	FEA—improved
Lateral load force (N)	70,956	87,278	90,800
Lateral displacement (mm)	NA	222.8	223.5
Lateral load energy (J)	14,886	14,887	15,124
Vertical load force (N)	225,515	225,515	225,515
Longitudinal load force (N)	56,765	56,765	56,765

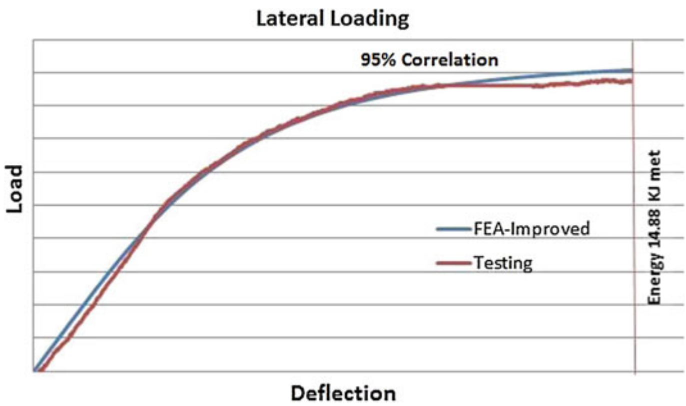

Fig. 6 Comparison of load versus deflection curves for improved method

methodology has 95% correlation with the test results. This improved FEA methodology was further used to validate ROPS structure of various other machines and aided in achieving 'first time right' structure by designing the structure which meets acceptance criteria in testing the first prototype.

5 Conclusion

A non-linear finite element analysis has been used to simulate the ROPS testing of a front end loader cabin which was fabricated and tested. The FEA results have been compared with that of experimental testing and found through multiple iterations that parameters like element type and material model plays a vital role in the accuracy of FEA results. The FEA methodology has been improved to get a good correlation (95%) with experimental results. In future, this improved FEA approach will be used to finalize the optimized design prior to destructive testing which minimizes the number of prototypes, development cost and time.

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Personal 3D Printer: Self-design and Manufacturing

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Abstract Rapid advancements of 3D printing technologies have created new opportunities and challenges. The material extrusion and the stereolithographic 3D printers, which were recently launched in a desktop size, herald a new time whereby common people will be able to own manufacturing means in their home. The prime motivation of this study was driven from the gap that existed between the market that offers desktop 3D printers, along with access to 3D printed products, and the users which still had not widely adopted this new technology. The study was derived from a wider continuous research that examined the personal desktop 3D printing market, and to better understand the existing situation, the study reviewed 5 CAD softwares oriented at product design for non-professional users and 16 websites that offer 3D printed parts and products.

Keyword 3D printing · Mass customization · Personalization · Indie · workflow

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1 Introduction

Scientific discoveries and technological developments are constantly emerging. Tying sporadic discoveries and developments into a new purpose, creates an invention, and few of those inventions can be included under the definition of a transformative change invention. The digital revolution which we are now experiencing, evolved from the transformative change invention of the computer, and was intensified by the invention of the Internet. In the initial phase, when computers were room size machines and not affordable to the common people, they were in use mostly for calculative data analysis e.g. Aiken's Automatic Sequence Controlled Calculator—Harvard Mark 1 (1944). The effort to minimize the size of the computers, had led to the secondary phase which enabled integration of computers to manufacturing means, e.g. the first milling machine that was constructed in the early 50th of the 20th century at MIT. As long as computers were large scale machines and not affordable for the common people, they were owned by central-power sources (factories, companies, institutes, etc.). Anderson (2012) characterizes transformative changes as a phenomenon when industries democratize, i.e. when their sole domain is handed over the common people [1]. Such a change, in the context of the digital revolution, can be attributed to the year 1984, when Steve Jobs presented Macintosh—the first desktop personal computer. The ability to minimize and manufacture relatively inexpensive computer components enabled production of compatible computers for home environment and made them affordable. Moreover, combining few applications (gaming, drawing, entertaining, and type writing) into one product made it beneficial, wanted and required by the common people. This democratic move reflects a natural course of most of the transformative change inventions which initially concentrated in the hands of central-power sources, and after a while certain applications become available for the common people. Since the first PC was marketed many improvements were made in the aspects of the hardware, software, and the complementary means (mouse, keyboard, etc.) that comprise it into a whole product. One of the first accompanying products that was integrated and instructed by the desktop computer was the desktop printer. In an experts' panel that was conducted at Rochester Institute of Technology and was discussing trends in the printing industry, two major changes that happened in the printing industry were mentioned: (1) Desktop publishing; (2) Personalization [2]. Both of these changes were a consequence of the invention of the PC and the desktop printer, and they deeply influenced the design and the manufacturing process, and the workflow in between. They shortened the time and expanded the options from the industry perspective, and as initial step from the common people perspective, text and document printing became accessible. In the same year when Jobs introduced the Macintosh, the first 3D printer (3DP) was introduced by the American engineer Chuck Hull. Unlike the personal computer, that is a branch that grew from the computer tree, the 3D printing technology (3DPT) was a brand new technology (even though it was controlled by a computer). A table that was presented in the colloquium that was discussing the printing industry [2] shows that the distribution of the printers' uses, (holds relevancy for 2004—20 years after the launching of the personal desktop printer) was as such: 76.0% of the printers (not only desktop types) were held by factories and designated shops; 19.0% were held by offices; 3.5% by home users; 1.5% described as "Other". The table was divided to three sub-categories that represent the main purpose of the printers: copier, printer, and press. The press category holds 71.0% of printers in the market, and the copier and the printer categories hold the remaining 29.0%. Out of the remaining 29.0, 13.5% of the usage was made by small size printers, which means that the use in desktop size printers holds 46.5% of all non-press jobs. By normalizing the 3.5% of the usage by home users relative to the 13.5% of the usage by desktop printers shows that the home users hold almost 26.0% of the usage. This distribution analysis cannot predict whether the 3DP market will act the same, but because both the digital printer and the 3DP function as a manufacturing mean, and because the digital printer launched significantly earlier, it's possible to follow the steps that need to be taken in order to successfully integrate similar manufacturing mean in home environment.

2 The Independent User-Designer

Along the history, parallel to the mainstream of the mass production system of many industries, some people were producing alternate solutions and products. In the sustainable products market, the need of some non-professional people to design/manufacture/assemble/customize their products, addressed by themselves by using their personal tools. In modern times, the punk (mostly in fashion) and the DIY movements were and are reflecting those needs. A recognition by industries that this need is there, and it can provide a competitive advantage, along with technological developments and integration of computers has led to the Mass Customization approach. The term Mass-Customization (MC) was coined in 1987 by Davis [3] and practical methods and paradigms were developed since then by followed scholars [4–14], mostly by relying on the industrial mass production system. The Internet that has intensifying the digital revolution opened a new route to market, distribute and sell services and products to customers, and increased the level of democratization in several industries. The recorded music industry can represent an example of how the desktop computer and the Internet enabled to democratize it. The Independent (Indie) movement is an outcome and a response to those inventions, and today a musician can produce a composition by himself and distribute it through designated websites, or in social networks. With the right basic complementary means such as microphone, speakers, earphones etc., together with a desktop computer and the Internet, a musician can communicate directly with the virtual audience without any intermediaries. If an Indie musician is gaining genuine popularity, and he/she wants to commercialize and produce albums and more, a step up from the cyber to the real world is required, and the same old intermediaries are taking their actions (agents, record labels, etc.). While the computer and the Internet increased the level of democracy also in the fields of graphic design and textual creations, the desktop digital printer added a dimension that empowered the Indie branch in those fields. It is almost obvious today that people can create a graphic or a textual creation and print it in their homes if needed. Despite that, if a person wants to print a high quality printout, or to print something which is off the sheet size standard for desktop printers, a commercial or an industrial source is required to complete the manufacturing phase. The material extrusion and stereolithographic 3DPs which recently were launched in a desktop size, herald the beginning of the Indie time in product design, as a part of what experts tend to define under the title of the "Next Industrial Revolution". Potentially, anyone can design and manufacture sustainable products, but as studied from the recorded music and the graphic design industries, not all of us became musicians or graphic designers. Even though, there are things that can be studied from those industries in order to maximize this potential.

2.1 The Design Process

Nowadays, there are varied ready to use softwares for non-professional users, such as typography, illustration, packaging, architecture, graphics, editing, animation, and so on. CAD software for product design can be classified to two main categories: Professional and non-professional CAD software. Most of the non-professional softwares are share-ware (free of charge) and can be found widely on the Internet. The fields of graphic design and word processing offer enormous amount of free softwares for different purposes, e.g. free writing, documenting, presentation, free graphic design, data analysis, questionnaires, etc. Each software provides the relevant tools, and **enables to accomplish the design and the manufacturing workflow in a unified stream**. A simplification of the product design process as presented by Pahl et al. [15] is representing the steps that need to be made in order to get from the ideation phase to the actual design phase (Fig. 1). Despite the fact that this process is conceptually similar for professional and non-professional designers, there are lots of differences in the way it is being implemented. While in the first 2 links (the definition of the task and the specifications) the professional designer is relying on knowledge and experience, the non-professional designer is crossing those stages intuitively without awareness to any design methodologies.

Fig. 1 A simplification of the product design process

The process that leads to the formulation of the concept and the preliminary design, is usually where the CAD software is required for the first time. In the popular text processing and graphic design softwares, the developers succeeded to generate fluent workflow by enabling the following parameters: creation tools, editing tools of a new creation, or of a readymade creation, failure prevention and evaluation features, technical support and tutorials, generation of a suitable file for digital printer and direct connection to the printer. Those parameters were conceptually converted to 3D CAD softwares, and 5 product design oriented free softwares for non-professional users were compared **(3D Builder—Microsoft, Tinkercad and 123D Design along with Meshmixer—Autodesk, 3D SLASH, FreeCAD)** according the converted parameters. A comparison table (Table 1) compares between the mentioned softwares according to the parameters that were converted as follow:

1. **Creation tools**: This parameter was split into two sub parameters: basic bosses and complicated bosses. The comparison examined whether each software provides basic tools only (primitive shapes and extruded bosses) and/or provides complicated tools (revolved, swept, lofted bosses and Boolean actions). This parameter is the initial step, and thus not influencing the workflow, but can give an impression of how the developers perceive the users.
2. **Editing tools**: This parameter was examined under two sub parameters as presented above: editing a new and/or readymade design. Both of the sub parameters classified under two sub categories: basics and advanced features. The basics features include scale, move and rotate options, and the advanced features include features like mirror, patterns, fillet, chamfer, shell, split and the basics.
3. **Failure prevention and evaluation features**: In order to get a qualitatively definite design, the professional designer/engineer is doing 3 important actions: 1. Applying fit tolerances between holes and shafts in a case of an assembled product; 2. Adjusting the design to the manufacturing technology; 3. Evaluating the design in order to prevent engineering failures by using finite elements analysis add-ons or designated softwares, and by producing and testing prototypes. Since applying fit tolerances in a design requires professional knowledge, it was not taken into consideration while examining and comparing the softwares. The adjustment of the design action was not taken in consideration as well because it requires professional understanding and there is only one manufacturing technology involved in this case (3DP). The third action was the only one to be compared, and the parameter of the prevention of engineering failures relates to it.
4. **Technical support and Tutorials**: This parameter was examining whether there is an integrated feature that provides technical support and tutorials.
5. **Generate suitable file for 3DP**: This parameter was examining the possibility to generate a standard suitable file (.stl) for 3DP.
6. **Connection to the 3DP**: Like the Ctrl + P keyboard shortcut, this parameter was examining the directness of the shift from the CAD software to the 3DP.

Table 1 Comparison between 5 free 3D CAD softwares

	Basic bosses	Complicated bosses	Editing features	Modify readymade design	Preventing engineering failure feature	Tutorials	Generate suitable file for 3DP	Connection to 3DP
3D builder	+	–	Basics	+	–	–	+	Indirect
Tinkercad	+	+	Basics	+	–	+	+	Indirect
123D Design	+	+	Advanced	+	+ (Meshmixer)	+	+	Indirect
3D SLASH	+	–	Basics	+	–	+	+	Indirect
FreeCAD	+	+	Advanced	+	–	+	+	Indirect

The comparative analysis that was done shows that there is a lack of uniformity in the approach toward the users. While all the softwares provide basic tools for designing and editing a virtual model, part of the lack of uniformity is reflected in the possibility to generate complicated shapes and by editing the virtual model by using advanced tools. Even though this lack of uniformity can be explained by directing the softwares for different levels of users. Unlike word processing softwares, there are differences in the most basics actions that are being operated by using the mouse, like moving, zooming and rotating the virtual model. The option to import a readymade design is available in all the softwares, but modifying it is possible only according to the software's tools. Beside 3D Builder all the softwares have a built in support feature including tutorials, but a highly critical feature that prevents engineering failures is missing in all the softwares. A testing virtual model of a $50 \times 50 \times 50$ mm shelled cube with 0.01 mm wall thickness was built, and all softwares did not alert that there might be a failure in the design. 123D Design directs to an external software (Meshmixer) which enables to analyze the design, but it is not done automatically. It should be noted that Meshmixer enables to design virtual models but it more of a free design oriented software like for jewelry design, sculpted elements, etc. and less for product design. Therefore, it was not compared with the other softwares. The analyze tool was examined and it can be considered as a very basic and semi reliable comparison to a professional finite analysis software. As can be seen, all the softwares enable to produce a suitable file for 3DP. Despite that, the connection to the 3DP is indirect, and it creates a break in the design to manufacturing workflow. The main reason for the indirectness of the connection to the 3DP is the way in how desktop material extrusion and stereolithographic 3DPs are being operated. The vast majority of the desktop 3DPs are designed as an independent machine i.e. each machine has a suitable software (there are few generic ones) that converts the meshed geometry file to a G-code that instruct the 3DP how to operate. All the settings before the manufacturing process is being made through the controller of the 3DP. In the vast majority of the desktop 3DPs a flash memory portable device is required in order to upload the G-code file that was copied from the PC, to the 3DP. Another reason is because the raw material in the vast majority of the desktop material extrusion 3DPs is hanged freely aside (usually behind) the 3DP and the 3DP is not detecting it automatically, similarly like a desktop digital printer detects the ink cartridge and the paper. Based on the design to manufacturing fluent process of the desktop digital printers and the preproduction softwares that feed them, the indirectness of the connection to the 3DP can be pointed as the disruption point in the workflow. The comparison that was made was testing the ability to design a single part. Since many products are assembled from more than one part, an assembly module could significantly contribute to understanding the design of an assembled product. Such a module is not a disruptive factor in the design to manufacturing workflow, and thus it was not examined as an influencing one (FreeCAD offers such a module).

3 The Readymade Products Market

In the initial phase 3DPT were considered as rapid prototyping technologies (RPT), because the quality of the parts was insufficient for other uses except as prototypes in favor to test designed outputs in the product/machine design process. Moreover, mostly models workshops, academic institutes and factories had economic justification to own such machines. Improvements in the quality and the properties of the manufactured parts enabled to integrate 3D printed parts in assembled components e.g. Boeing company that integrated housing for a compressor inlet temperature sensor that was manufactured by powder solidification 3DPT, in its engines. Along with the improvements in the quality of the parts, the reduction of the price of 3DP and the raw materials, and the reduction of the size of the 3DP had led to the development of the 3D printed products market. Therefore, 3DPT are considered not only as RPT, but also as an additive manufacturing technology (AMT) and as an independent manufacturing technology. The market of the 3D printed products offers to the common people very few designated shops and mostly cyber space shops (e.g. http://n-e-r-v-o-u-s.com/). The main reasons that 3D printed products are offered to the common people are because of the ability to customize and personalize those products and because of the exoticness of the technology.

3.1 The Cyber Space Market

A review of 16 websites [21–38] which offer 3D printed products reveal that there are two types of business models: 1. Traditional model; 2. Democratic model. The traditional model represents perception in which the responsibility to manufacture the product is in the hands of the seller, and therefore its being sell through the Internet like any other sustainable product. The democratic model takes in consideration personal 3DP and offers 3DP files so the customer can download a file and manufacture the product in his home environment. Both of the models stance two different approaches relating to the products: 1. The standard approach; 2. The customization and the user involvement approach. The standard approach offers readymade non customizable designs and the customization approach offers open architecture designs that can be modified and customized in different levels by the customer, according to his needs. The taxonomy matrix (Fig. 2) describes the subtypes of the mentioned business models in the 3DP cyber space market, according to the types of condition of the architecture of the products.

Customized Democratic Model. A unique example for that model can be seen in **Thingiverse**. As this website offers readymade designs available to download for personal 3DP it also offers with some designs the option to customize them under pre decided conditions.

Standard Democratic Model. This model is the most popular one. Examples for that model can be seen in the following websites: **pinshape, YouMagine, My**

		3D Printer	
		Personal	Industrial
Design Architecture	Open	*Customized Democratic Model*	*Customized Traditional Model*
	Close	*Standard Democratic Model*	*Standard Traditional Model*

Fig. 2 A taxonomy matrix of business models in the 3D printed products cyber market place

Mini Factory, Cults, REPABLES, cg-trader, 3DShook, and MakerBot Digital Store. Free of charge or not, those websites provide a bank of readymade designs and enable to download a suitable file for 3DP.

Customized Traditional Model. This model which follows MC approaches for mass production system, exploit the advantages of the 3DP together with the PC and the Internet, and enable to produce customized and tailor made products. Examples for that model can be seen in the following websites: **Nervous System, Sculpteo and Digital Forming**. The manufacturing process is exclusive to the firm, and there is no option to download a suitable file for personal 3DP.

Standard Traditional Model. Websites like **e-bay, Amazon and Etsy,** that offer all kind of good, and **Kraftwurx** that offers 3D printed products follow the standard model in which the customer selects a non-customizable readymade design and the manufacturing process is exclusively in the hand of the seller. This model is considering the 3DP more as AMT and thus, the existence of a personal 3DP is irrelevant.

3.2 Types of Users

MC methods define types of users based on the fact that the manufacturing means are in the hands of the powered-central source. The democratic model represents a new MC approach in which the manufacturing mean is in the hand of the user, and there is no necessity to flex industrial design and manufacturing processes. Even if the user does not own a personal 3DP, the type of the products is such that the option to manufacture them by using personal 3DP is there. A taxonomy matrix (Fig. 3) defines types of users according to the new MC approach along with the factor of the user involvement in the design.

Producer. This type of user formed out from the option to customize a readymade design by him, and by the fact that he/she owns a personal 3DP. The customized democratic model is constructed for this type of users, and it represents full responsibility of the user for the design and the manufacturing process.

Fig. 3 A taxonomy matrix of types of users in a democratic model

		Personal 3D Printer	
		Own	Doesn't own
Involvement in the product design	Involved	Producer	Customizer
	Un-involved	Manufacturer	User

Manufacturer. The standard democratic model perceives the user as a manufacturer. This is a fluid status, because the user can decide whether to manufacture the offered readymade design, or to modify it by using CAD software and thus to become voluntarily a producer.

Customizer. This type of user perceived as a producer but consciously or without conscious puts himself in a position of a customer in a traditional market.

User. This type of user perceived as a potential manufacturer, but like the customizer, he/she puts him/herself in a position of a customer in a traditional market.

4 Summary and Conclusions

There is a clear gap between the market which already provides 3D printed products and the potential customers. A major conclusion that emerges from the reviewed cases is that the workflow in the cases which relate to personal 3DP is not fluent. Once the user wishes to manufacture the selected design he/she has to treat the 3DP as an independent machine, unlike the fluent workflow of the digital printers. Theoretically, once many people will own personal 3DP, there will be an option to develop types of semi democratic products. This branch which relates to 3D printed products mixed with non-printable components e.g. batteries, motors, etc., or to non-printable products which can integrate customized personal 3D printed parts, e.g. a customer can buy a car (which is not printable) and customize the buttons, handles, etc. The new-born 3DP market is now making its first steps. In order to redefine the term mass production as not only by the ability of a source to produce high volume of parts in short time, but also as the number of parts that people manufactured in their home environment, several actions need to be taken. There are references that analyzed the abilities and the limitation of the 3DPT [16–20] and the referred issues along with the improvement in the workflow aspect should take the market to its next level.

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An Initial Study of Function Switching for Design of Adaptable-Function Mechanical Products

C.-W. Zou, Y.-M. Deng and H.-B. He

Abstract An adaptable-function mechanical product belongs to a specific category of products that are feasible in delivering multiple functions by replacing/changing some of its components. The functions are referred to as being adaptable because they suit to different applications. To design such a product, it is necessary to study the process of function switching, during which there shall be detaching and/or disassembling of some existing components, as well as attaching and/or assembling some new components. Existing work on modular design and structure-sharing design provides certain research basis but has not directly addressed such a function switching process. In this paper, we make an initial attempt to study the mechanism and characteristics of the process. The mapping relation between the prior function and the prior structure, as well as the mapping relation between the posterior function and the posterior structure are investigated and represented. Specifically, in order to get a proper disassembly-assembly sequence in the process of function switching, we propose a sequence optimization method consisting of both disassemble (of existing non-sharing parts) and assemble (of new non-sharing parts). To simplify the conventional interference matrix used for the disassembly-assembly sequence planning, an aggregated interference matrix, which was used to express the interference of parts in the individual direction, was proposed. The disassembly-assembly sequence was optimized by using MATLAB. A case study was also presented to demonstrate the applicability of the proposed methodology.

Keywords Adaptable-function mechanical product · Function switching · Disassembly-assembly sequence

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1 Introduction

The *adaptable-function products* can deliver multiple functions, also referred to as *adaptable functions*, by replacing/changing some of their components [1]. Compared with the traditional products with fixed functions, the adaptable-function products not only can save resources by sharing some of their components among different functions, but also have the advantages of expandability and upgradability. Besides sharing of structural components, one of the other most prominent characteristics of this kind of product is that, there is a so-called *function switching* process during the application of the product. This is a process for the product to switch from one function to another, during which it will inevitably involve replacing/changing some of its non-shared components, including detaching and/or disassembling of some existing components, as well as attaching and/or assembling some new components. During this process, the disassembly-assembly sequences of components will not only incur a time cost, but also affect the performance of the product, even affect its working life. As a result, it is of great importance to do research on the disassembly-assembly sequences in the process of function switching for the adaptable-function mechanical products.

There are some existing researches that have investigated structure sharing, for example, Chakrabarti [2] introduced the concept of *structure sharing* and proposed a computational approach for supporting designing of structure-shared products. Chakrabarti and Singh [3] proposed methodologies for assessing as well as enhancing structure sharing of such products; Koren et al. [4] introduced the concept of *open architecture* for product development and advocated designing open-architecture products to support structure sharing. As can be seen, even though adaptable-function products also advocate structure sharing, none of existing works has specifically studied the function-switching process, let alone the disassembly-assembly sequences during this process.

As mentioned, function switching often contains two processes: assembly and disassembly. As for assembly planning (AP), there are in general three main problems involved, including assembly sequence planning (ASP), assembly line balancing (ALB) and assembly path planning (APP) [5]. Since the other two are not so prominent for the adaptable-function products, this paper will focus on ASP. Due to the fact that the term *part*, rather than *component*, is used predominantly in the area of ASP, we will use both of them thereafter without distinction. Jiménez [6] presented a rather comprehensive overview on ASP in a literature survey, including the elements of sequence planning. Somayé et al. [7] modeled the deformability of flexible assembly parts by introducing a matrix, i.e. the assembly stress matrix (ASM), specialized for assembling the flexible parts. Zeng et al. [8] presented a multi-agent evolutionary algorithm for connector-based ASP integrated with the multi-agent systems. Generally, disassembly and assembly can be seen as two reversed processes [9], and since the geometry information of an assembly is generally complete and easily accessible, hence the disassembly sequence planning (DASP) is more widely used instead of ASP. Prior studies mainly apply heuristics algorithm [10] and meta-heuristics algorithm to seek near optimum or optimum solutions and attain disassembly sequences. Meta-heuristics algorithm includes genetic algorithm [11–13], ant colony optimization [14] and particle swarm optimization [15, 16]. In the following, we will investigate the ASP and DASP for adaptable-function products, after a brief analysis of the function switching characteristics of such products.

2 Function Switching Characteristics of Adaptable-Function Mechanical Products

Similar to multi-function mechanical products, the adaptable-function mechanical products can realize two or more functions. Their difference comes from the distinction between their respective function switching processes. The adaptable-function products need to replace some of the system components with others, while the general multiple-function products do not. For example, a kitchen utensil that is able to be used as a cutter at one end and as a scooper at the other end is a general multiple-function product, because it does not require changing product structure when delivering the two functions. The juicing machine shown in Ref. [1], on the other hand, is an adaptable-function product, because, even though it can also deliver multiple functions such as juicing, stirring, grinding, mincing meat, etc., these functions can be delivered only one at a time, and there should be changing of certain components before a specific function is usable.

Beyond above characteristic, there are some additional characteristics of an adaptable-function product involved in function switching. For example, an adaptable-function product can be regarded as consisting of a group of sub-ordinate products, each of which delivers a specific function, i.e. an adaptable function. These sub-ordinate products share some of the system components. We may also regard these sub-ordinate products as distinctive physical states of the original adaptable-function product. Different from the physical states of a general product, whose physical structure remains unchanged among these states, the different physical states of an adaptable-function product correspond to different sets of physical components.

To study the function switching process of the adaptable-function products, this paper will establish a model of disassembly-assembly process, where the perspective of a product with multiple physical states will be employed.

2.1 Model of Function Switching

As stated above, each state of an adaptable-function mechanical product corresponds to a specific adaptable function, hence function switching means state

Table 1 Relationships between functions and parts

	P_0	P_1	P_2	P_3	P_4	P_5
F_1	1	1	1	1		
F_2	1	1	1	1	1	
F_3	1	1	1			
F_4	1		1	1	1	
F_5	1				1	1

changing, which also implies changing of relevant components. Suppose there is an adaptable-function mechanical product with five functions: F_1, F_2, F_3, F_4, F_5, six parts: P_1, P_2, P_3, P_4, P_5, P_6, one sub-assemble P_0, shown in Table 1, in which the number '1' means the part is necessary for the delivery of the corresponding function and all other parts are unnecessary in this regard.

As can be seen, the sub-assembly P_0 is necessary for all the five functions, so this kind of parts (here a sub-assembly) belong to the "sharing components", and the rest of the system are "non-sharing components". In this way, switching from one function to another means to redesign and reconstruct the non-sharing components, and there are four cases in all, as listed below:

Case 1: attaching and/or assembling some new components. For example, from function F_1 to F_2, we need to attach a new component P_4 at the certain position;

Case 2: detaching and/or disassembling of some existing non-sharing components. For example, from function F_1 to F_3, we need to detach the existing component P_3 to achieve function switching;

Case 3: detaching of some existing non-sharing components and attaching some new components. For example, from function F_1 to F_4, we need to detach the existing component P_1 to and attach a new component P_4 at the certain position;

Case 4: detaching of all the existing non-sharing components and attaching some new components. For example, from function F_1 to F_5, we need to detach all the existing component P_1, P_2, P_3 and attach new components P_4, P_5, P_6 at the certain position.

2.2 Aggregated Interference Matrix

The adaptable-function products consist of sharing components and non-sharing components, and this section will focus on analyzing the interference of the latter. Considering the normal interference matrix based on global coordinate system, we can see that it is difficult to deal with the parts in the directions not parallel to the standard orthogonal coordinate axes. To address this problem, we propose a global interference matrix, including six directions ±x, ±y, ±z, based on assemblies' coordinate system and local interference matrix, including six directions Λx, Λy, Λz, based on parts' coordinate system, which make the parts be more feasible and flexible when choosing the directions of disassembly or assembly. In this paper, global interference matrix and local interference matrix are aggregated into one matrix, called *aggregated interference matrix* (AIM). In this way, the generated matrices will be greatly simplified. We define AIM as M = [M_{ij}], among which

$$M_{ij} = \begin{cases} 0 & \text{interference does not exit between part i and part j} \\ 0.1 & \text{friction interference exits between part i and part j} \\ 1 & \text{collision interference exits between part i and part j} \end{cases}$$

Similarly, interference relations between the parts can be categorized into three conditions: no interference, friction interference and Collision interference. Friction interference means parts may be disassembled or assembled along one direction, and this is feasible but there will be friction between parts, so friction interference should be avoided if possible. That the value of friction interference is set as 0.1 (collision interference is 1). To emphasize the collision interference, which should be forbidden, there is a fundamental difference between them. According to the AIM, we can calculate the value of each sequence, then screen sequences based on the value of F, which can be calculated by Eq. (1).

$$F = n - \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} M_{ij} \tag{1}$$

In Eq. (1), the parameter n indicates the number of parts. In this way, the sequence with the maximum value of F will be the optimal solution. Each functional state of the adaptable-function product has a corresponding AIM, for example, the exemplar machinery mentioned in the last section has F1, F2, F3, F4, F5 five functions, then the corresponding AIMs will be M1, M2, M3, M4, M5, respectively. These AIMs can be added into the interference matrix library for future use.

2.3 Interference Detection Based on Bounding Volume Boxes-Projection

Traditional bounding box algorithm mainly select the smallest rectangle that can hold the target part thoroughly in the global coordinate system, and each of its surface is either parallel or vertical to the coordinate plane of the global coordinate system. Since the geometric characteristics vary from parts to parts, select the same coordinate system as the benchmark will result in many 'virtual spaces', and if creating a coordinate system individually for each part and selecting the minimum rectangle within its own coordinate system, this will reduce the 'virtual spaces' and improve the accuracy of interference checking effectively. Based on this, this paper propose an algorithm as follows: set up a corresponding local coordinate system

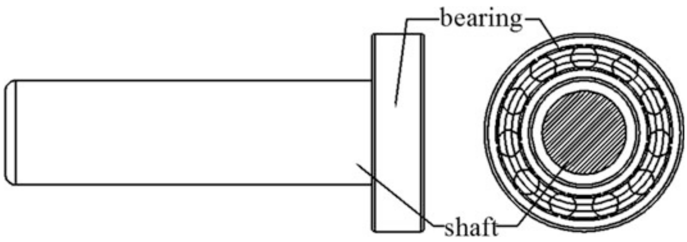

Fig. 1 Projection of shaft and bearing

according to the part itself, then generate the minimum bounding box and a sweep volume along the disassembly or assembly direction which is one of ±X, ±Y, ±Z in the local coordinate system. Let the virtual rectangle sweep along the direction. Simultaneously, check whether it will interfere with other parts. Firstly, parts which are in the other directions and which do not have intersection with the minimum virtual rectangle can be excluded, and the other parts will be checked precisely next. Through this method of roughly check, the complexity of the interference check can be reduced effectively. In addition, there are two instructions for the procedure of interference check:

(1) As the bounding box may contain extra space, the scenario that the bounding boxes interfere but the parts themselves do not interfere in the disassembly (or assembly) direction may take place. So, in this case, we can project the parts to one of the coordinate planes of the local coordinate system, which is vertical to the disassembly (assembly) direction, and observe whether the projection have any intersection. If the answer is yes, the two parts will interfere; otherwise no interfere exists. As shown in Fig. 1, the bounding boxes of shaft and deep-groove ball bearing have intersection, but their projections do not. As a result, it does not belong to collision interference but rather friction interference.
(2) Traditional disassembly directions are along one of the six directions in the coordinate system, and they will not be changed during the disassembly procedure. By employing the definition for turning interference matrix [17], we select the disassembly directions according to their own coordinate directions based on the geometrical characteristics, thus they can be multidirectional, i.e. the directions can be changed if needed. In this way, unnecessary interference can be avoided effectively.

3 Disassembly-Assembly Sequence Planning

As mentioned before, it is necessary to study the disassembly-assembly sequencing problem for the adaptable-function products. To this end, we propose the following Genetic Algorithm (GA):

(1) For any two functions to be switched, choose their corresponding AIMs from the interference matrix library;
(2) Set the crossover rate, the mutation rate, the initial population and the number of generations, then generate initial sequences randomly;
(3) Calculate the fitness of each group of sequences according to the interference of matrices, then select the sequences whose values of F are larger.
(4) If the results converged or the generation number reached the specified value, the algorithm terminates; otherwise, go to Step 5;
(5) Apply the operations of crossover and mutation randomly for the selected sequences;
(6) Adjust the resultant generations to be feasible solutions according to AIMs, and calculate the fitness of the adjusted sequences, got back to Step 3.

4 Case Study and Discussion on Practical Applications

4.1 The Sequence Planning Problem

In this section, a micro tillage machine is taken as a case study to attain an optimized disassembly and assembly sequence when switching from one function to another. The machine can be regarded as an adaptable-function machine. Equipped with accessories, it can achieve multiple functions such as transportation, rotary tillage, sowing and spraying. Different from the general multi-function machines, it needs to disassemble some parts and assemble some new parts while switching from one function to another.

4.2 Generate the Optimized Sequence

Firstly, we define a part set, D_i, which contains the parts to be disassembled, and another component set, A_j, which contains the parts to be assembled. So D_i and A_j can be described as: $D_i = \{1, 2, 3,\ldots, n\}$; $A_j = \{n + 1, n + 2,\ldots, n + m\}$. The whole process of switching is described by W, $W_{ij} = \{D, A\}$ for switching from function F_i to function F_j.

Next, we need to acquire the interference relationships between the parts based on bounding volume boxes-projection interference detection proposed in Sect. 2. Represent the relationships with quantitative value and mark the values in the AIMs. Then, according to the aforementioned Genetic Algorithm, we can obtain the

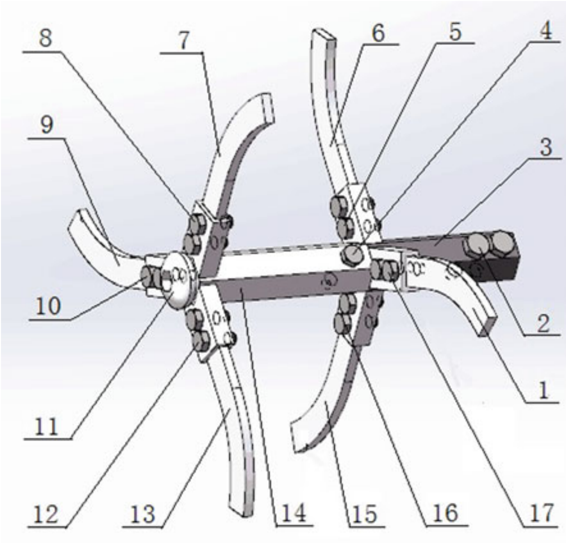

Fig. 2 Rotary blade

optimized sequences with the help of MATLAB. Take the rotary tillage function and the transportation function as the function switching example. There are 17 non-sharing parts related to rotary tillage function, as shown in Fig. 2, whose AIM is shown in Table 2, and there are 6 non-sharing parts related to transportation function, as shown in Fig. 3, whose AIM is shown in Table 3.

By applying the proposed genetic algorithm, the disassembly-assembly sequence planning about rotary tillage function and transportation function can be carried out. The specified population size is 20, the crossover rate is 0.95, the mutation rate is 0.01 and the number of generations is 25. The convergence conditions are defined by the average value of sequences, which is close to or equal to the maximum value. The result of optimize convergence curve is shown in Fig. 4. From the figure we have the following results: the disassemble sequence has the convergence value of 14.7 at the 19 generations and the assemble sequence has the convergence value of 5.8 at the 5 generations. One of the optimized disassemble sequence of rotary tillage function is “11-8-7-12-13-10-9-4-14-17-1-5-6-16-15-2-3” and one of the optimized disassemble sequence of transportation function is “22-23-20-19-18-21”. So the optimized disassemble-assemble sequence “11-8-7-12-13-10-9-4-14-17-1-5-6-16-15-2-3-22-23-20-19-18-21”.

Table 2 AIM of rotary tillage function

0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.1	1	0	1	1	0.1	0	0	0	0	0	0	0	0.1	0.1	1	1
0	0	0.1	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0
0	0	0.1	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0
0	0	0.1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	0	0	0	0	0.1	0	0	0
0	0	0	0	0	0	0.1	0	0	0	0	0	0	0.1	0	0	0
0	0	0	0	0	0	0	0	0	1	0	0	0	0.1	0	0	0
0	0	0	0	0	0	0	0	0.1	0	0	0	0	0.1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1	0	0.1	0	0	0
0	0	0.1	1	0	0	0.1	1	0.1	1	0.1	1	0.1	0	0	0	0
0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0
0.1	0	0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

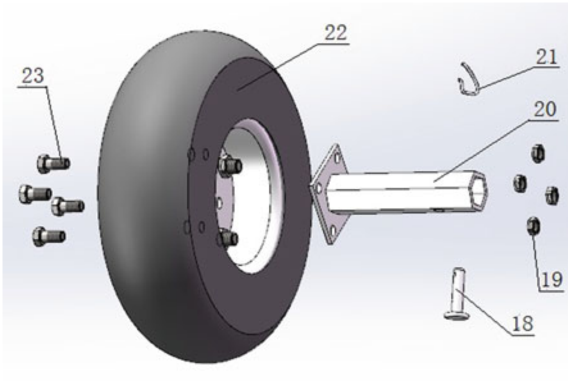

Fig. 3 Exploded view of wheel

Table 3 AIM of transportation function

0	0	0	1	0	0
0	0	0	0	0	0.1
1	1	0	1	0	0
0	0	0.1	0	0	0
0	0	0	1	0	1
0	0.1	0	0	0	0

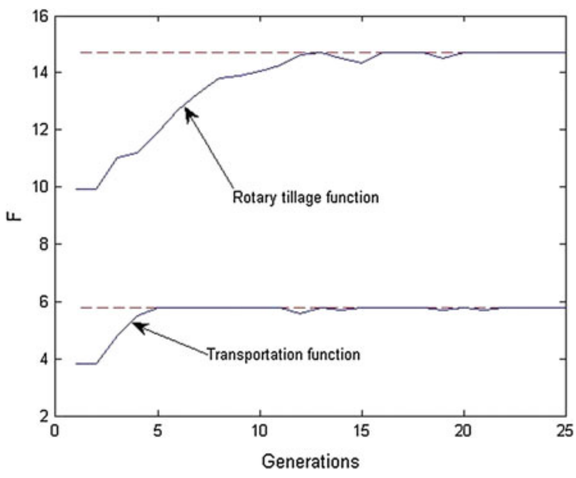

Fig. 4 Convergence curve

5 Conclusion and Future Work

The above sections studied the characteristics of function switching process of the adaptable-function mechanical products, as well as the disassembly-assembly sequence. A Genetic Algorithm is proposed and implemented to attain its optimization. This method gets the interference matrices in all directions, which can effectively simplify the process of disassembly-assembly sequence planning.

The case study demonstrates that the proposed method can effectively deal with the disassembly and assembly sequence of parts in the process of function switching. Further research is necessary when more complex products are involved, causing interference matrix be more difficult to generate. Besides, how to generate the interference matrices quickly is also one of our future research works.

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Development of an Adjustable Gang Drilling Attachment for Radial Drilling Machine

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Abstract The objective was to develop an adjustable gang drilling attachment for radial drilling machine using retrofit approach. General purpose machines are not designed for mass production and to increase productivity is by the use of Special Purpose Machines (SPM's). SPMs such as 'Gang Drilling Machines' are generally which are usually employed in order to drill multiple holes simultaneously are too expensive for small scale industries. Hence there was a need to develop an attachment that provides multiple drilling capabilities at variable diameter and low cost. This attachment can increase the productivity and performance of existing radial drilling machine. The first step was a detailed kinematic study of radial drilling machine. Several designs of drilling attachments were developed and analyzed for kinematic properties, manufacturing viability and cost. The 'Telescopic link type' attachment was selected. This was followed by a detailed design of each component of the attachment and its manufacturing.

Keywords Radial drill · Retrofit · Adjustable gang drilling attachment

1 Introduction

Most jobbing operations with radial drilling machine involve the drilling multiple holes of different diameters. If this is done simultaneously it will reduce the manufacturing time and cost significantly. Automated special purpose machines are capable of drilling multiple simultaneously but are very expensive. Such high capital investments are not economical for small scale industries that typically take several different work orders.

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Hence it is essential to find a cost effective solution for drilling multiple holes at varied distance simultaneously specifically for small scale industries. Drilling multiple holes at varied distance simultaneously is not possible in existing radial drilling machines. It is necessary to fit an attachment on the existing radial drill machine to facilitate multiple drilling features. Also, the same attachment must facilitate drilling operations at different distances/diameter in order to make the process faster and cost effective.

The attachment that we have developed allows simultaneous drilling of holes at different diameters. This significantly improves the flexibility and the productivity of the existing radial drilling machine. The design was finalized after extensive modeling and simulation of the different attachments. Simulation and kinematic analysis was undertaken in order to obtain a motion synthesis and the results obtained have confirmed the efficacy of the attachment.

2 Literature Review

Various measures of productivity are Machine Productivity, Labor Productivity, Capital Productivity and Energy Productivity. In this paper, Machining Productivity is considered and units of output per machine hour, dollar value of output per machine hour are considered as the main criteria [1]. It is observed that there are some Multi-spindle drilling attachments but most of them are having fixed PCD. Those having varying PCD are complex in construction and do not provide manufacturing flexibility.

Drilling multiple holes simultaneously can be achieved using the multi-spindle drilling machine otherwise or alternatively by developing a separate drilling attachment for the existing radial drilling machine. As Multi-spindle drilling machine is too costly and it requires separate floor space, Multi-spindle Drilling Attachment is preferable. Also initial as well as operating cost is very low for Multi-spindle Drilling attachment. When Multi-spindle Drilling Attachment detached from main machine tool the drilling machine can be used as GPM. In mass production work drill jigs are used for guiding the drills in the work piece so as to achieve accurate results [2].

Though the literature mentions various machines, a scope remains to make them user friendly and reliable particularly for small scale industry. Apart from this industry faces an acute shortage of skilled labor. Hence it is difficult to increase the workforce for increasing manufacturing output and reducing manufacturing time as well, also to achieve good quality of product. This created the need for developing a cost effective and reliable attachment that could be retrofitted to an existing drilling machine. The design methodology, design built-up and synthesis for the proposed attachment is based on the concepts [3] produced by researches.

3 Design Methodology

3.1 Problem Identification

Currently in most the small scale industries, drilling of number of holes on single job are carried out one by one with radial drilling machine. They require fast production rate so solution to this problem is Multiple-spindle drilling machines. The above mentioned machines are very costly. The Special purpose machines for drilling multiple holes have the limitation of fixed Pitch circle diameter (PCD), but the Industry requires drilling multiple holes at varied PCD.

3.2 Possible Solutions

After much iteration, following possible solutions are obtained according to need. Figure 1 shows the first idea in which the drilling multiple holes simultaneously is carried out, however limitation of this design was the pitch circle diameter (PCD) is fixed. In this design if the PCD changes it was necessary to change the whole attachment. This attachment is useful when there is no requirement of change in PCD.

To convert this single spindle drilling machine to multi-spindle drilling machine, power sharing using a typical transmission system is required. The transmission can be obtained using one of the following methods.

Fig. 1 Attachment with fixed PCD

a. Gears Transmission.
b. Belt Transmission.
c. Transmission via telescopic drive (novel system developed for compact attachment).

In the power transmission using gear mechanism, a very little scope is available to change the PCD of the holes. PCD variation for a gear driven multi-spindle head is difficult in most of the cases. One can achieve variable PCD by changing the gears however the system becomes complicated. Variation in PCD is attained by adjusting the drill spindle in the slotted plate [4]. In belt driven drills, the transmission is achieved by using belts of different lengths. This mechanism is however suitable only for small capacity drilling. In transmission through telescopic drive mechanism, all the kinematics is same as that of the gear mechanism. Only difference is that the output of the gear drive is given to the universal joint. Use of telescopic arrangement facilitates the adjustment of each drill at any PCD offering the maximum flexibility. The universal joint at both the ends of shaft transmits the motion at specific angle.

Figure 2 shows the CAD model of an adjustable PCD gang drilling attachment design using retrofit approach. Unlike the first design this attachment is capable of drilling multiple holes simultaneously and at different PCD. The attachment comprises of four parts: (a) telescopic joint, (b) simple gear system, (c) mainframe and (d) guide ways. The drills are driven by the main spindle and the central gear through a number of simple gears in mesh with the central gear and the telescopic joints. The positions of the tool holders are adjusted on radial and circular cross guide ways depending upon the requirement of work. Each tool holder possesses a telescopic joint to allow its change in PCD and orientation.

Figure 3 represents adjustment of drill point location.

This attachment is an ideal solution to the problem of drilling multiple holes simultaneously and at different PCDs. Moreover with this attachment apart from drilling different operations such as reaming, countersinking or spot facing can be done simultaneously.

3.3 Construction of the Attachment

The design of the attachment is carried out by considering different design methodologies such as design for assembly (DFA), design for reliability and design for disassembly (DFD). The design was comprised of two parts;

(a) System design
(b) Mechanical design

System design is mainly concerned with the various physical constraints, ergonomics, space requirements, arrangement of various components on the main

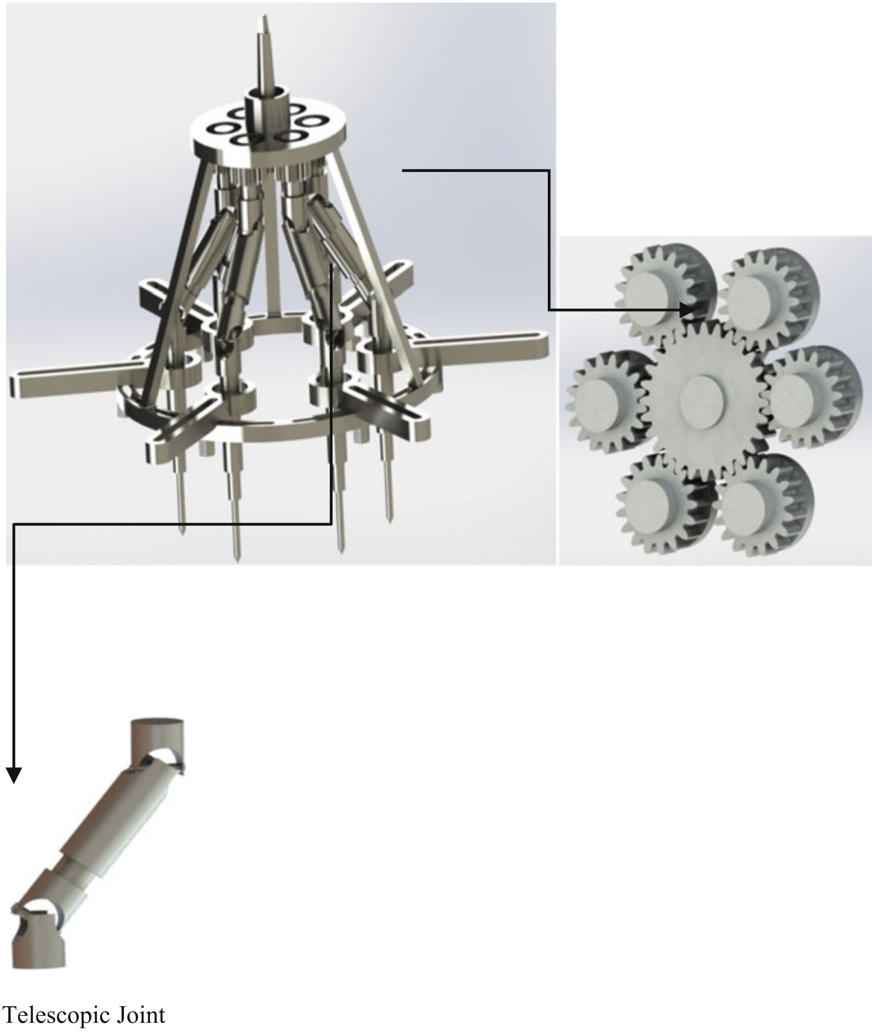


Fig. 2 CAD model of telescopic variable PCD attachment simple gear system

frame of machine, number of controls, position of these controls, ease of maintenance, scope of further improvement, height of machine from ground etc.

The Mechanical design comprises of two parts.

- Design and manufacture of parts in-house
- Selection and purchase of OEM parts

It is an important task to decide which part is to be designed and manufactured, and which part is to be purchased from the market. For designed parts detail design is done and dimensions thus obtained are compared to next highest dimension which are readily available in market, this simplifies the assembly as well as post

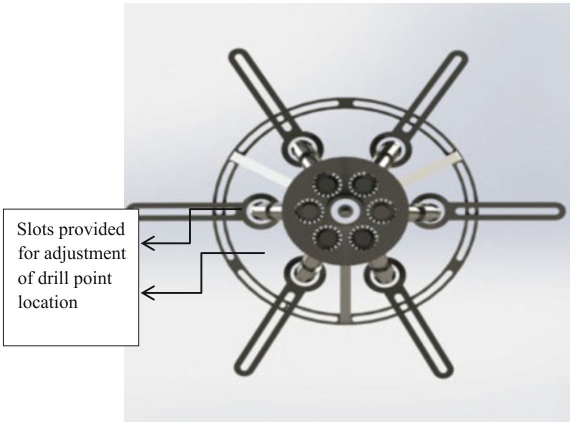


Fig. 3 Top view

production servicing work. The various tolerances on work piece are specified in the manufacturing drawings. The process charts are prepared & passed on to the manufacturing stage. The parts are to be purchased directly are specified &selected from standard catalogues. In system design we mainly concentrate on the following parameter such as system selection based on physical constraints, arrangement of various components, components of system, chances of failure, servicing facility, height of m/c from ground, weight of machine, etc.

4 Design Details

The design of the attachment is on primary level with consideration of industry constraints, need and other factors. This satisfies basic need about the attachment for reliability and user friendliness. It's also beneficial for small scale industries. The design creates good base for development of such type of attachment. A flow chart shown in Fig. 4 mention the guidelines about the steps involved in construction of this attachment.

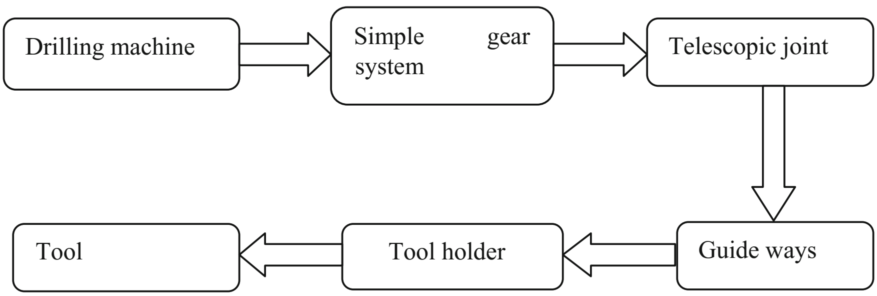


Fig. 4 Guidelines for designing of attachment

5 Cad Model and Prototype of Attachment

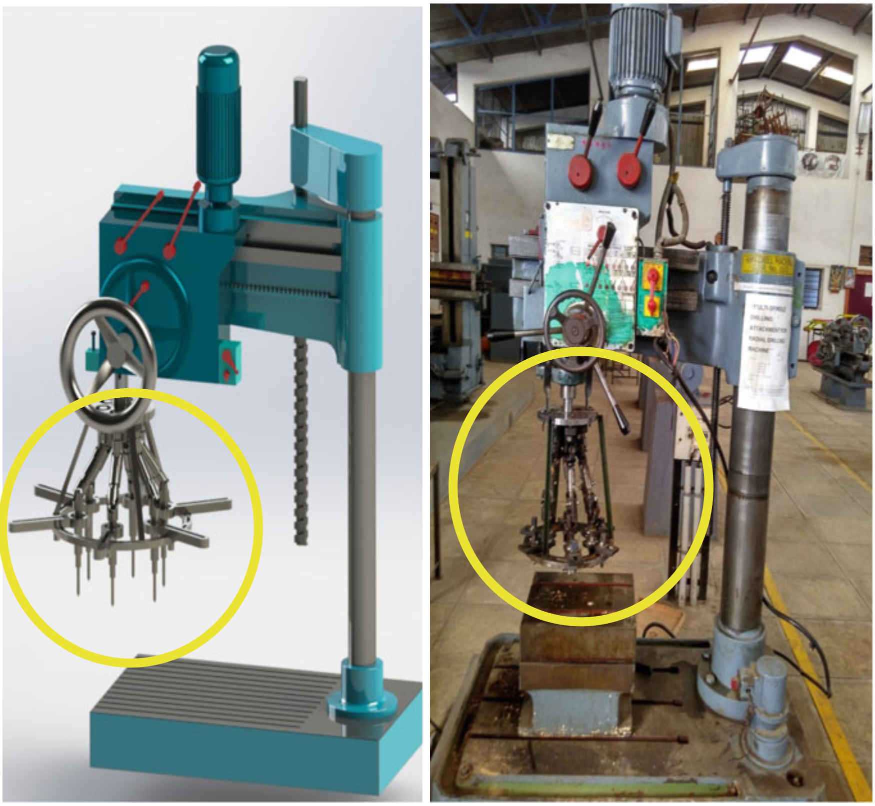
Final iteration of solid model is mentioned in Fig. 5a and the developed attachment installed on machine is shown in Fig. 5b.

6 Result

Table 1 gives the information about the results obtained from the testing of the attachment. Total time saved is 5 min per work piece, and total cycle time is reduced by 78%.

A result obtained from number of iterations is illustrated in Fig. 6.

Surface finish obtained during machining is measured and mentioned in Table 2.



(a) CAD model (b) Prototype

Fig. 5 An adjustable gang drilling attachment on radial drilling machine

Table 1 Machining time

Operations	Machining time without attachment (min)	Machining time with attachment (min)	Saving time (min)
Drilling one hole	0.5	–	–
Drilling 6 holes	3	1	2
Loading and unloading	3.5	0.5	3
Total	6.5	1.5	5

Fig. 6 Drilling multiple holes at different PCD

Table 2 Surface finish

Tool	Conventional rigid tool	Proposed tool
Surface finish (μm)	6.3–8	8–10

7 Conclusions

The results obtained from this attachment indicate that the time required for the cycle is significantly reduced to 1.5 min in comparison to general method (6.5 min). The attachment is hence a potential solution to the problems discussed in current practice. The best way to improve the production rate and productivity along with quality is by using this attachment on existing radial drilling machine instead of using special purpose machine (SPM's) in small scale industries.

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A Study on 'Design Thinking' for Constructability

S.P. Sreenivas Padala and J. Uma Maheswari

Abstract It is a well-known fact that the design phase is fragmented from the construction phase predominantly due to the differing perceptions of the two phases. In any construction project, the decisions in design take place without foreseeing the constructability issues thereby resulting in changes, errors, omissions, repetition, redesign or rework. The ideal solution to overcome this is to integrate these two phases which is complicated to achieve. Thus, the objective of the present study is to investigate an integration mechanism for construction projects. Integrated Project Delivery (IPD) is the recent buzz word in construction firms that has the potential features to integrate teams, processes, information, etc. Although researchers had identified BIM (Building Information Modeling) as one of the potential virtual tools for addressing the constructability issues, still it is inadequate. In this paper, two approaches-Point-based and Set-based design process were explored and compared to understand its pros and cons. Further, a generic integration framework was proposed to improve constructability during conceptual design planning of construction project.

Keywords Fragmentation · Integration · Constructability · Point-based design · Set-based design

1 Introduction

Globally, design phase of AEC (Architecture, Engineering and Construction) projects are portrayed as evolving, iterative, information-rich, etc. [1, 2] while the construction phase is represented as labor-oriented, hazardous, risky, etc. [3]. The reason behind this can be attributed to several reasons such as (a) functional design dependencies versus logical/physical construction relationships, (b) top-down design execution process versus bottom-up steps of construction execution,

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(c) information-rich design process flow versus stringent/inflexible construction workflow process. This additional perception of the design and the construction phase aggravates the fragmentation between the two phases.

In any construction project life cycle that starts typically from client requirements, design brief, until commissioning, handover, operation, and maintenance, several stakeholders play a dominant role at various stages of the project. These stakeholders within a subgroup have differing views of the entire project. Figure 1 shows different views of stakeholders for bridge design and construction. With the fragmented set up of executing the construction projects, decisions are made at each stage of the project without foreseeing the subsequent project stages [4]. Apparently, numerous rework, repair, and redesign occur during construction stage or sometimes even post-construction stages.

Integrated Project Delivery (IPD) is an alternative project delivery, has the potential to integrate teams, processes, information, etc. at an optimal level throughout all the stages of the project execution [5, 6]. However, IPD offers stakeholders collaboration but does not provide a tool to share information, perform the constructible analysis. Although researchers had identified BIM (Building Information Modeling) as one of the potential tools for addressing the design integration issues [7], still it is inadequate. BIM utilization can be enhanced by the integration of constructability concept in the design phase [8]. Point based design and Set-based design process are two well-established approaches which can aid designers to perform constructability reviews on design solutions. Both approaches have its pros and cons towards decision-making in the design process.

Thus, the objective of this paper is to investigate an integration mechanism for construction projects that can aid designers to integrate constructability concept in the design phase. The present scope of the study is limited to design-construction phase of the AEC project life cycle. A hypothetical case example on bridge design-construction is used for illustrating the proposed concept.

2 Background

In this section, the two approaches—Point-based design and Set-based design process to integrate design and construction processes are elaborated and discussed.

2.1 Point-Based Design Process

The Point-Based Design (PBD) is a sequential decision-making process, and it is a traditional approach [9–11] for constructability concept integration in the design phase. It comprises selecting a one best design option at each level of detail in the design process and then refining that design option iteratively while developing more information (construction, operation, and maintenance) [4]. If the chosen

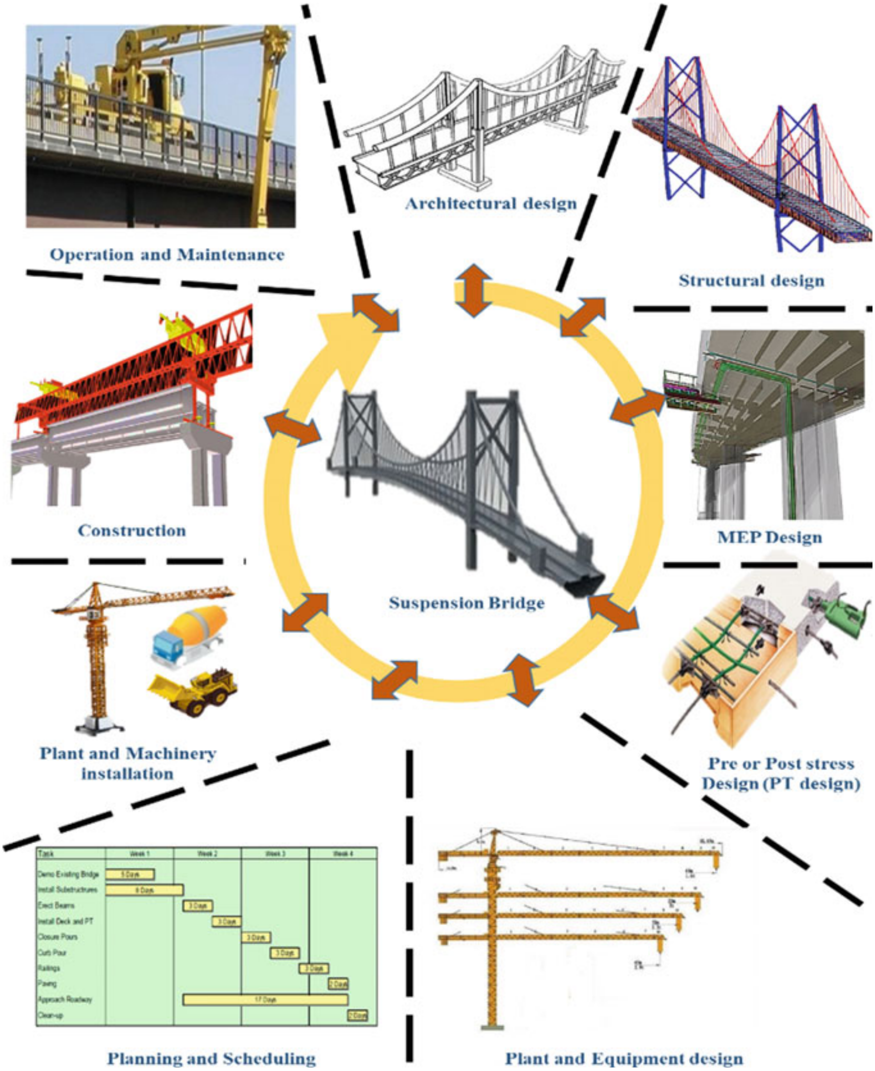

Fig. 1 Differing views of stakeholders on the bridge project

design solution is not constructible, then redesign occurs in a design phase. Since iterative process usually takes more time and increases the cost of a design process, there is an inclination to announce that design is complete at the end of the stipulated duration without narrowing the design space [12]. Iterative based design process increases the design development time and cost [13]. This sequential process also imposes constraints to determine the best construction methods in successor steps due to finalization of the design solution in predecessor step.

2.2 Set-Based Design Process

Ward et al. [14] introduced a Set-Based Design (SBD), which was originally developed by Toyota production system. The set-based design works on principles of concurrent engineering for integration by evaluating design and construction alternatives simultaneously [14, 15] as shown in Fig. 2. The significant difference between PBD and SBD is working on a set of alternatives, rather than working on a single design (point) solution then perform rework if it does not meet stated goals. According to Sobek et al. [16], SBD works basically on three principles: (1) Map the design space, (2) Intersection of independent solutions (eliminate infeasible alternatives), and (3) Establish feasibility before commitment. SBD delays the convergence of final design solution till last responsible moment by working on a set of all possible options and eliminates each solution which is infeasible [2, 16, 17]. Feasibility of construction can be analyzed concurrently from the beginning of design phase to generate constructible design solutions. A comparison of PBD and SBD is shown in Table 1.

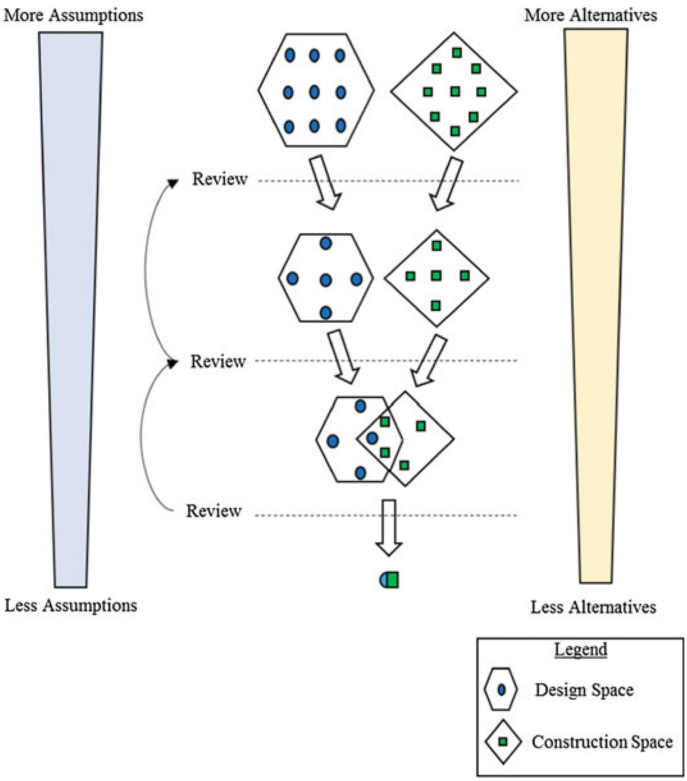

Fig. 2 SBD approach for a typical construction project

Table 1 Comparison of PBD and SBD in construction projects

Characteristics	PBD	SBD	Remarks
Strategy	Selection of feasible solution	Elimination of infeasible solution	[12, 14, 15]
Process	Works on single (point) solution	Works on many (set) solutions	[4, 15]
Design decision	Early convergence	Delay till last responsible moment	[2, 14]
Negative iterations	Cannot minimize redesigns	Minimize redesigns	[4, 12, 15]
Uncertainty	Increases	Decreases	[12, 15]
Integration approach	Sequential approach	CE principles	[4, 12, 15]
Stakeholders participation	Sequential manner	Throughout the design phase	[4, 12]

If the chosen design solution satisfies construction requirements in the first iteration, then PBD is an economic process. SBD is superior to PBD in minimizing re-designs or rework but inferior relating to the cost of implementing in the design phase since various stakeholders are required to participate from the beginning of the design phase. In SBD also redesigns can happen if elimination is performed incorrectly. Therefore, merits of both PBD and SBD should consider and utilize well in the conceptual design planning of construction projects.

3 An Integration Framework for Design and Construction

A generic integration framework was developed as shown in Fig. 3 which depicts integration mechanism in a design and construction. In a construction project, design decisions indirectly influence the progress of a construction project because there exists an *indirect* relationship between design and construction. Construction projects broadly classified into two stages: 1. Permanent structure design and construction 2. Temporary structure design and construction. Permanent structure broadly consists of sub-structure: foundation, piles, piers, pier cap and super-structure: columns, slabs, walls, deck, and so on. Temporary structure such as formwork (to support foundation, columns, walls and slabs fresh concrete), false-work to support temporary structures) supports permanent structure for a particular duration of execution. It provides an *intermediate function* (for contractors) rather than *final function* to end users [18]. Intermediate functional requirements are also equally important to analyze in the design phase along with final function requirements. Unlike manufacturing industry, in construction, formwork systems represent up to 60% of the cost of a concrete structure [19, 20]. Since formwork is a labour intensive work, manpower is the only productive resource, and it costs around 30% of total cost of structure [21]. Moreover, these temporary structures design and construction requirement changes from project to project due to design complexity in the permanent structure design and site conditions.

4 Bridge Project Case Example

To illustrate the integration framework as discussed above, a bridge project case is chosen as shown in Fig. 3. As mentioned earlier permanent structure design (Fig. 3a) decisions have an indirect impact on permanent construction due to its direct influence on temporary structure design and construction decisions. To

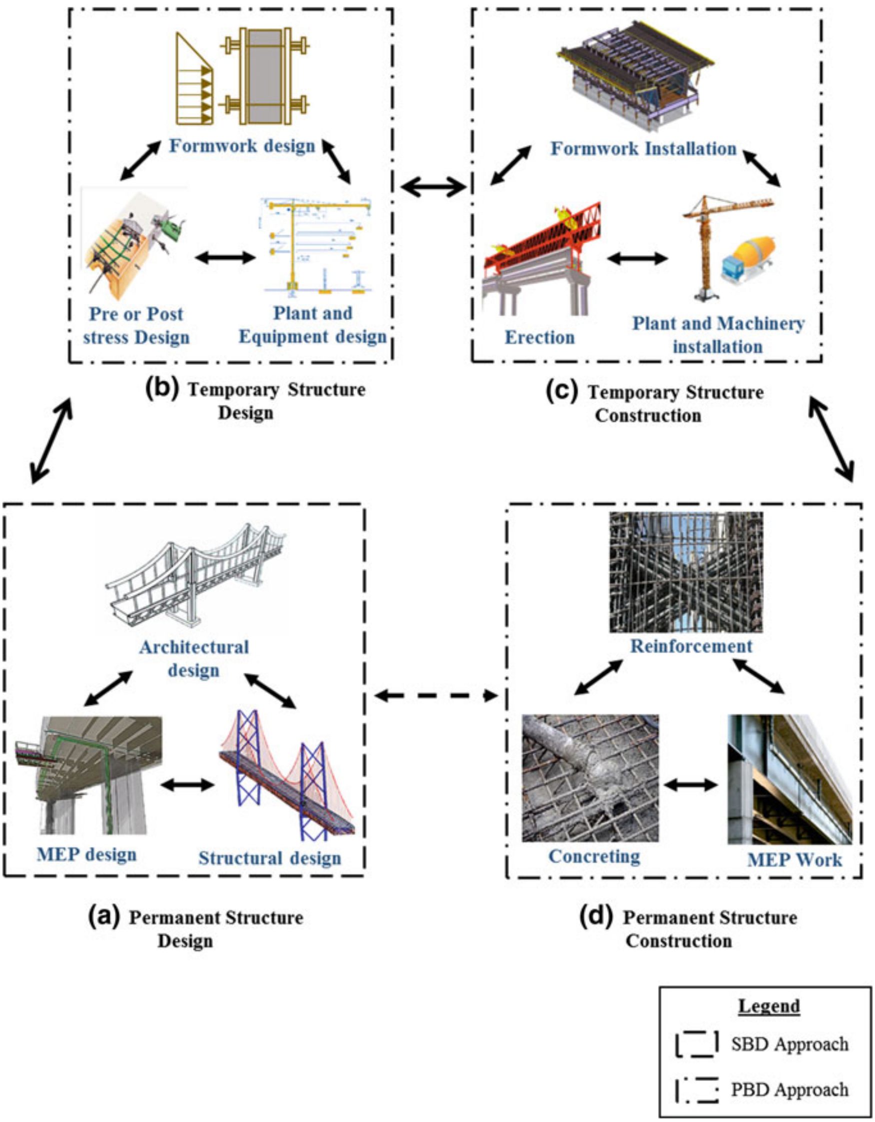

Fig. 3 A generic integration framework for design and construction

evaluate permanent structure design alternatives, various requirements are required to consider such as architectural, structural, mechanical, plumbing, and so on. This multi-criteria analysis to choose final permanent design alternative can be attained by SBD approach. Whereas temporary structure design-construction (Fig. 3b, c) and permanent structure construction decisions (Fig. 3d) are directly related. It means temporary structure design and construction decisions can still be made using PBD approach. Similarly, permanent structure construction decisions can employ PBD principles.

Design decision making in the construction projects towards achieving constructability can be accomplished through the integration of SBD and PBD approach. As shown in Fig. 4, possible sets for bridge design and construction are identified from the construction industry to create solution space. In each set, a list of criteria, bridge design, and construction alternatives are presented. It is evident from the Fig. 4 that to evaluate permanent design alternatives (Fig. 4a) using SBD, several criteria are required to be analyzed. Once permanent structure final design is selected, temporary structure design-construction (Fig. 4b, c) and permanent structure construction decisions (Fig. 4d) can be made linearly (by meeting constraints generated from permanent structure design decisions) using PBD approach. It is essential that inter-relationships of decisions between different domains have to be taken into account while finalizing the alternative in each domain. As mentioned earlier goal of temporary structures is to satisfy intermediate functions of a project. Once permanent structure construction decisions are finalized, a review process has to be performed by designers to check the feasibility of attaining both final and intermediate functions of a project.

5 Discussions and Summary

The proposed integration framework using PBD and SBD can apply to all types of construction projects such as bridges, buildings, dams, ports, and railways. Every construction project has a unique design and construction requirements (final and intermediate functions), constraints which are required to analyze before making final decisions. Two challenges can be emphasized from the integrated approach (Fig. 4) for constructability improvement. First, selection of best alternative which satisfies various criteria such as design, construction, operation, and maintenance is a Multi-Criteria Decision Making (MCDM) problem. Second, to solve MCDM problem, several stakeholders are required to participate at various stages of the design. Each stakeholder has a different view on the entire project as mentioned earlier in Fig. 1. Aggregation of all stakeholders' preferences to one unified preference to choose the best alternative becomes a Group Decision Making (GDM) problem. Further, the process of selection of the best alternative from the design and construction space is part of the conceptual design phase, and it can reduce major revisions in the subsequent design stages if all criteria related to the entire project are assessed. However, early design decisions are often challenging

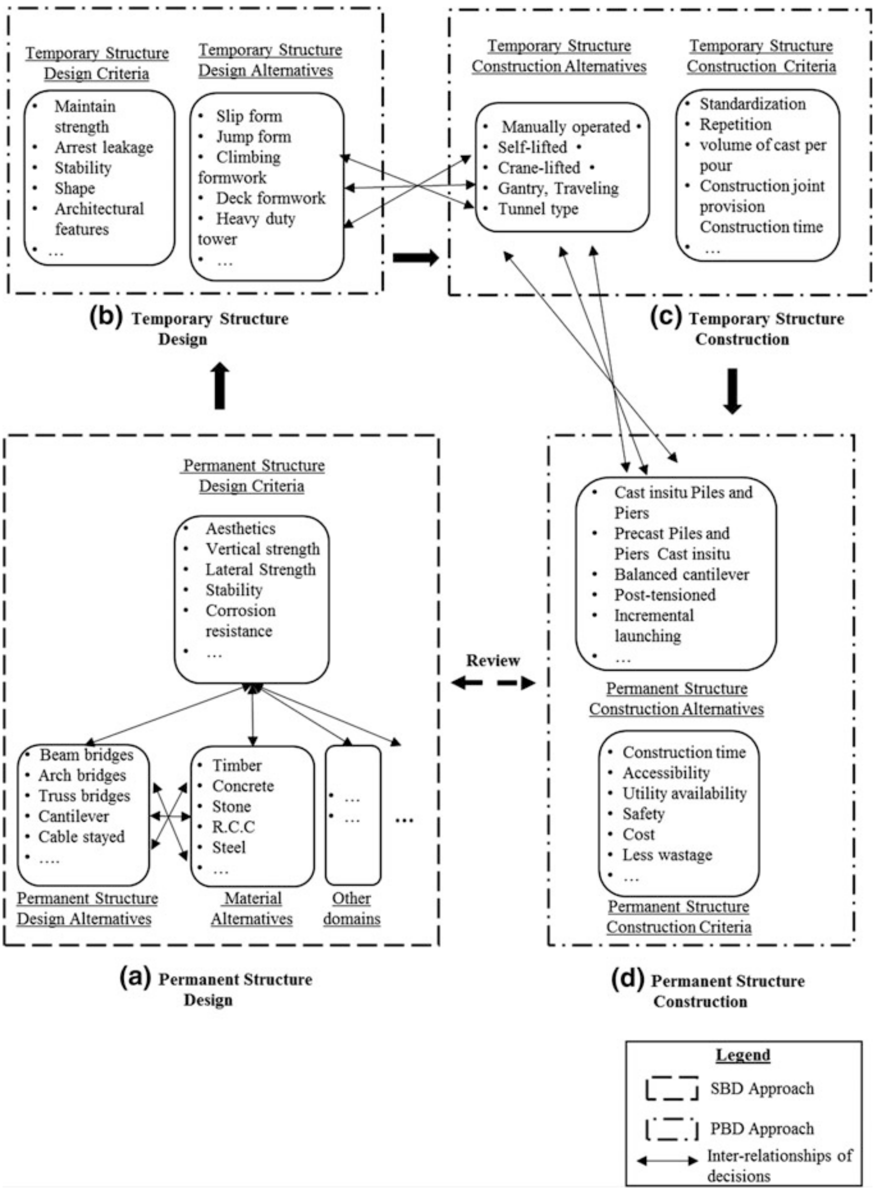

Fig. 4 Conceptual integrated SBD and PBD approach for constructability

due to non-quantifiable, unclear and incomplete information on alternatives [22]. Therefore, uncertainty quantification is essential in the early decision making in the construction projects.

This paper elaborates and discusses the two decision-making approaches-PBD and SBD which can aid designers to generate constructible design solutions. There exist direct and indirect relationships between design and construction decisions which have to analyze accurately while evaluating design and construction alternatives. An integration framework has been proposed to show a roadmap to achieve constructability of designs. In future, a detailed methodology will be developed which can aid designers to solve MCDM and GDM problem under uncertainty during the conceptual design planning for improving constructability of construction projects.

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Evaluating Modularity and Complexity of Alternate Product Architectures

Nikhil Joshi

Abstract Choosing the right design alternative requires consideration of various attributes, such as functionality, cost, ease of manufacture, etc. In the early stages of design there usually isn't enough information to make assessments of all these attributes. Often times, designers base these early decisions on qualitative assessments of indicators such as complexity, flexibility, or modularity, in place of the attributes of interest. Various methods have been proposed in literature to quantitatively calculate such indicators. However, the methods need design information to be provided in non-standard formats leading to errors, inconsistencies, and subjectivity in evaluation. This paper argues the benefits of using a standard modeling language such as SysML to capture design information and extract consistent information for calculating these indicators. Using alternate hybrid vehicle architectures as an example, the paper presents a framework to calculate two such indicators, viz. modularity and complexity.

Keywords SysML · Architecture · Complexity · Modularity · Design evaluation

1 Introduction

Today's products involve complex designs with a large number of parts working together through a combination of scientific principles in order to achieve the desired functionality and characteristics. As described by Simon [1], complex designs tend to have a hierarchical nature. Consequently, most complex products are designed in stages, starting with key architectural decisions up to detailed component design or selection. These design decisions are often seen as choices between alternate feasible configurations. Choosing the right configuration requires consideration of various attributes, such as functionality, quality, reliability, cost, ease of manufacture, etc. In early design stages, there isn't enough information to

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apply quantitative physics based models to make assessments of these attributes. Often times, designers base their decisions on qualitative assessments of indicators such as complexity, flexibility, or modularity, in place of the attributes of interest.

Various methods and approaches [2–4] have been presented in academic literature to quantitatively calculate such indicators for a given design. However, these methods often require specific information about the design (such as component interactions, number of types of elements, complexity of interfaces, etc.) to be presented in non-standard formats, that cannot be readily generated from CAD models or other traditional formats of recording design information. Subjectivity, inconsistencies and errors are introduced while providing this information for the alternate configurations. This article explores the use of SysML (Systems Modeling Language) as a standard format for capturing information about a design configuration.

The rest of the paper is organized as follows. Section 2 provides a description of SysML and the benefits of using SysML to capture design information. Section 3 introduces an example problem, and indicates how the alternate design configurations are modeled in SysML. Section 4 describes the calculation of two indicators, viz. modularity and complexity, for the alternate design configurations. Section 5 describes the results of the calculation for the example problem. We conclude in Sect. 6 with the envisaged advantages of the proposed framework, as well as some comments on the extensibility and scalability of the approach.

2 Systems Modeling Language

The Systems Modeling Language (SysML) [5] is a general-purpose modeling language with a semantic foundation for system requirements, behaviour, structure and parametrics. SysML is defined as an extension of a subset of the Unified Modeling Language (UML). SysML has been adopted by the Object Management Group (OMG) as OMG SysML and has evolved into the de facto standard for Model-Based Systems Engineering (MBSE) applications.

SysML uses a set of diagrams to capture information about the requirements, the structure, and the behavior of a system or design. Figure 1 shows the different types of diagrams used in SysML. Each SysML diagram presents a view of the system showing the concepts (denoted by blocks) in the particular design or system, and their inter-relationships (denoted by arrows or connectors). Using these diagrams and constructs, SysML is able to model a wide range of systems, which may include hardware, software, information, processes, personnel, and facilities.

SysML presents certain advantages when it comes to capturing design information. It is a formal, open standard and provides common, well-defined means to capture design information. It is domain independent and does not require a well-defined form or geometry to capture information. SysML models created using software tools are machine readable, which enables automatic checks for consistency between different views, as well as ensuring consistent and unbiased translation to any format as needed for further analysis. SysML models are already used

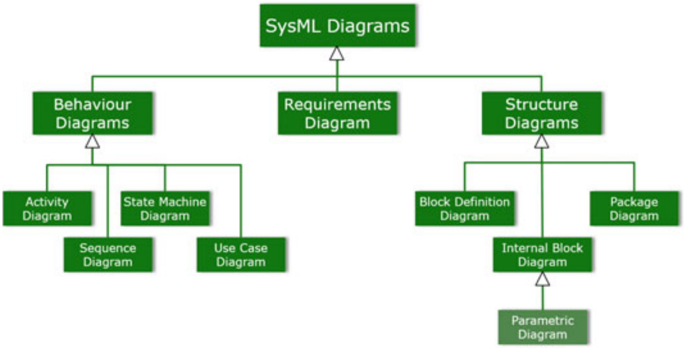

Fig. 1 SysML diagram taxonomy [5]

as master models to provide input to domain specific physics based analysis (often using different proprietary software) for quantitative evaluation of design attributes, such as functional performance, reliability, etc.

3 Motivating Example

In order to understand how SysML can also assist in unbiased and consistent evaluation of indicators, such as modularity and complexity, let us consider a practical example of an early stage design decision. Consider the design of a hybrid electric vehicle, where the decision to be made is a selection between four possible architecture alternatives (a), (b), (c) and (d), as shown in Fig. 2.

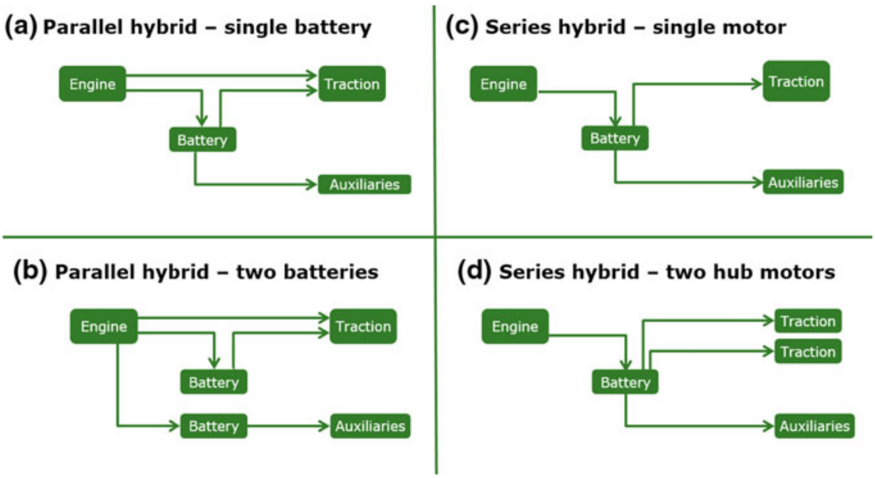

Fig. 2 Alternate hybrid electric vehicle architectures

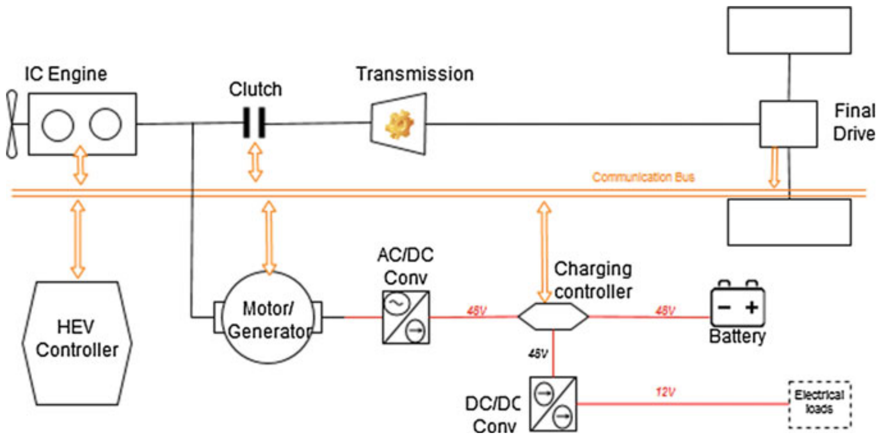

Fig. 3 A schematic diagram of the Parallel hybrid—single battery architecture

It is evident that the selection between the architecture alternatives would not be driven by the attributes of complexity or modularity only. Such early stage decisions often involve high level trade-offs between multiple attributes, such as reliability, cost, performance, modularity, etc. This paper does not focus on the process of performing the trade-offs and selecting the best alternative. This paper describes a methodology to precisely calculate indicators, such as modularity or complexity, for which otherwise imprecise or subjective methods are employed.

When faced with the task of evaluating such indicators, designers often employ schematic diagrams to capture additional details of the design alternative. Figure 3 shows such a diagram developed for alternative architecture (a) "Parallel hybrid—single battery". While this diagram contains information that can be readily understood by the designer, it is not captured using standard conventions or level of detail. Consequently, the information may not be equally understood by other designers. Moreover, this representation is not machine-readable. Thus, this may lead to inconsistencies between alternate representations or inaccuracies when this representation is used to provide input for calculation of indicators.

Figure 4 shows the SysML model for the alternative architecture (a) "Parallel hybrid—single battery". The model uses two different diagrams. The "Block Definition Diagram" shown in Fig. 4a captures the hierarchical structure of the design alternative. Different components or subsystems in the design are represented as blocks of specific types. The arrows in the diagram show a "part-of" relationship. For example, components 'transmission', 'hEV_controller', 'wheel_rh' and 'wheel_lh' (and others) are a part of the 'Parallel_HEV_1_batt' system, and while the 'transmission' and 'hEV_controller' are of types 'Transmission' and 'HEV_controller_A' respectively, both 'wheel_rh' and 'wheel_lh' are of the same type 'Wheel'. The "Internal Block Diagram" shown in Fig. 4b captures the connections and relationships between the components. The connections or relationships also have defined types. For example, there is connection through which rotational power is transmitted

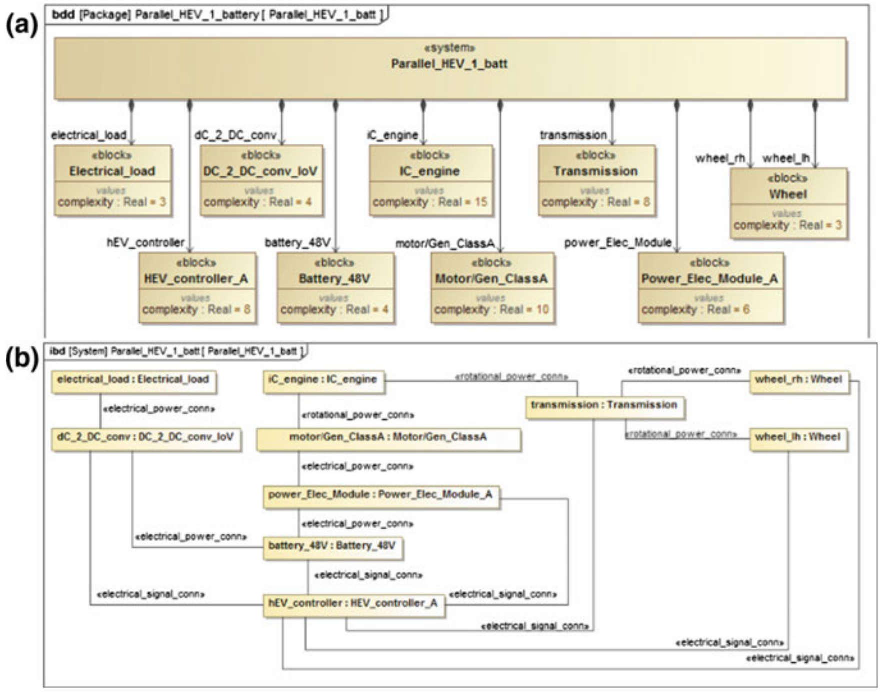

Fig. 4 SysML diagrams for Parallel hybrid—single battery architecture

between the ‘transmission’ and ‘wheel_rh’. This is shown by a connector of type ‘rotational_power_conn’. Similarly, connectors of type ‘electrical_signal_conn’ and ‘electrical_power_conn’ are used to show the connections that transmit sensor/controller signals and electrical power respectively. Using a common library containing the types of blocks and connectors, all the different design alternatives can be consistently modeled.

It should be noted that although multiple diagrams are used for capturing information about a design alternative, these diagrams are all a part of a single model. For example, one could use separate internal block diagrams to capture the rotational power connections and electrical signal connections respectively, or separate diagrams to show connections in separate subsystems, but they would result in an equivalent model. Thus, SysML can allow information about different aspects of a design to be captured separately (for example, by the respective domain or functional expert), while maintaining a single consistent model.

4 Evaluation of Indicators

As mentioned in the introduction section, formal methods for calculating indicators require specific information about the alternatives to be provided in specialized formats. SysML enables capturing information about the design alternatives with a consistent level of detail, and in a standard, machine-readable format. Thus, it is envisaged that the information required for evaluating the indicators can be extracted from SysML models in a way that is consistent, comprehensive and unbiased. This section describes the evaluation of two such indicators, namely modularity and complexity.

4.1 Evaluation of Modularity

Modularity is an indicator of various attributes, such as ease of design or manufacturing, ease of repair, flexibility to reconfigure or upgrade, etc. This has led to various perspectives or approaches to evaluate modularity. Browning [2] and Sosa et al. [6], propose methods based on evaluation of matrix properties of a Design Structure Matrix (DSM) that captures component interactions. Guo and Gershenson [3] propose a formula for evaluating modularity based on the degree of connectedness between components within a module, and the degree of connectedness between components across modules.

Most proposed metrics require prior definition of module boundaries among the components, and are often dependent on the total number of components in the design. This paper employs a metric called Singular Value Modularity Index (SMI) that has been proposed by Hölttä-Otto and de Weck [7]. This metric is independent of the scale of the design (i.e. number of components in the design) and any prior definition of module boundaries. The SMI measures the decay rate of the Singular Values of the Design Structure Matrix (DSM) capturing the connections between components. Singular Values are the square roots of Eigen Values of the matrix $\mathrm{DSM}^{\mathrm{T}}\mathrm{DSM}$. Thus, the SMI can be calculated using the following equation;

$$SMI = \frac{1}{N} arg\min_{\infty} \sum_{i=1}^{N} \left| \frac{\sigma_i}{\sigma_1} - e^{\frac{-[i-1]}{\alpha}} \right| \tag{1}$$

… where N is the number of components and σ_i *for* $i = 1\ldots N$ are the Singular Values of the DSM.

Most software tools used to build SysML models would provide some functionality to extract information about relationships between components in the system in the form of a matrix or DSM. Figure 5 shows such a DSM extracted for the alternative (a) “Parallel hybrid—single battery”. It should be noted that a single DSM incorporating all connections can be extracted even if the information about

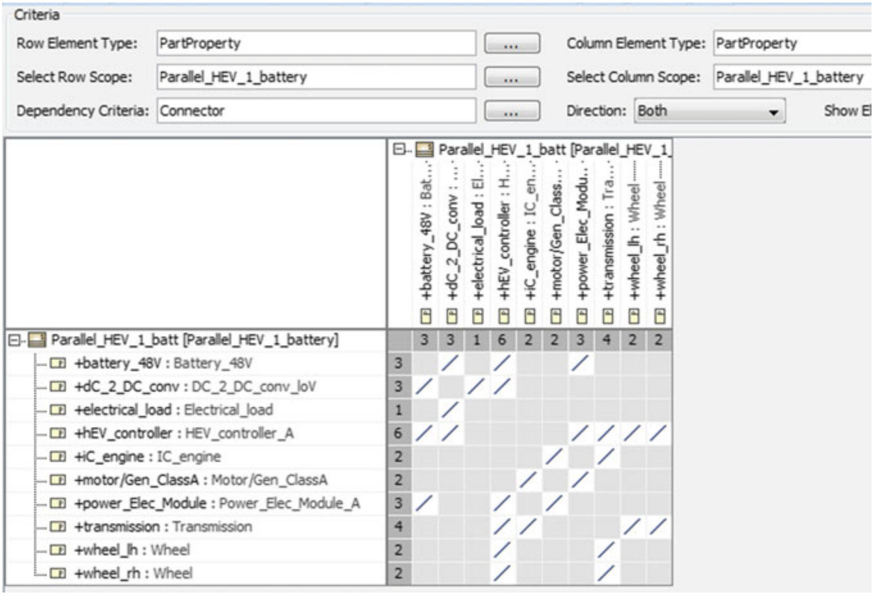

Fig. 5 DSM extracted for design alternative—“Parallel hybrid—single battery”

the connections is captured across multiple diagrams. One could also choose the types of connections that should be included or excluded from the matrix definition. This allows such assumptions to be consistently applied for all alternatives under consideration.

Thus, the only requirement for precise evaluation and comparison of architecture alternatives using this approach is that components in the architecture and their connections are captured consistently and with the same level of detail in the SysML models for the alternatives. This model may be created by a single designer, or by a team with specialists elaborating the design of particular subsystems. It seems reasonable to expect that over time a design team would develop guidelines for consistency and level of detail in their models. Once we have the desired input information about the design in the required format, we can carry out the calculations to determine the SMI. Figure 6 shows a screenshot of the calculations performed in a popular mathematical solver for the alternative (a) “Parallel hybrid—single battery”.

4.2 Evaluation of Complexity

As is the case of modularity, complexity is used as an indicator of multiple attributes, such as cost, ease of design or manufacturing, ease of use, potential for failures, etc. Consequently, various perspectives on complexity such as structural

$$\mathrm{DSM} := \begin{pmatrix} 0&1&0&1&0&0&1&0&0&0\\ 1&0&1&1&0&0&0&0&0&0\\ 0&1&0&0&0&0&0&0&0&0\\ 1&1&0&0&0&0&1&1&1&1\\ 0&0&0&0&0&1&0&1&0&0\\ 0&0&0&0&1&0&1&0&0&0\\ 1&0&0&1&0&1&0&0&0&0\\ 0&0&0&1&1&0&0&0&1&1\\ 0&0&0&1&0&0&0&1&0&0\\ 0&0&0&1&0&0&0&1&0&0 \end{pmatrix} \qquad \mathrm{M\_SVD2} := \mathrm{svd2(DSM)}$$

$$\mathrm{sing\_values} := \mathrm{M\_SVD2}_0 \qquad \mathrm{sing\_values} = \begin{pmatrix} 3.366\\ 2.183\\ 1.816\\ 1.678\\ 1.543\\ 1.301\\ 1.07\\ 0.651\\ 0.384\\ 0 \end{pmatrix}$$

$$\mathrm{alpha} := 1$$

Given

$$\sum_{i=1}^{\mathrm{length(sing\_values)}-1} \left| \frac{\mathrm{sing\_values}_i}{\mathrm{sing\_values}_0} - e^{\frac{-(i-1)}{\mathrm{alpha}}} \right| = 0$$

$$\mathrm{alpha\_star} := \mathrm{Minerr(alpha)}$$

$$\mathrm{alpha\_star} = 3.651$$

$$\mathrm{SMI} := \frac{1}{\mathrm{length(sing\_values)}} \cdot \mathrm{alpha\_star} \qquad \mathrm{SMI} = 0.365$$

Fig. 6 Calculation of SMI for design alternative—"Parallel hybrid—single battery"

complexity, dynamic complexity, process complexity, computational complexity, etc. have been discussed in literature. Edmunds [8] and Kinnunen [4] provide a good overview of the various methods and metrics that have been proposed to compute complexity.

This paper focuses on computing the structural complexity of the design. Lankford [9] presents a method to compute complexity of a system defined in UML based on the number of classes, messages, relationships, states and state transitions. Kinnunen [4] proposes a method based on a model of the system defined using Object-Process Methodology (OPM) [10]. Many studies, e.g. Meyer and Lehnerd [11], propose metrics based on weighted functions of the number of components, the number of types of different components, and the number of interfaces. This paper employs a metric, Complexity Index (CI), which is based on a combination of ideas presented in these studies. The metric used is as described in the equation below:

$$CI = (Total\ \#\ of\ parts) + \sum_{unique\ part\ types} (CI\ of\ part\ type) + (Total\ \#\ of\ connections) + \sum_{unique\ connection\ types} (CI\ of\ connection\ type) \tag{2}$$

It should be noted that SysML models already incorporate information about the type of each component. For example, Fig. 4i showed that the alternative “Parallel hybrid—single battery” had two parts “wheel_lh” and “wheel_rh” of type “Wheel”. Thus, the information about the total number of parts and connections, as well as the types of parts and connections in a particular design alternative can be readily extracted from the SysML models. The CI to be assigned to a part type or connection type depends upon the perspective of the design decision. For example, from a design perspective a battery may be fairly complex if it has to be designed for the specific purpose. However, the battery would not be considered complex if it is has to be bought off-the-shelf. Thus, the CI of a part type or connection type must be provided by the designer.

While this does introduce bias or subjectivity in the calculation, the CI values can be incorporated as parameter values of the part or connection stereotype in the SysML model. Over time, a design team can build its own library of stereotypes with defined CI values based on the shared perspective of the organization. Since, all the alternative architectures would use components and connections from the same library of stereotypes, it would reduce any bias or subjectivity, or at least ensure that it is applied equally to all the alternatives being considered. Moreover, the formula for CI ensures that the CI can be recursively calculated across the hierarchy (for parts that are components or sub-systems containing many components) to arrive at the CI for the system. Figure 7 shows the extracted information and the calculation of the CI in a mathematical solver for the design alternative (a) “Parallel hybrid—single battery”.

5 Results

The methodology described in Sect. 4 was used to calculate the modularity and complexity for all the four design alternatives under consideration. The results of the calculation are shown in Fig. 8. As can be seen, the alternative (a) “Parallel hybrid—single battery” is most modular as well as least complex. The alternative (c) “Series hybrid—single motor” seems to be a more integral architecture (i.e. least modular), while the alternative (d) “Series hybrid—two hub motors” seems to be the most complex. As mentioned earlier, these values can be used by the designers in making early architecture decisions, by considering tradeoffs with other attributes of interest.

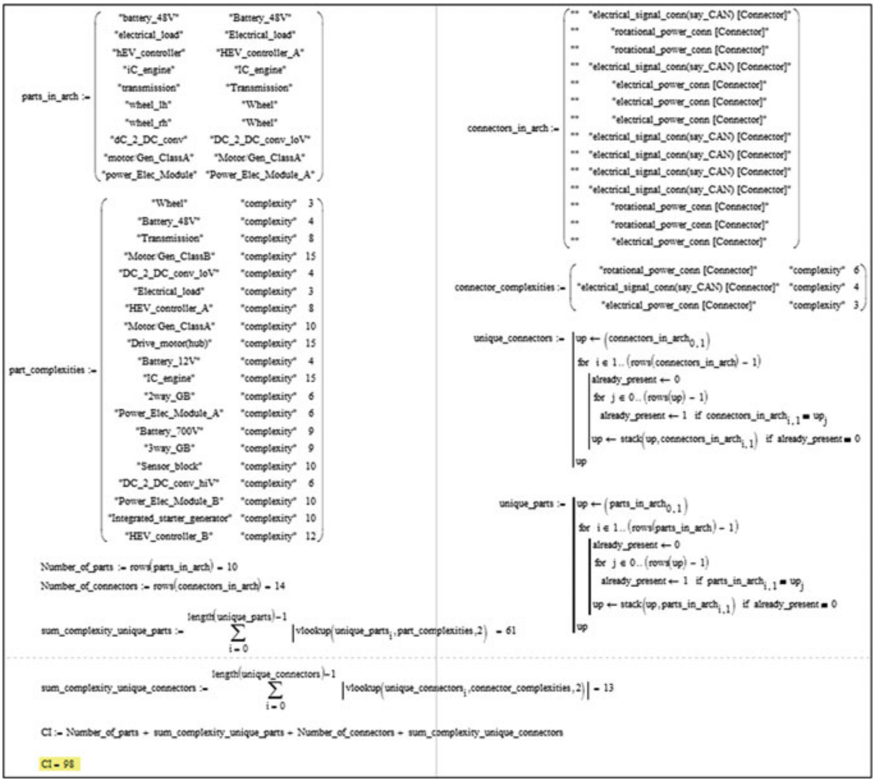

Fig. 7 Calculation of CI for design alternative—*"*Parallel hybrid—single battery"

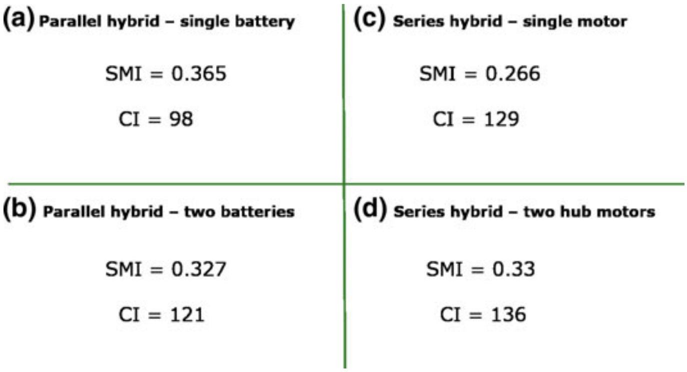

Fig. 8 Calculated values of SMI and CI for the design alternatives

6 Conclusion

Thus, this paper has demonstrated a methodology to calculate attributes, such as modularity and complexity, for a given design alternative. Capturing information about alternative architectures using a standard format such as SysML, enables extracting information required for computing these indicators in a way that is comprehensive, consistent and unbiased. This allows precise calculation of these indicators so as to give designers the confidence to use these indicators for making trade-off decisions. The methodology presented is domain independent, scalable and adaptable for calculation of various different types of attributes for a given architecture. Moreover, since SysML already has integrations with other engineering tools, the methodology can be integrated with the existing design software tools without disrupting the other design activities and processes. Therefore, the methodology presents a promising direction for future research in streamlining the early stages of the design process.

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Parameter Management, a Novel Approach in Systems Engineering

Ferdinand Toepfer and Thomas Naumann

Abstract Current approaches in Model-Based Systems Engineering lack of broad application in the automotive product development due to an unmanageable modeling effort and high complexity in system models. The paper describes a novel approach in Systems Engineering (SE), based on the systematic management of ordinary engineering parameters as quantifiable, relatable and traceable characteristics of Engineering Objects in product development. The approach aims for the support of a highly complex product development, by supplying engineering processes with the right information at the right time and by allowing traceability in implicitly generated system models on the level of Engineering Parameters.

Keywords Systems Engineering · Characteristics · Engineering Parameters

1 Introduction

To successfully persist in a global market requires car manufacturers to outrun competitors by offering customers the best products for the best price. Driven by customers' diverse and market-specific requirements, the automotive industry is facing the challenge of developing a wide variety of customizable and market-specific products. A growing number of vehicle types, variants and configurations are the strategic consequence, which can only be offered cost effectively through the systematic realization of module- and common-part strategies, resulting in vehicle spanning platforms and architectures [1]. Despite the enormous cost-saving potential, these strategies however lead to a significant increase in both technical and procedural complexity as parts and modules have to be deployed in different products [1, 2]. Additionally, products are often developed in different

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divisions of the organization, again leading to an increase in procedural complexity. Strictly pursued CO_2-strategies, in order to meet legal requirements and the call for sustainable and innovative products, force the automotive industry additionally to integrate new concepts and approaches in power units, material and functionality. As a main source of innovation, cross-disciplinary application functions, realized through mechatronic systems, comprise and couple multiple subsystems (each coupled with multiple parts and often part of other systems) with one another creating a highly complex and cross-linked product. The development of such systems requires the cooperation of multiple disciplines (e.g. mechanical engineering, mechatronics, and informatics) and thus intensifies organizational and procedural complexity, leading to a significant increase in interaction and communication among designers.

To handle this high-level complexity, Systems Engineering (SE) approaches are intended to help enabling a successful interdisciplinary development process. A substantial aspect of commonly known SE approaches is the explicit modeling of technical systems, in order to describe system properties and behavior, to specify and verify a discipline spanning solution concept and to enable traceability between a multitude of Engineering Objects (EOs) [3, 4].[1] These approaches however lack of broad acceptance among designers, mostly due to an unjustifiable modeling effort and the lack of flexibility for the variety of applications and needs. The occasional unwillingness of learning and managing additional and particularly complicated tools is additionally fueled by the enormous time pressure prevailing in an increasingly parallelized development process.

The paper therefore describes a novel approach in SE and its prototypical implementation which allows for the support of a highly complex product development process on the level of Engineering Parameters (hereinafter simply referred to as "parameter").

2 Current Approaches in Systems Engineering

Taking the previously mentioned aspects into consideration, product development in the automotive industry can be characterized as a highly complex system with an unmanageable amount of interdependencies on a technical, procedural and organizational level. It is to be noted that technical complexity goes hand in hand with organizational and procedural complexity [5, 6]. It leads to an increase in information, represented in various EOs, and an increase in their relations to other EOs termed *Engineering Object Relations* (EORs) [7]. SE as an "[…] interdisciplinary approach to enable the realization of successful systems" [8], deals with the

[1]EOs are referred to as the entity of structured information represented by heterogeneous graphical formats, in partial models of an integrated product- and process-model [3, 4]. In the context of this paper, e.g. requirements, functions, elements, concept elements, systems as well as parameters are considered as EOs.

methodological and tool-supported management of complex systems as well as with the development of products [9]. Model-Based Systems Engineering extends this approach by generating and using a centrally available digital system model to facilitate interaction between various IT-Tools and allowing for traceability between EOs, comprised in the system model. As defined by [10] traceability is the "[…] degree to which a relationship can be established between two or more products of the development process […]". Therefore, traceability in general allows for a better understanding of dependencies in systems and helps to keep EOs up to date and consistent. A lack of modeled or documented EORs leads to lower transparency about decisions, changes and the impact of changes. Inconsistencies in data are a possible consequence [11]. Despite the existence of multiple prototypical and a handful of industrial tools that allow for system modeling and traceability, current approaches are still lacking of broad implementation and use in practice. This is on one hand due to a vast modeling effort originating from the complexity of the underlying knowledgebase which makes the creation and maintenance of EORs an unmanageable effort [11–13]. "The degree to which system complexity can be represented in a model relies on the type of data and the type of relation that is to be coupled" [14]. Interdependencies in a model can be limited to pure qualitative information only or also include quantitative information.

Other obstacles are differing traceability needs in different projects, organizations and from different users, the integration of both formal and informal sources and a very heterogeneous set of tools and methods applied in product development [11, 12]. An additional fact which limits the use of traceability in practice is a clear assignment of roles and responsibilities. According to [15] SE follows the task of designing the "total package […] including their interrelations […]." In automotive development this "total package" requires the cooperation from designers who have to supply detailed information from single parts or modules but don't profit from that information, whereas others only consume the information and benefit from it.

Considering the prior mentioned aspects, the main research question arises, how is a SE approach ought to be conceptualized in order to surmount the challenge of despicable system complexity while unifying EOs and their relations in one constantly up-to-date system representation without being hindered by inhomogeneous toolsets and excessive modeling effort?

3 Approach of Parameter Management

The previously mentioned challenges, identified in both literature and development practice, currently hinder the implementation of SE approaches in practical application. In order to surmount these challenges, processes and engineering data were analyzed, to identify key factors for acceptance and successful application of a novel SE approach. Therefore, interviews with different departments (each with differing responsibilities, roles and demands) were conducted. Coherently their respective workflow and flow of information as well as processed data types and formats were analyzed.

For an approach to be suitable for the application in a highly complex automotive development environment, the following criteria were identified:

- High degree of representable system complexity
- Low modeling effort (compared to procedural and organizational benefit)
- Low adaption effort of information in the model for changes, especially in the early phases
- Model instantiation for individual product configurations
- Integration in existing engineering processes and
- Interoperation in the engineering IT-Environment and their services.

3.1 Derivation of Parameter

Parameters are an essential part of product development. But when asking among designers about a definition, one will get just as many answers as individuals asked. It is a phenomenon of a term that lacks of clear definition and was thus gradually adopted from various disciplines in both engineering disciplines and other branches of science. Vajna et al. [16] emphasize this phenomenon by discussing the meanings and interpretations of the term parameter in the context of Mathematics, Informatics and Engineering.

It is thus a matter of terminology to derive a clear definition that allows for a common understanding. In that sense [17] serves as a guideline for terminology, in order to derive and categorize terms by definition. For that, everything that is the matter of perception or imagination, of material or nonmaterial is considered an object, characterized by properties (Eigenschaften). In order to differentiate between (and name) a set of different objects, it is necessary to identify and define those properties that are object specific and allow for differentiation, so called characteristics (Merkmale). The abstraction of certain characteristics thus allows for the derivation of terms. A distinction of characteristics is drawn between characteristics of quality (Beschaffenheitsmerkmale) and characteristics of relation (Relationsmerkmale). Characteristic of quality describe direct properties of objects that are defined by a term. Characteristics of relation describe the relation between two or more terms.

Characteristics of function are of particular interest as they are able to describe the behavior or the function of a technical system. The function of an object (system) can be categorized as a characteristic of relation as it is realized by the interaction of at least two parts (system elements) on the basis of working principles and underlying physical effects. The interacting parts (elements) of the object again can be specified as characteristics of quality. A change in function can thus only be realized by a change of characteristics of quality of the involved parts (system elements). Accordingly, [18] emphasize the scientific meaning of identifying quantitative relations between characteristics of quality and characteristic of relation (sic.). According to [19], a quantity is to be seen as a special type of characteristic. Following the definition of a system as the model of entireness, a system consists of a multitude of interrelated elements and system boundaries, comprising the systemic aspects of function, structure and hierarchy. A system can thus be described by the characteristics of its elements and by the characteristics of their relations [20]. Parameters as quantifiable characteristics can thus describe all quantifiable and measureable entities of a system, as well as the system itself.

Definition of Engineering Parameter: *An Engineering Parameter represents any characteristic of quality and relation which can specifically be described by a quantity. It thereby explicitly carries the name of the describing characteristic and a quantity (numerical value and optionally a unit).*

EOs, defined as the entity of structured information in an integrated process- and product model are represented in heterogeneous graphical formats (see definition). The parameter as a quantifiable information of model-/object-specific characteristics falls under this definition and can thus be considered an EO itself. However, the parameter plays a special role as it is an EO within various EOs. It is the smallest EO and unlike other EOs not limited by heterogeneous formats.

3.2 Parameter Management, a Bottom-up Approach in Systems Engineering

Model-Based approaches in SE use machine readable graphical modeling languages that allow for system design and analysis [21]. SysML (Systems Modeling Language) offers a predefined set of diagrams which allows for the modeling of system behavior, requirements, structure and parametric in a holistic system model [22]. Furthermore, it allows for the interoperation with other partial models by defined interfaces (FMI: Functional Modeler Interface). As depicted in Fig. 1, generating a system model thus means to explicitly define and model all objects and relations in an equivalent modeling tool and to gradually incorporate EOs, by defining and maintaining EOs and their relations. Upon the creation of system models, EOs can be traced and their parameter information can be retrieved and exchanged. It is thus to be seen as a top-down approach as it follows the path from creating a holistic system model, to incorporating EOs, to acquiring parameters from the EOs. These top-down modeling approaches however are mainly limited by the complexity of the system model due to the sets of inhomogeneous Engineering tools representing diverse partial models.

An approach to surmount the effort of modeling and maintaining system models was established with the prototypical implementation of SysMT (System Model and Management Tool). Based on the Meta-Model of Product Development [7] a data model was defined which incorporates elements and their relations of both the technical and the social system. The template-based approach allows for integrative

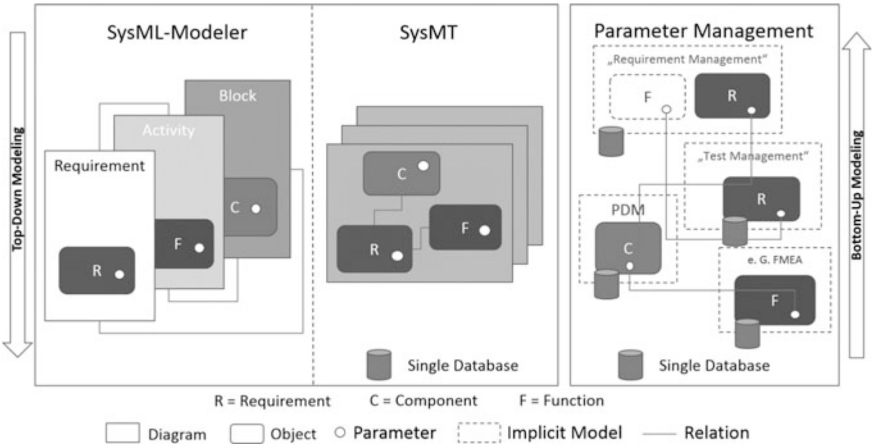

Fig. 1 Comparison of top-down model-based SE approaches with parameter management as bottom-up approach

acquisition of data from EOs and enables traceability through EORs which are defined by the system's meta-model [11]. The acquisition of parameters also follows the previously mentioned top-down procedure, as parameters are retrieved through EOs which are displayed in system model representations.

Contrarily, Parameter Management can be seen as a bottom-up approach in SE. Differing from model-based approaches, parameter management doesn't require the modeling and operating of system models. Instead, parameters are defined and managed in a single source principle application. Parameters only possess a reference to their individual representation of EOs they originate from. Already existing EOs and their implicit relations to one another are thus represented by parameters, instead of representing them explicitly in a model. Hence, the approach of parameter management doesn't require the reproduction of existing entities in a model.

4 Prototypical Implementation

The presented approach was implemented in a prototype (Fig. 2) and is described hereafter with its main three aspects. A data model for the organization of parameters (Sect. 4.1), functions within in the database application, to create a working environment (Sect. 4.2) and functional enhancements on the basis of the central data model (Sect. 4.3).

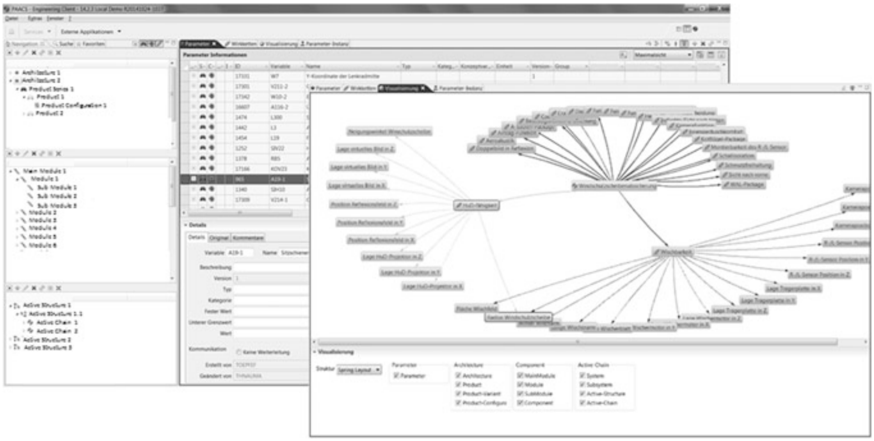

Fig. 2 Prototype of parameter management application

4.1 Parameter Repository

The first aspect of the approach determines the documentation of parameters in a single source, providing up-to-date parameter values for all users. This is of particular importance as inconsistencies in engineering data are typically caused by individually handled documents and redundantly managed data [11]. It has to be understood that product development itself is a highly dynamic system in which social systems are bound to different organizations and hierarchies. In order to drive forward product maturity, social systems interact and communicate on a large scale to provide, acquire and exchange information [23]. Nowadays, a multitude of databases, knowledge repositories and single documents (in particular Excel) are being managed in different engineering departments and teams, to support specific processes in product development. In a product development that is increasingly driven by discipline-spanning systems, the importance of discipline spanning collaboration increases. The approach therefore reaches out to establish a database that serves as a common basis for all parameters.

The meaningful organization of parameters facilitates a practical navigation in well-established structures (e.g. product structure), making required information retrievable to all users. Therefore, the underlying data model for the parameter repository has to be able to represent data through different filtering criteria. At the same time, it has to take the multitude of vehicle architectures, variants and product configurations into consideration which are representing instances of the product. The navigation is therefore realized by four different partial structures:

- **Product Portfolio structure**, which determines the entity of products in an aggregation of products and their configurations.

- **Product (Components) structure**, which is both an aggregated and composed representation of a product [24].
- **Function structure**, which is a composition of sub-functions to a main function.
- **System structure**, which is composed of functions or sub-functions, assemblies or single parts.

From a workflow perspective, parameters are defined in the database application as generic characteristics before they are assigned to their context-specific partial structures. Through the respective selection in the structures, parameters can then be displayed and instantiated with their context specific value.

In order to achieve traceability among interrelated objects, every parameter carries detailed information. According to [25] these information include

- All numerical information and possible variables
- Information about who created or changed the parameter
- A reference to the origin of the parameter (e.g. PDM System)
- Date and time of the changes on a parameter
- A comment slot for remarks about changes.

4.2 Parameter Management Functions

Based on the structured arrangement of parameters, the second aspect of Parameter Management focuses on key functionalities in order to provide a process-supporting working environment. In that way it creates a benefit instead of causing additional work for designers. These functionalities particularly support the processing, use and retrieval of parameter information.

Driving a product from a conceptual level to product maturity requires the definition of requirements on individual levels of hierarchy for multiple products and their configurations. In order to validate these specifications, it must be possible to assign target values and target ranges to parameters, both generically and for specific product configurations only. Hence every parameter value can be checked for validity. Violations of target values are then being identified and communicated.

Changes in components cause changes in functions and contrarily changes in functions cause changes in components. It is important to understand this systemic interrelation between functions and their underlying components' characteristics. As parameters can describe either aspect, their coupling allows for direct traceability between components, functions and systems. Bound together in active structures as depicted in Fig. 3 parameters and their entities are directly coupled to one another [cf. 26]. When parameters are changed it allows for a direct notification for any coupled parameter and at the same time gives feedback about the affected components functions or systems.

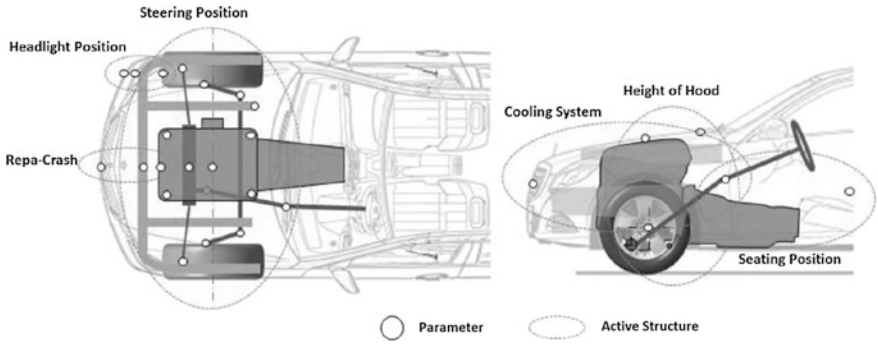

Fig. 3 Coupling of parameters in active structures

Engineers from various disciplines work in different Engineering applications, representing partial models of an integrated product model. In order to trace changes directly from an engineering application it is of benefit, to have a direct interface between the parameter repository and the partial models. This can for example be accomplished by using XML-Technology. By coupling CAD Models to a PDM System, parameter information of updated CAD Files can be retrieved from the PDM-System and updated in the repository. Hence, the parameter repository functions as a database supplying and coupling various engineering services with up-to date data. For example, when requirements are changed, one can instantly draw a connection to the corresponding CAD-File.

Communication plays a major role in the socio-technical system of product development, as it is a function of the social system in order to drive forward product genesis [7]. Supporting the processes of product development, parameter management incorporates a function for communication. It is thereby a major source of transparency for all affected participants in the occurrence of changes. The approach allows for both, a notification and a commenting function. The notification function triggers a messaging service to inform affected users in case of changes and critical impacts of these changes. The commenting function allows the explaining of decisions and the making of remarks about parameter changes and their current values.

The assignment of roles and responsibilities is an important aspect in order to accomplish consistency in the data repository, but goes beyond the scope of this paper.

4.3 Application Functions

Based on specific preselected subsets of parameters, application functions allow for the enhancement of parameter management functions in external tools. By filtering and arranging parameters, subsets of parameters can be exported for recurring design tasks reliant on the flow of selected parameters. Such tasks can be any sort of chart generation, for example in Excel sheets, to name the easiest, as well as the analysis and presentation of parameter information in more advanced tools. These tasks are however not only limited to the department of research and development. Profiteers can also be departments like Sales or Strategy.

Another major benefit from processing parameters externally is the support of early functional layout processes through the computation of solution spaces. The analysis of Solution spaces can be used to derive a good starting layout in a highly iterative process of problem solving in the early phases. In a field of many contrary design objectives a solution for one specific problem is usually driven from one starting design to many gradually improved design solutions while considering interdependencies to other design objectives one by one [27–29]. Knowledge about quantifiable interdependencies allows for the computation of solution spaces which consider all design objectives at one time and thereby compute a set of optimal solutions for a multidimensional design task. Coupling of parameter management to this approach allows for the flow of parameters into the computation of solution spaces. Parameters would then function as variables in the multidimensional optimization problem. With parameters each possessing their own permissible ranges of target, their values can be adjusted in a way that they allow an optimal solution together with parameters in other design tasks.

5 Validation of the Approach

Upon the creation of the prototype the approach was validated in the architecture development process. As described by [14], the support of missing transparency in an extensive architecture development was enforced by coupling CAD data to the parameter repository. A product series spanning vehicle architecture enables common part strategies by standardizing certain characteristics for a broad range of vehicles in different product series [30, 31]. This however requires predevelopment to keep standardized characteristics steady over many years and products which are developed in different departments. Deviations from architecture specifications are not properly communicated and can thus not be prevented. Benefits for the designers are retrieved as the approach traces changes of Parameters directly from the PDM and CAD System. A deviation from architecture specifications is hence directly reported and allows instant action. The benefit is clearly confirmed by the designers and reflected in the adoption of the approach from pilot users.

However, it has to be taking into consideration that the level of benefit from such a holistic system model varies. Benefits are gained in particular for those who are responsible for comprehensive aspects like the departments of predevelopment and full vehicle development. The motivation to supply data into a holistic system model for designers, who don't directly profit from it, remains one of the key challenges for every SE approach. The effort to supply information from partial models into a holistic model is therefore kept at an absolute minimum and has repeatedly been confirmed by information-supplying designers.

Another benefit for designers is the targeted communication of changes and possible impacts of changes. The need for designers to widely spread information via mails and documents to communicate changes can thus be reduced significantly. Furthermore, designers working in different partial models can interact more easily as parameters are neutral towards formats and processes.

Difficulties in the implementation and roll-out of the approach can be noted in process-specific handling of data, which neutralizes information content and requires additional adaption.

6 Outline

The paper discussed a novel approach in SE which aims for transparency and consistency of engineering data and has been validated in a highly complex development environment in the automotive industry. The approach is considered a bottom-up approach as is facilitates the implicit reproduction of existing EOs and EORs by bringing together parameters as smallest EOs with a homogeneous format. Furthermore, the approach allows for the linking of parameters in active structures to model interdependencies. With the underlying background information about the origin of the parameter, the approach allows for traceability apart from an explicitly modeled system model. Partial models already exist in product development and are represented by various Engineering Design tools. Their existence is thus not redundantly modeled within a system model. The approach was implemented as a prototype, successively validated and enhanced. It is currently adopted by various engineering departments as is allows for a holistic application in any discipline. Based on the presented approach, intentions to merge redundantly managed databases across product development are currently enforced by the Engineering IT, as it offers the potential of reducing inconsistencies and maintenance efforts of single side solutions.

With further adoption from more engineering departments, EOs will be brought together forming a bigger repository of data. Through the continuous and increasing crosslinking of parameters the implementation of the approach offers a powerful tool to support communication about changes and will thus reduce the perceivable complexity for participating users.

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Optimal Assembly Sequence Planning Towards Design for Assembly Using Simulated Annealing Technique

G. Bala Murali, B.B.V.L. Deepak, M.V.A. Raju Bahubalendruni and B.B. Biswal

Abstract Recent development in Design For Assembly (DFA) has motivated product designers towards minimizing the number of parts in a product so as to reduce the assembly efforts. Assembly sequence for the reduced number of parts with the modified part topologies may not be possible. Determination of optimal assembly sequence for the modified product by performing assembly sequence planning is highly time consuming and it demands high skilled user intervention. In order to achieve the optimum feasible assembly sequence with less computational time, researchers in the past proposed many methods. In this paper, an attempt is made to generate optimal feasible assembly sequences using DFA concept by considering all the assembly sequence testing criteria from obtained feasible assembly sequences. A simulated annealing technique is used to generate all sets of feasible assembly sequences. The obtained sequences consist n − 1 levels during assembly, which will be reduced by DFA concept. DFA uses functionality of the assembled parts, material of the assembled parts and liaison data of the parts to reduce the number of levels of the assembly by considering the directional changes as the objective function.

Keywords Design for assembly · Assembly sequence planning · Simulated annealing · Multi-objective optimization

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1 Introduction

DFA plays a key role in manufacturing industry to minimize assembly cost by optimizing the assembly process and to reduce the number of parts during assembly [1, 2]. DFA simplifies the design and reduces the number of parts in the assembly because the process of assembly is one of the major cost contributors in the manufacturing industry. In order to overcome this problem, researchers have worked towards implementation of knowledge based methods. As these methods consume lot of computational time due to huge search space for products with more number of parts [3–5], researchers focused on Artificial Intelligence (AI) techniques to avoid huge search space problem. Though these approaches are successful to certain extent the major limitation with these approaches is local optimal solution.

In most of the AI techniques, the input supplied to the process is generated manually, which is also time consuming. Hence computer aided methods have been evolved to extract such information through various Computer Aided Design (CAD) exchanging data formats [6–11]. Graphical methods are used for testing the geometrical feasibility in the early stages. These methods, advanced CAD based assembly attribute extraction is used to reduce the human error and minimize the computational time.

Besides liaison and geometrical feasibility predicates, stability and mechanical feasibility are two essential assembly predicates to yield the appropriate results. The computer aided extraction of stability was discussed by several researchers [12–14]. Some AI techniques applied to achieve optimal assembly sequences are listed in Table 1.

In this paper a SAT algorithm along with CAD integration for extraction of liaison data, stability feasibility, mechanical feasibility and geometrical feasibility is used to achieve all set of feasible assembly sequences. This algorithm is mostly used compared to other techniques because the solution does not fall under local optima during obtaining an optimal assembly sequence.

DFA concept is applied to obtain the optimum feasible assembly sequence by reducing the number of levels of the assembly.

2 Assembly Sequence Validation and Assembly Information Extraction

Generally, required input data which generates manually for implementing the algorithm to obtain optimize feasible assembly sequence is a time consuming process. This section details about the methods to extract liaison matrix, interference matrices, stability matrix and mechanical feasibility matrix from CAD environment. Computer Aided Three-dimensional Interactive Application Version-5 (CATIA V5R17) is used as CAD tool and programming is done in VB (Visual

Table 1 Assembly predicates and limitations from the cited research literature

Reference	Algorithm	Objective function (Minimization of)	Predicate criteria considered	Limitations
Smith et al. [15]	GA	Computational time	Liaison, Geometrical and Stability criteria are considered	Complexity in achieving global optima solution
Chen et al. [16]		Energy	Liaison and Geometrical criteria are considered	Local optimum solution
Chang et al. [17]	AIS	Assembly cost	Liaison and Geometrical criteria are considered	Complexity in achieving global optima solution
Deepak et al. [18]		Computational time	Liaison, Geometrical and Stability criteria are considered	Complexity in achieving global optima solution
Biswal et al. [19]		Directional changes	Liaison and Geometrical criteria are considered	Complexity in achieving global optima solution
Bahubalendruni et al. [20]	PSO	Directional changes	Liaison, Geometrical and Stability criteria are considered	Local optimum solution
Milner et al. [21]	SAT	Assembly cost	Liaison and Geometrical criteria are considered	Complexity in achieving global optima solution
Motavalli [22]		Computational time	Liaison and Geometrical criteria are considered	High execution time
Hong [23, 24]		Energy	Liaison, Geometrical and Stability criteria are considered	Complexity in achieving global optima solution
Nayak et al. [25]		Assembly directional changes	Liaison and Geometrical criteria are considered	High execution time

Note PSO Particle Swarm Optimization, *GA* Genetic Algorithm, *AIS* Artificial Immune System, *SAT* Simulated Annealing Technique

Basic) scripting to extract the outcomes. A gear assembly structure consists of 9 parts is considered in this investigation as shown in the Fig. 1. The directions for assembly are given as 1:+x, 2:−x, 3:+y, 4:−y, 5:+z, 6:−z.

2.1 Liaison Extraction

Liaison data gives the information about all possible mating surfaces of an assembly. Weights 0 & 1 are assigned for the no mating and mating parts

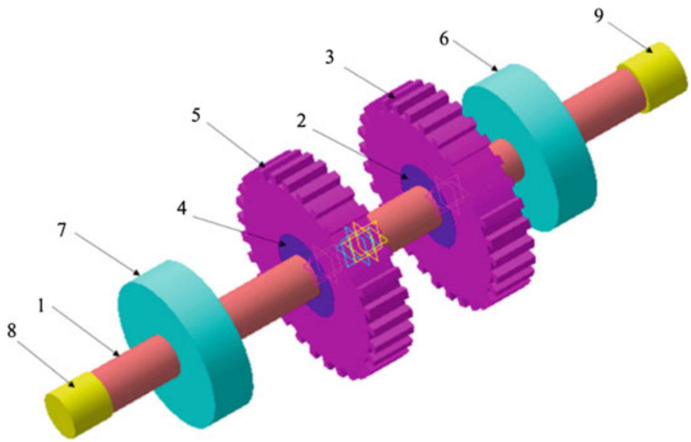

Fig. 1 A hypothetical assembly. *1*—Shaft, *2* & *4*—Bearings, *3* & *5*—Gears, *6* & *7*—Rotating discs, *8* & *9*—Nuts

respectively. Since in the current investigation a nine-part assembly structure has been considered, a matrix of size 9 × 9 is extracted from the CAD tool-CATIA (V5R17). The obtained liaison matrix for the considered nine-part mechanical assembly structure is as follows:

$$\text{Liaison matrix} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array} \begin{array}{c} \begin{array}{ccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \end{array} \\ \begin{bmatrix} 0 & 1 & 0 & 1 & 0 & 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

2.2 Interference Matrix

The interference matrices provide the information about all possible interferences of the components during the assembly operations in the real environment. Weights 0 & 1 are assigned for the interference and no interference respectively. Part movements during the assembly process are in six directions. Six interference matrices corresponding to each direction are obtained. Six matrices of 9 × 9 size are extracted from the CAD tool-CATIA (V5R17).

The obtained interference matrices for the considered nine-part mechanical assembly structure in +X and −X directions are obtained as follows:

$$+X \quad \begin{array}{cc} & \begin{array}{ccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array} & \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix} \end{array} \qquad -X \quad \begin{array}{cc} & \begin{array}{ccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array} & \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix} \end{array}$$

The interference matrices along the positive and negative Y axes are obtained as follows:

$$+Y \quad \begin{array}{cc} & \begin{array}{ccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array} & \begin{bmatrix} 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 1 & 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix} \end{array} \qquad -Y \quad \begin{array}{cc} & \begin{array}{ccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array} & \begin{bmatrix} 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 0 & 1 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 1 & 0 & 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

The interference matrices along the positive and negative Z axes are obtained as follows:

$$+Z \quad \begin{array}{cc} & \begin{array}{ccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array} & \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix} \end{array} \qquad -Z \quad \begin{array}{cc} & \begin{array}{ccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \end{array} \\ \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array} & \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix} \end{array}$$

2.3 Stability Matrix

Stability matrix gives the information about the stability of the parts during assembly. The matrix represents the information about the parts which are incomplete stable, partial stable and complete stable. In this study three weights, 0, 1 & 2 have been allotted for incomplete stable, partial stable and complete stable assemblies respectively. A matrix of size 9×9 is extracted from the CAD tool-CATIA (V5R17).

$$\text{Combined stability matrix} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array} \begin{array}{c} \begin{array}{ccccccccc} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \end{array} \\ \begin{bmatrix} 0 & 1 & 0 & 1 & 0 & 1 & 1 & 2 & 2 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

2.4 Mechanical Feasibility Matrix

Mechanical feasibility is true for an assembly sequence when the assembly tools can perform the specified assembly operation without any collision; hence it is dependent on tools and methods used to perform the assembly operations. The hard connectors trajectory constraints can be represented through a three dimensional matrix of $n \times n \times n$. The third dimension represents, whether the part represented in it offers any interference to place hard connections between parts represented in first two dimensions. Since, there is no requirement of the mechanical feasibility matrix because absence of physical connectors.

In this paper, directional changes have been considered as the objective function to reduce the cost of the assembly.

The directional change is represented as (D_C).

3 Simulated Annealing Technique

Simulated Annealing Technique is taken from the mechanical annealing process. In this process, metal is heated to higher temperatures (i.e. recrystallization temperature) and allow the metal to cool slowly at room temperature so that mechanical properties of the metal increases.

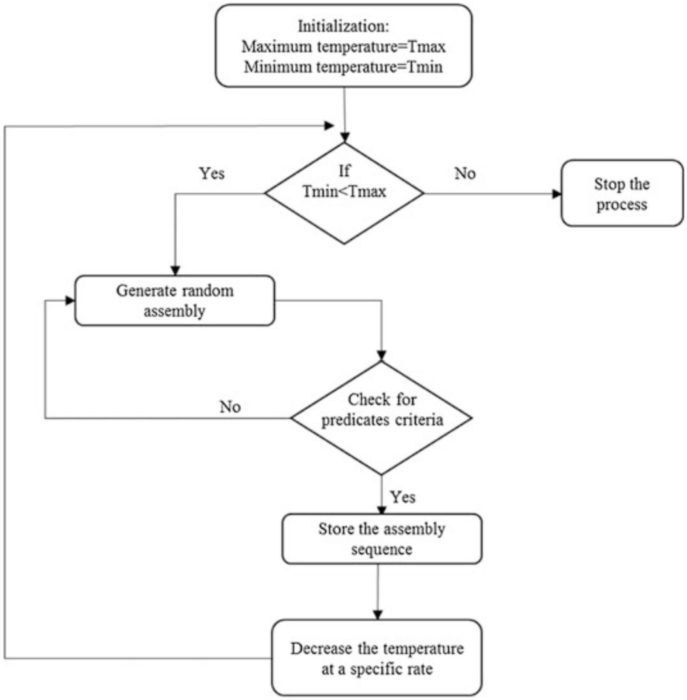

Fig. 2 Detailed flow chart of the SAT for all set of feasible assembly sequences

Simulated annealing technique is used to generate all set of feasible assembly sequences by testing all the predicate criteria. In SAT, a random assembly sequence is generated based on the higher temperature and lower temperature limits. The generated assembly sequence will be tested for liaison predicate, geometrical feasibility predicate, stability predicate and mechanical feasibility predicate respectively. Lowering the temperature by a specific rate, run the iterations until the condition fails for generating all set of feasible assembly sequences. The detailed flow chart of simulated annealing technique is as follows in Fig. 2.

The temperature is decreased at a specific rate by the equation

$$t = e^{x} \tag{1}$$

$$x = (fp - fq)/T_{max} \tag{2}$$

where fp is the fitness function of P.

fq is the fitness function of Q & T_{max} is maximum temperature.

4 DFA Methodology to Reduce the Levels in the Assembly Sequence

DFA methodology is applied to reduce the levels in the assembly sequences by considering the directional changes as objective function. In this methodology three criteria functionality, liaison predicate and material of the part have been used to test the assembly sequence for achieving the low levels of the assembly sequence. As the levels of the assembly sequence is reduced, cost of the assembly is reduced.

In the assembly sequence, to merge two parts as a single component initially they should have contact and same direction of sequence. After satisfying these two criteria, the two set parts have to check for the material and functionality. During merging of parts, the functionality of the parts should not disturb and should made of same material. The detailed methodology is explained using flow chart in Fig. 3 is as follows.

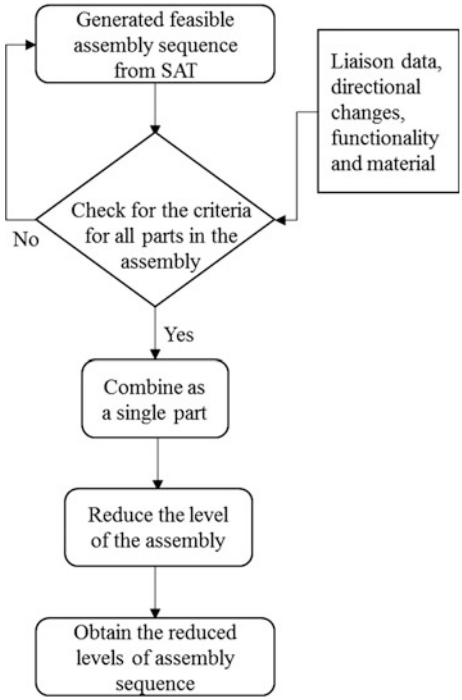

Fig. 3 Detailed flow chart of the DFA methodology

5 Results and Discussions

The developed methodology has been implemented on a hypothetical gear assembly for obtaining an optimum feasible assembly sequences. This assembly consists of nine parts (parts labelled with 1–9) as shown in Fig. 1 and the possible sequences are 9-factorial. From the possible assembly sequences, SAT generates 352 number of feasible assembly sequences after 98 iterations. In the present work, a set of ten assembly sequences are considered for DFA concept to reduce the number of levels for the assembly sequence.

Assumptions:

1. Part 2 & 3 are made of same material
2. Part 2 doesn't move relative to the part 3.

Generally, the nine-part assembly consist of $n - 1$ levels (i.e. 8 levels). The set of ten assembly sequences are considered as follows in Table 2.

In this paper, analysis has been performed for two cases of industrial settings. A set of ten assembly sequences are considered for DFA analysis.

Case-1: Grouping the parts in the ten set assembly by considering the liaison predicate and directional changes.

In Table 3 (2,3) and (4,5) represents one set of parts and (4-4) represents one set of directional changes. The optimum levels obtained for the assembly sequences are six.

Case-2: Checking the functionality and material of the grouped parts along with liaison predicate and directional changes.

In Table 4 (2,3) represents one set of parts and (4-4) represents one set of directions. The optimum levels obtained for the assembly sequences by considering functionality and material of the grouped parts along with liaison predicate and directional changes are seven.

Table 2 A set of ten feasible assembly sequences from the 352 number of feasible assembly sequences

S. no	Assembly sequence	Direction	Direction changes
1	1-2-3-4-5-6-7-9-8	4-4-4-4-4-3-4-3-4	4
2	1-2-3-4-6-5-7-9-8	4-4-4-4-3-4-4-3-4	4
3	1-2-3-4-6-5-9-7-8	4-4-4-4-3-4-3-4-4	4
4	1-2-3-4-5-6-7-8-9	4-4-4-4-4-3-4-4-3	3
5	1-2-3-4-5-7-6-8-9	4-4-4-4-3-4-4-4-3	3
6	1-2-3-4-6-5-7-8-9	4-4-4-4-4-3-4-3-4	3
7	1-2-3-4-5-6-9-7-8	4-4-4-4-4-3-3-4-4	2
8	1-2-3-4-5-7-6-9-8	4-4-4-4-4-4-3-3-4	2
9	1-2-3-6-4-5-7-8-9	3-3-3-3-4-4-4-4-3	2
10	1-2-3-4-5-7-8-6-9	4-4-4-4-4-4-4-3-3	1

Table 3 Optimum feasible assembly sequences for the considered ten sequences

S. no	Assembly sequence	Direction	Levels
1	1-(2-3)-(4-5)-6-7-9-8	4-(4-4)-(4-4)-3-4-3-4	6
2	1-(2-3)-(4-5)-6-7-8-9	4-(4-4)-(4-4)-3-4-4-3	6
3	1-(2-3)-(4-5)-7-6-8-9	4-(4-4)-(4-4)-3-4-3-4	6
4	1-(2-3)-(4-5)-6-9-7-8	4-(4-4)-(4-4)-3-3-4-4	6
5	1-(2-3)-(4-5)-7-6-9-8	4-(4-4)-(4-4)-4-3-3-4	6
6	1-(2-3)-6-(4-5)-7-8-9	3-(3-3)-3-(4-4)-4-4-3	6
7	1-(2-3)-(4-5)-7-8-6-9	4-(4-4)-(4-4)-4-4-3-3	6

Table 4 Optimum feasible assembly sequences

S. no	Assembly sequence	Direction	Levels
1	1-(2-3)-4-5-6-7-9-8	4-(4-4)-4-4-3-4-3-4	7
2	1-(2-3)-4-6-5-7-9-8	4-(4-4)-4-3-4-4-3-4	7
3	1-(2-3)-4-6-5-9-7-8	4-(4-4)-4-3-4-3-4-4	7
4	1-(2-3)-4-5-6-7-8-9	4-(4-4)-4-4-3-4-4-3	7
5	1-(2-3)-4-5-7-6-8-9	4-(4-4)-4-3-4-4-4-3	7
6	1-(2-3)-4-6-5-7-8-9	4-(4-4)-4-4-3-4-3-4	7
7	1-(2-3)-4-5-6-9-7-8	4-(4-4)-4-4-3-3-4-4	7
8	1-(2-3)-4-5-7-6-9-8	4-(4-4)-4-4-4-3-3-4	7
9	1-(2-3)-6-4-5-7-8-9	3-(3-3)-3-4-4-4-4-3	7
10	1-(2-3)-4-5-7-8-6-9	4-(4-4)-4-4-4-4-3-3	7

6 Conclusion

Simulated Annealing Technique algorithm with CAD assistance along with DFA concept has been introduced in this research work to obtain optimal feasible assembly sequence for a given product. The developed methodology has been explained by considering a hypothetical gear assembly. Two cases have been considered for reducing the number of levels of the assembly sequence. In the former case, liaison predicate and directional changes have been considered for grouping the parts as single set, which reduces the 9 levels of assembly sequence to 6 levels of assembly sequence. In the later case the grouped parts are checked for the functionality and material, which yields the final assembly sequence of 7 levels. The methodology is found to be successful in obtaining the optimal feasible assembly sequences by considering the functionality, material properties, liaison predicate and geometrical feasibility. As a future work, the developed algorithm can be applied effectively for larger assemblies.

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Technological Assistance for Fall Among Aging Population: A Review

Nilakshi Yein and Swati Pal

Abstract Recent studies report that globally unintentional fall among aging population is one of the most costly and complex healthcare issue. There is a possibility that elderly might fall when they are alone and no one is there to help them. In such conditions if the fall remained unnoticed for a long duration its impact can be fatal. To avoid any severe after- fall damage there are various technology based solutions available which can reduce such issues. These include fall detection system which can be Video Based, Environmental Sensor Based, Wearable and Mixed Approach, i.e., combination of two or more techniques. It assists elderly and their caregivers through detecting falls and calling for help as soon as falls occur via triggering notification alarms. This paper gives a review for technologies related to fall detection for aging people and their caregivers along with suggestions for future research directions. Cost effectiveness, privacy, perceived usefulness and ease of technology used are the important factors for a successful technology intervention.

Keywords Elderly fall · Fall detection system · Smart phone based system · Wearable device

1 Introduction

Proportions of elderly are globally increasing due to joint impact of declining fertility rate, increased longevity along with improved healthcare. Among this growing aging population unintentional fall is one of the most costly and complex health issues across the world [1]. The main consequences related to fall are injuries and physical impairment, hospital admission and fall treatment cost, fear of further falls, distress and embarrassment, loss of independence for mobility [2]. It can be

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life-threatening if after fall the person is not promptly rescued. In this era technology is expanding at an unprecedented rate throughout the globe and coupling the technology with elderly service products i.e., fall, or/and elderly fall monitoring system can be very effective to make their life more independent and secured.

From literature it is clear that to improve the comfort and protect elderly people's life; telemonitoring, gerontechnology appears to be a future solution [3]. Using computers and information technologies such as smart phones elderly people can get immediate access to a wide range of information services and sources that might reduce post fall problems faced by elderly. Such product or system can differentiate falls and active daily life activities accurately, and can send timely message or contact ambulance or trigger alarm if needed. Fall detection technology can be comprised of e.g., cameras, sensors-wearable or mounted on a particular location, tiny computer with sensing, processing, storage and communication capabilities. Wearable devices can also include interfaces and with actuation capabilities and so it can provide feedback response to the user and contact the family members and medical support [2, 4–8]. All such services and products have both positive and negative impact on elderly.

The elderly population in India will increase from 7.4% in 2011 to 17% in 2051 as reported by Social Statistics Division, Central Statistics Office [9, 10]. This is the high time to think of such services considering this growing Indian elderly population. Such products are already in use in other developed countries like Spain, Hong-Kong, United States etc. Earlier studies have mentioned that acceptance in not an issue if elderly people understand the advantages and will be able to control the technology to minimise the potential disadvantages, [11–13, 3]. But cost factor was mentioned as a critical aspect influencing behavior intention and self-satisfaction and facilitating conditions [14].

This is a crucial point in Indian context where 80% of the total elderly population staying in the rural areas and a large percentage of 30% of them are below poverty line [15], and up to 65% of elderly are economically dependent on others, especially widowed women [16]. To overcome the inhibition for technology based products from Indian elderly is also an important point to focus. In this regard, there is a need to revisit the existing techniques used and to redefine the technologies used for fall detection so that we can bridge the gap and can provide cognitive and social support to the aging population as well as their family members with advanced technology. In this paper, we review on the available literature related to technological solutions for elderly fall problem. This study also included their varieties, mountings, methods of fall detection, and their perspective in the elderly people and related research.

2 Methodology

For this article an extensive research on publications was conducted to ensure the inclusion of as many relevant records and studies that have described the technological solutions specifically related to elderly fall problem. Searches on multiple

Table 1 Inclusion and exclusion criteria for the review

Sl. no.	Inclusion criteria	Exclusion criteria
1	Topic: Technological solution related to fall	Studies mainly for children or youth
2	Studies mainly focuses on elderly population (60 years or above), but sometimes participants are may be below 60 years (only for participatory purpose)	Studies mainly based on records of persons under age 60 years
3	Technology related interventions: devices, system etc.	Records of medical, nutritional. Medicine effect, cognition, surgical interventions, yoga programs, environmental hazard modification
4	Languages English	Low technology devices (canes, walkers, phones without any technology supported measures for fall, e.g., apps)

electronic databases, internet searches, as well as manual checks are done published in English language. For this paper fall among age group of 60 years and above are considered (defined as "Senior citizen" or "Elderly" by "National Policy on Older persons' in January", Government of India, 1999) [17]. The keywords used for exploring the literature were fall interventions in elderly, gerontechnology, elderly fall and technology, assistive technology, alarm, and home monitoring system (alone or in combination). At first, number of identified publications are 70 at least on the basis of abstract reading. Then based on the full text articles for final selection 52 papers were selected. Finally, 28 publications were included in reference excluding papers containing similar findings and approach for the experiment (Table 1).

3 Outcome

Fall detection or monitoring system can follow different sampling techniques to identify elderly fall and to differentiate elderly fall with their daily life activities. It can be classified via different signal sampling techniques. Fall can be detected via Environmental Sensor Technology (e.g., Doppler radar sensor, pressure sensor etc.), Video Technology (e.g., camera), Wearable Sensor Technology (e.g., accelerometer, gyroscope etc.), Mixed Approach (combination of all/any of these) [18, 19, 20, 21, 22]. Video based fall detectors have weak script of limited detection range and have risk for disclosure of personal privacy. Environmental sensor based fall detectors can be mounted on different locations, such as, ground, ceiling and floor and it has little accuracy but the privacy problem can be overcome. Wearable sensor based fall detectors can be mounted on glasses, hats, shoes, clothes etc. In case of mixed approach multi sensors and two or more methods are used to detect the fall. It is found that wearable sensor based fall detection system is more suitable as there will be no limitations of the detection location [18].

On the basis environmental sensor, wearable technology, video fed technology and mixed approach method e.g., accelerometer, Arduino board, sensors etc., different studies have been done. Studies based on accelerometers have been done by Kulkarni and Basu [19], Gibson et al. [22], Sudarshan et al. [2]. Gibson et al. [22], studied multiple classifier based fall detection using an accelerometer. For remote health monitoring the diagnostic system was implemented on a wearable Shimmer device. Here if fall occurred, Base station receiver triggers the alarm with a source like a designated carer, or a hospital and gets medical aid response. Saborowski et al. [23] conducted a series of qualitative interviews with care professionals or advise on technical aids for the elderly. This study indicated different disadvantages, such as, technology malfunction, difficulties in using assistive technology, lack of financial resources, privacy concern, lack of competence or training etc. Acceptance of such technology in different studies is also done. Plaza et al. [11], confirmed that use of mobile applications have a positive impact in aging population. Another study by Ma et al. [14] has mentioned that non-widowed, younger people with higher education or people with better economic condition related to family support or salary were more likely to use smart phone. Study mentioned that cost was another critical factor influencing behavior intention and self-satisfaction. Perceived usefulness and perceived ease of use of the technology are key influencing factors to facilitate the condition.

Huang et al. [4] discussed about a stairway falling detection prototype that has been designed to warn when elderly people fall. Here Arduino board (Arduino Mega) was used as central physical device to collect/send information from/to deployed sensors in a stairs environment. Pressure Mats were used as the major signal inputs for recognizing the stair on which someone was standing. A pressure mat on every stair was put and then the whole stairway was covered with carpet to make the mats invisible to users. For this prototype, a door bell was used to raise alarms. For cancelling the false alarms two buttons were fixed on the wall at the two ends of the stairs. It was only a prototype; evaluation of the study was not done. Few other findings from different studies are described in the Table 2.

The basic schematic representation of the unit operations associated with such methods for obtaining and processing of situational data using sensors/cameras is shown in Fig. 1. For example, if elderly fall is detected by a wearable/camera, data can be processed in the wearable/using segmentation algorithm to recognize

Table 2 Description of studies found in literature

Sl. no.	Aim	Study done	Country	Intervention	Study design, participants	Findings/Limitation/Comments
1	To detect fall by using, microprocessor, accelerometer and wireless communication technology	Ye et al. [18]	China	Fall detection algorithm	Participants: 10 elderly (age: 60 years and above) Experiment design: 50 sets of trials Algorithm analyzed: Different actions with different threshold ranges of energy, displacement, angle for auxiliary criterion, and temporal speed	With low-intensity daily activities: Identification of the falling actions very efficient With high activity intensity daily activities: Identification of falling actions were relatively difficult Some false judgments were showed during slipping action, fall action without lying down
2	To evaluate low-complexity fall using accelerometers attached at the wrist, waist, head	Kangas et al. [25]	Finland	Fall detection algorithm	Participants: One female (38 years) and two males (42 and 48 years) Experiment design: Each subjects performed three directional intentional falls towards a mattress of thickness 20 cm	Tri-axial accelerometer worn at the waist or head: Fall detection was efficient with simple threshold-based algorithms with specificity of 100% and sensitivity of 97–98% Waist worn accelerometer: Fall detection was optimal as algorithm recognized the posture and after fall impact Limitations: With head worn device: Usability and acceptance With wrist worn device: It did not found to be an applicable site
3	To detect a fall using Real Time Locating System (RTLS)	Mary Elizabeth Bowen, et al. [26]	USA	Real-Time Locating Systems (RTLS)	Participant: One female (30 years) Experiment design: 2 phased trial. Phase 1: used mannequin Phase 2: used human subject	Mannequin falls: 89% Human falls: 80% of accurately identified

(continued)

Table 2 (continued)

Sl. no.	Aim	Study done	Country	Intervention	Study design, participants	Findings/Limitation/Comments
4	To reduce the problem of false alarms	Abbate et al. [27]	Italy	Personal Emergency Response System (PERS)	Participant: Two female (33, 60 years) Five male (20–67 years) Experiment design: 86 fall- like events:14 Jumping/Running/Walking, 44 Falls, 14 Sitting/Lying and 14 Hitting the sensor (unintentional)	Monitors: Movements of patients, recognizes a fall, and automatically sends a request for help to the caregivers Specificity: Distinguished false alarms from real fall by 100%
5	To develop a fall detection system based on a mobile application with a wearable sensor unit, and a website	Freitas et al. [28]	Portugal	Smart phone-based fall detection system	Participant: One person (age not mentioned) Experiment design: Performed forward, backward and side falls. Falls from a chair, running, walking, standing and sitting that is, activities of daily living (ADL)	If fall happens a pop-up window appears in the screen within 30 s No false positives were detected
6	To propose an indoor environments based automatic fall detection method for preserving privacy	Gasparrini et al. [20]	Italy	Depth-based fall detection system	Experiment design: Depth sensor, mounted on-ceiling to analysis of depth frames. Camera was used to monitor the environment and Ad Hoc segmentation algorithm is used to detect fall	Results showed the effectiveness even in complex scenario
7	To propose a fall detection system using a kinect sensor	Yang et al. [21]	China	Depth-based Fall Detection	Experiment design: Kinect sensor recorded the depth video sequence. The depth images are converted to disparity map, which is obtained by the horizontal and vertical projection histogram statistics	It showed this proposed method can detect fall incidents effectively

(continued)

Table 2 (continued)

Sl. no.	Aim	Study done	Country	Intervention	Study design, participants	Findings/Limitation/Comments
8	To detect fall using two pulse-Doppler Range Control Radars (RCR)	Liu et al. [24]	USA	Doppler radar-based fall detection system	Experiment design: 450 samples are taken in two classes: 'falls' and 'non-falls' More than one sensor is used to detect falls in any direction	Results showed: Falls: 109 Non-fall: 341

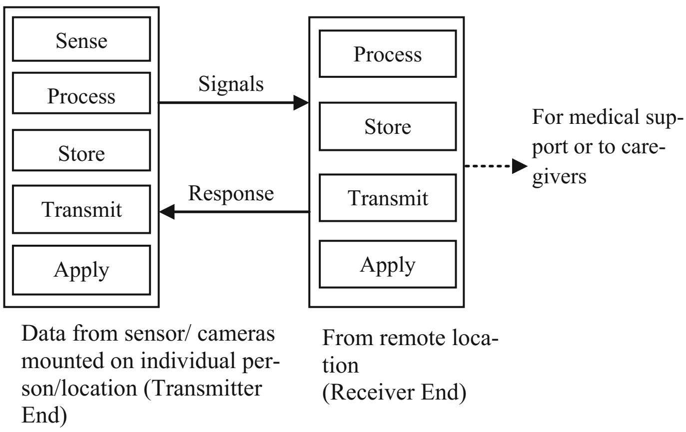

Fig. 1 Schematic representation of the unit operations associated with obtaining and processing of situational data using sensors/cameras

all the elements captured in the accidental scene; and an alert can be generated. Simultaneously, it may be transmitted to a remote location for confirmatory testing and the results- along with any appropriate response (i.e., elderly fall is detected, immediate help required) and can be communicated to the user/family and friends or hospital in real-time to potentially save a life.

4 Discussion

Fall is a critical problem in elderly affecting their healthy life style. Care givers and family members are constantly worried about elderly fall and after- fall hazards. Using fall detection technology after- fall rescued duration can be minimised and eventually can provide an active and healthy life in old age.

Different ways of fall detection are available with the help of which fall can be detected and immediate help can be provided to the person. Though such technologies have positive as well as negative impact, but the negative impact of technology intervention can be reduced [12, 23]. As in case of camera, segmentation algorithm is used to recognize all the elements captured in the accidental scene; a constant monitoring of day- to-day life activities have to be captured. Privacy issue is an important factor which hinders the acceptance of such technology, specially using camera/video technology, among the elderly. However literature suggested that 87% of respondents are willing to give up their privacy to get help during fall and emergency situation [12].

Computer Vision based approaches are very complex and it is difficult to obtain a system that can work under real life conditions. Such video based technology will monitor each daily activity of elderly, so privacy is also a concern behind the elderly people's acceptance of such method. Techniques like Depth Based, Doppler Radar Based, Pressure Mat [20, 24, 4] etc. can be used as these techniques will not disclose any privacy and if these are coupled with Smartphone, Arduino board, zigbee system etc. repeated warning messages can be send to care givers and hospitals. In case of Pressure mats the setting of time interval between two steps is also an important issue which may affect usability of the system. In contrary to this technology, body-worn accelerometers are very much useful as it will take care both indoor and outdoor. In case of wearable gadgets particular location of the body where to wear is an issue to consider. A waist worn accelerometer, using after-fall posture and impact recognizing algorithm might be optimal for fall detection. Use of mobile applications for older people during emergency conditions had a positive impact [11]. To improve such systems in real life situations probably it is needed to include various modes in order to support the multi-use environment such as indoor, outdoor environment in a rural to urban area of a developing country like India.

Factors like: economic condition, education level, cultural behaviour, and awareness for technology are varying among countries. Thus, same design guidelines can't solve a particular problem in every country. In developed countries the scenario of elderly care, acceptance of such technology, economic condition, culture, education, design perspective etc. are different than India. From user perspective facilitating conditions and self-satisfaction [14] were proved to be important factors for influencing perceived ease and perceived usefulness of technology use. Cost was also considered as a critical factor to influence behavior intention for using technology like smart phone [14]. Over years in India the prevalence of elderly fall is increasing from 14 to 53% [16]. To fulfill the context specific need of the end user, there is a need to explore the feasibility, acceptance, perceived usefulness and perceived ease of use of the technology intervention in India, in a cost effective way. Further research in this area will certainly help the Indian elderly to lead an active life with confidence by ensuring their safety.

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Designing Static Visual Narratives as Prompts for Practising Creative Writing

Saurabh Singanapalli

Abstract Language teachers are increasingly using image prompts in their composition classes, in keeping with the increasingly visual culture that learners are exposed to. However, there seem to be no specific guidelines or frameworks towards designing images for use as writing prompts, nor any reasoning as to why certain images might work best for this purpose. This paper tries to address this, and looks specifically at image prompts and how they are used by institutions and practitioners who try to teach creative writing. It builds on two earlier studies about images as narrative prompts, which are 'Prompting Narratives: The Kaavad Tradition' (IIC Quarterly Autumn, [7]) and 'Eliciting stories: Exploring images as prompts' (He Kupu J **3**(5):92–100, [8]). Based on the above studies, as well as those of image prompts currently used in Indian schools, this paper suggests that static visual narratives are well-suited for use as prompts for practising narrative writing, and attempts to define a number of criteria that designers may want to keep in mind when trying to design image prompts for the writing classroom.

Keywords Materials design for education · Static visual narratives · Teaching writing · Images and words · Prompts

1 Introduction

Presently, in language classrooms, writing is taught through a variety of methods, but a mandatory element of any writing class is the part where learners have to produce or create their own responses. Since writing is defined as a language skill,

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getting enough practice in that skill will always be an important component of its acquisition. In most writing classes, this practice is done by asking the students to write responses on a variety of topics, usually by aiding them with what is called a 'prompt'. The importance of writing prompts to the process of teaching writing in general, and creative writing in particular, cannot be overstated.

It thus becomes imperative that these writing prompts be selected with due care and attention to detail. In the case of text-only prompts, there have been attempts made at defining criteria that may be used for selection or to assess the suitability of such prompts; however, there seem to be no specific guidelines or frameworks towards designing images for use as writing prompts. This paper is an initial step towards trying to address this. Following a study and analysis of such image prompts, this paper suggests that static visual narratives, specifically those with multiple, non-sequenced visuals, may fit the purpose as prompts for practising narrative writing, and describes a number of criteria that designers may want to keep in mind when trying to design writing prompts. It begins by defining and giving examples of writing prompts and static visual narratives, and then attempts to understand different kinds of image prompts currently in use in Indian schools in recent years. It also looks at some similar recent research in this area by looking at previous studies, including two papers that discuss eliciting narratives through the use of image prompts [7, 8]. Finally, it gives two examples of static visual narrative images which may be used in the classroom to elicit writing.

This paper is part of a larger study that aims to understand and improve image prompts used in the writing classroom. Materials designers, especially those who are looking to prepare course books or classroom materials in the field of general education or even design education, may find its results to be of particular interest, as it seeks to provide a rationale for selecting and designing images for use in a specific teaching-learning scenario.

2 Definitions

2.1 Writing Prompts

In this paper, writing prompts may be defined as any portion of text, images, or any other media that is used to elicit written responses from learners. A text-only writing prompt is one that uses only words to define the task and its context; a text prompt with image support is a prompt that uses mainly words to define the task and its context, but uses an image to make the context richer; an image-only prompt would be one that uses solely an image to provide context for the learner (words may be used to give instructions, but do not attempt to explain, describe, or add to the image).

2.2 Static Visual Narratives

The definition of static visual narratives is partially taken from Pimenta and Poovaiah [6] and defined as "A visual narrative where the visual is fixed on the surface of the medium and is interpreted by the viewer at their own pace and in their choice of sequence."

2.3 Creative Writing

In this paper, the term "creative writing" is understood to be synonymous with "narrative writing", that is, the production of a narrative like a story or an imaginative essay. The scope is restricted to prose narratives only.

3 Current Types of Writing Prompts

A brief survey of materials presently available shows that a wide variety of prompts are in use, as detailed below, however, amongst them, text-only prompts appear to be most common. Let us take a quick look at how each of these prompts work.

3.1 Low-Context Text-Only Prompts

These are prompts that use only text, but, in addition, the prompts are sparse and may consist only of the most basic information or instruction for the learner to begin writing. For example, 'Write an essay on your best friend' is a low-context prompt.

3.2 High-Context Text-Only Prompts

These are prompts that use only text, but give a lot more information to the learner as assistance for creating their composition or narrative. An example of such a prompt, with some more context, is given below:

> Imagine that you have a magic carpet, and can travel wherever you want. One day, you travel to a mysterious island where everyone owns magic carpets. But they have a limitation: they can only fly around the island, and don't know that there are other lands outside the island. Imagine how you will describe your home, your family and your country to the people of this island.

This is just an example of how more detailed contexts are possible with text-only prompts; richer contexts are certainly possible and are often used to not only assist the writer but to also give them a base to produce a more detailed response.

3.3 Low-Context Text Prompts with Image Support

These are text prompts that use images for support; however, they have very little contextual information to aid the learner. It may be presumed that some of this contextual information may come from the image, if the image is appropriately selected. However, sometimes, the image itself may not have enough information to provide a richer context for the learner, as shown in the example in Fig. 1.

3.4 High-Context Text Prompts with Image Support

These prompts also use images to support text, but provide a greater context for the learner (Fig. 2). However, it is seen that in current materials, most of this context is provided via the words, while the image is used mostly as supporting material. Sometimes, however, the learner may be asked specifically to describe the image, or to use elements in the image to answer specific questions leading to the construction of a narrative (as in Fig. 2). But even in such cases, the images often do not seem to have sufficient details to facilitate the learner to write.

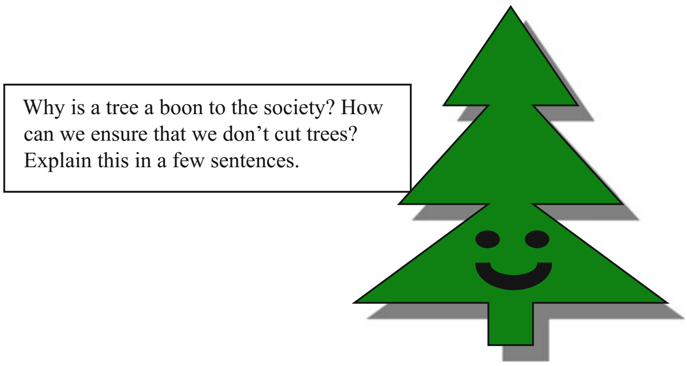

Fig. 1 A low-context text prompt (Class 5) with image support. Note that in this case, the image does not really add much to the question

The picture below shows a young girl trying to take care of some younger children. Try to write a story based on this picture. You could try to cover the following points in your story

- Why do you think the young girl looks confused?
- Who do you think the young girl is in this picture?
- Why are many of the children crying?
- What do you think the young girl can do to make all the children happy?
- Think of a good title for your story.

Fig. 2 A text prompt with image support (Class 5) that has some more context to assist the writer. However, while the image has a more central role than in Fig. 1, it still seems subservient to the text. (*Image source* https://pixabay.com/en/child-care-worker-crying-babies-624742/)

3.5 High-Context or Low-Context Image-Only Prompts

These are prompts that use only images, and may use text just for basic instructions. It is presently difficult to find such prompts that use only images to provide the context, although there are questions that may give an image and ask the learner to “Describe the Picture.” However, these are mere picture description exercises which cannot be classified as true narrative writing. In current materials, it is rare to find tasks that use only images (whether low-context or high-context) to obtain written responses.

Image-only prompts, if chosen appropriately, can be equally effective as text-only prompts, or possibly even more so, when used in writing classrooms. Certainly it is not desirable to use images in the manner in which they have been used in Fig. 1, for the image there is just that of a smiling tree, which adds nothing to the task. At best, it may appeal to the learner, but does not help them to write. Figure 2 is a better prompt, but still the image there depends largely on the text, which asks learners to have only one single interpretation of what they are seeing.

The subsequent sections of this paper discuss the possibility of using certain kinds of image-only prompts for the purpose of teaching writing, based on theories of using prompts and some specific studies on eliciting narratives using image-based materials.

4 Desirable Features for Writing Prompts

Kroll and Reid [4] have identified a number of variables that teachers and test designers (and these may also be applicable to materials designers) must pay attention to. While these were given for mostly text-based prompts in an assessment scenario, they are also pertinent to a classroom scenario, and thus can be used to define desirable features of image prompts in this paper.

4.1 The Writing Situation (Contextual Variables)

This refers to the contextual information provided in the task. Kroll and Reid state that the prompt designer/materials designer must make the context clear to the learners or test-takers, thus seeming to argue in favour of high-context prompts that give enough information to the learners to work with. When translated to images, this would probably translate as two things: (a) that the characters and surroundings in the image match the context within which the students are located (for example, if the students are from an Indian village, then characters in the image must wear Indian clothes), and (b) that there are enough elements in the image to help the learner-writer to draw enough contextual information from and use that in their own writing.

4.2 The Subject Matter (Content Variables)

Kroll and Reid further propose that the ideas that the prompt requires the learners to explore must be something that they are familiar with or already have been exposed to. Good writing tasks often introduce new ideas by first providing preliminary reading material to the learners, and then ask them to explore those ideas. In the absence of such reading material, it becomes even more crucial that learners are not asked to write about topics that they will feel completely at a loss to handle, thus leading to a loss of motivation for writing as well. In terms of image prompts, this holds true as well, as one needs to be careful to provide such elements in the image that the learners can interpret comfortably and reasonably accurately.

4.3 The Wording of Both the Prompt and the Instructions (Linguistic Variables)

This point refers to the wording in a text prompt and the instructions, and says that it should be in language that is easily understood by the learner. The instructions must be clear and precise, which applies to the context of image prompts as well.

4.4 The Task(s) (Task Variables), Rhetorical Variables, and Evaluation Variables

These three variables further specified by Kroll and Reid are more related to evaluation scenarios, since task variables are about the number of tasks in a single writing activity, and evaluation variables are about how the writing task will be scored. Rhetorical variables deal with the textual properties of the text prompt given. Each of these are not as important when looking at image prompts only (thus bypassing verbal rhetoric), and at this stage this paper deals with each writing assignment as a single task (thus removing the need for task variables), and furthermore is not immediately concerned with assessment (thus ignoring evaluation variables).

Thus, from Kroll and Reid [4], we can take at least two major pointers for the design of image-based prompts for writing activities as well, that is, context variables and content variables. In addition, for the task instructions (whether oral or written), linguistic variables play an important role as well.

5 Studies in Eliciting Narratives Through Images

Apart from existing theories on designing better prompts for writing tasks, in order to understand better how images may be used to elicit narratives, it would be useful to look at a couple of studies where image-based materials have been used to assist in the creation of stories, or in storytelling. Apart from a cross-section of research studies in the area, two papers by Nina Sabnani have been chosen for review, since they are very closely related to the topic under study here.

5.1 *'Prompting Narratives: The Kaavad Tradition' [7]*

In this paper, Nina Sabnani details her study of the *Kaavad* storytelling tradition in Rajasthan, which she then uses to illustrate how images can be used to induce narratives from children. The *Kaavad* is a painted wooden shrine which is used by wandering storytellers ('*Kaavadiyas*') to recite stories and genealogies for patrons. The *Kaavad* contains many folding doors and hidden panels, on each of which are miniature paintings that represent a particular story or narrative from Indian mythology or local history. The story is constructed by the shared knowledge of the storyteller and the patron. The images on the *Kaavad* are inherently polysemic, that is, they allow multiple interpretations and even allow multiple patrons to trace their family history within the same image. The paper further describes how the same idea of polysemy was used by the author in a special book called 'Home'. This is an illustrated book designed along the lines of the *Kaavad*, with folding panels as doors and see-through windows. There are images on each surface that serve as prompts which allow children to create multiple narratives around them. The author describes how the book was received by children at various workshops and book festivals, and feels that the book, through its unique placement of images and participatory, inclusive design based on the *Kaavad*, helped the children to construct their own meanings and their own narratives for the book.

While the author presents this finding as a hope for orality and oral narratives to become part of children's literature, it nevertheless has some relevance to this present study on written narratives as well. The images used in the 'Home' book take on lives as narratives because of their juxtaposition with each other, and because of the unique way in which they are often revealed to the child, through moving doors and panels. In essence, the images in the book come with an inherent narrative element already present in them, which can then be exploited by different storytellers in their own way. Thus, even in the context of the writing classroom, it would be useful to prepare image-based materials that (a) have an inherent narrative element to them, and (b) may have some means of being used repeatedly in combination with other such images, so that they can not only be re-used, but so that they may also have the possibility of forming an infinite number of connections with other images in the same series, leading to a potential for many different narratives. Text-only prompts do not have the same possibility for recombination, nor the inherent quality of polysemy.

5.2 'Eliciting Stories: Exploring Images as Prompts' [8]

This other paper by Nina Sabnani also deals with the *Kaavad* tradition and the subsequent investigation of image prompts with the 'Home' book; however, here, the possibilities of 'Home' are researched in greater detail. These further experiments revealed once again the plurality of meanings possible with image prompts, the possibility of connecting different images together to form multiple narratives, and how even elements like a shade of colour may have special meaning for a viewer, which may then affect the narrative they construct. The author's conclusion that pictures are a bridge to access memory, imagination and narratives from young children is apt, and most pertinent to this present paper. The author's views on what makes these images work are: (a) "The image offers stimulus and association to begin the narration" (b) "Images in the book have few details in the background, which leaves space for imagining different contexts." Point (b) especially seems to go against Kroll and Reid's dictum (discussed in Sect. 4 above) that a rich enough context ought to be provided to the learner. Therefore, it may be worth further study to find out what level of detail is ideal for the learner when trying to teach writing specifically.

5.3 Other Studies in the Area

A few other studies with relevant results for this paper must also be mentioned here. Nuryana [5] conducted a study with 24 fourth-grade students to test teaching writing using pictures. The results of the experiment and analysis gave a t-score that was statistically significant, using which the writer concluded that the technique of using pictures to teach writing worked better with the learners than traditional techniques. Ariningsih [1] conducted a similar study using picture series to improve students' writing, through improving learner motivation. The results of the analysis following this experiment showed that picture series were more effective than translation methods in teaching writing, and moreover, that learner motivation was greatly affected thanks to the change in teaching method, which in turn improved writing performance. Hibbing and Rankin-Erickson [2] used visual images in the context of reading, to help struggling middle-school students to understand what was being taught to them at school. They concluded that using visuals was very important with struggling readers, as it helped them to recreate images in their own mind as they read, and thus their potential for understanding the text was increased. Joshua et al. [3] conducted action research on the effects of pictures and prompts on the writing of students in primary grades. For younger students and, possibly, second-language learners, the pictures aided writing and drawing. However, beyond kindergarten, the picture paired with the prompt did not positively affect writing.

6 Towards Effective Image Prompts

From the above studies, as well as the section on writing prompts, we can thus suggest some reasons why image prompts could be used over text-only prompts, as well as try and understand what the features of such image prompts ought to be. Image prompts have clear benefits in allowing for multiple interpretations, and hence may give rise to multiple kinds of narratives as well. They are also more motivating when used with young learners. Images automatically also contain contextual information (for example, the features of a character, or the clothes they are wearing), which words cannot easily achieve. They stimulate the imagination in many ways: they allow the viewer-writer to remember past events more easily, they allow connections with similar-looking people or events, and they even facilitate better collaboration if the activity so requires it. Sequences in the image allow the learner-writer to better structure their narrative. All of these may lead to better written narratives.

The features of image prompts to be given to young learners in the writing classroom could thus be as follows:

(1) They must have a narrative element, which could be the depiction of a conflict, action, or event. Even in the 'Home' book, the narrative element was present through the juxtaposition of images and through the fact that there was potential to combine different images with each other in different ways.
(2) When providing multiple images, or when tracing multiple events or occurrences in a single-frame image, the sequence of the events or images need not be made obvious or apparent. This will allow learners to create their own sequence for the narrative.

Fig. 3 An example of two different kinds of image prompts, fitting the criteria given above, that might be used with young learners in schools to teach narrative writing

(3) However, contextual details must be provided in the image that makes the image somewhat familiar to the learner, failing which they may face anxiety trying to figure out what is going on in the image, rather than trying to build their own narrative.

This paper looks at only static images as prompts, since they are most widespread and most easily accessible to all schools, no matter their budget. They also require less technological equipment to create and distribute. Thus, it is felt that static visual narratives may be effective as prompts in the writing classroom. Some examples of such kinds of prompts are given below (Fig. 3).

Two different kinds of static visual narrative prompts are suggested in Fig. 3. While the one on the left has more details and different episodes, the sequencing is not clear, allowing the learners to imagine plots and situations for themselves. The one on the right has sparse details, but conveys a clear central idea, around which learners may build their stories. Both of them provide some contextual support for a narrative to take shape. These images need to be tested in an authentic teaching-learning scenario. If proven to be effective, similar images may be used by language teachers as prompts to elicit narrative writing.

7 For Further Study

The scope of this paper is currently restricted to discussing a possible description of image prompts that may be used to teach narrative writing to young learners (class 4–class 5), and it is intended to lay the ground for a detailed study into this specific area. However, while supporting studies and literature seem to point that these might work, as described above, they still need to be tested extensively in the field. The resulting observations are likely to give a more fine-tuned and detailed description of static visual narrative prompts for use in the English writing classroom. Moreover, opinions from teachers and students in the course of such a study are likely to be invaluable, and these must thus be the next steps forward to take this study forward.

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Percolation Framework and Monte Carlo Techniques for Improved Probabilistic Design of Variability in Products and Systems

Nagarajan Raghavan and Kin Leong Pey

Abstract Variability is an inherent feature of any manufactured product or system that can be caused by process inhomogeneity, environmental perturbations, operating stress-induced degradations or unexpected human interference during fabrication and use. The design of a product or system should account for and model the probabilistic nature of these variations that have an impact on its yield, reliability and robustness. This study is intended to present a combination of a theory based on the concept of "percolation" and an algorithm based on Monte Carlo that can serve as a key model-based design tool to quantify the variability in performance/lifetime/material properties/time-based events and identify the possible root cause(s) for the variance so that the design process could be refined to improve and optimize the homogeneity of the population of devices that would be manufactured on a large scale from the evolving product design stage.

Keywords Variability · Percolation theory · Monte carlo · Model-based design · Reliability

1 Introduction

Product design is a broad field of research which includes several aspects such as design for manufacturing, functionality, aesthetics, performance, reliability, sustainability, six sigma, ergonomics, maintenance, robustness and much more. In general, all these aspects together are termed as "Design for X" [1], which is a popular terminology in the industry today. Prior to the prototyping stage, there are several design iterations that are carried out and we then typically use a structured approach to evaluate the multiple design solutions, from which, one or two are

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selected that best satisfy most of the technical and user requirements, if not all. One aspect of design that is often ignored is the *variability* that we would expect to see in the manufactured prototype, when several identical units of these are fabricated using the same process flow conditions. Variability is intrinsic to nature and cannot be avoided as such. However, a robust design strategy should be able to quantify the possible variations one might expect to see in a product design when comparing and evaluating multiple design solutions that evolved from the concept generation and design ideation phases.

There are several types of variations that are inherent in a manufactured product, as summarized by Fig. 1. They can be classified into different types such as extrinsic/intrinsic, static/dynamic, localized/random, spatial/temporal, instantaneous/evolutional etc. One of them is the process flow variations due to small fluctuations in the process conditions such as pressure, temperature etc. that are bound to exist in any fabrication unit. The second type is the variations arising from atomic level inhomogeneity in any material stack, which is hard, if not impossible, to perfectly control. Atomic level perturbations in turn result in microstructural variations of a material that affect it's electrical, mechanical, thermal, optical and several other properties. The third involves time-dependent variations induced in the product as a result of operating stress induced gradual degradation of the product features. With every unit of a product having a different degradation profile, the variance in its performance or lifetime is here to stay and can get worse as the product ages and undergoes wear-out. The fourth type is the external perturbations from the global and local environment due to cyclic changes in the weather patterns, power fluctuations (voltage spikes) etc. The last one involves human interference (due to product slip from hand suffering a floor crash, water ingress from moist hands, charge transfer from human body contact etc.) and usage behaviors (over usage, abrupt reset of product etc.) that can have a big impact on the damage accumulated in a product over its service life. These sources of variations tend to affect the performance, reliability and maintainability of the product in hand.

While the sources of variation are easy to identify for any given context, their impact on the product in terms of its performance/reliability is often difficult to quantify. Several attempts to quantify variability tend to be purely "static" with the time component factor not accounted for [2, 3]. Other attempts assume a Gaussian distribution for all the variable inputs and use simple convolution approaches and/or empirical methods to quantify the output variance [4, 5]. While these approaches are a good initial step, they do not reflect the physical mechanism and dynamics of operation or behavior of the product/system and fail to capture the internal "links"

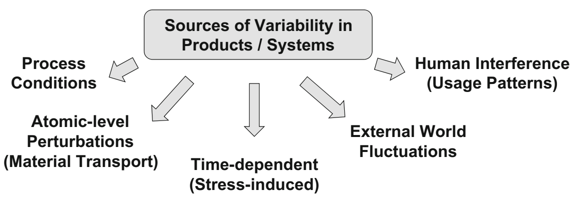

Fig. 1 Various possible sources of variability in manufactured products and/or systems during their operational life

that make up the product and the interactions of these links with each other based on their proximity in space or functionality or the existence of a common driving force for wear-out. As a result, the simulated outcomes of these exercises are not fully trustworthy.

In this work, we present a structured approach of simulating the expected variability in performance/lifetime of a product's design using the *percolation theory* [6, 7] as well as the Kinetic Monte Carlo (KMC) technique [8–10]. The combined use of these two tools enables a holistic quantification of the variability expected, should the design solution be taken in for prototyping and manufacture on a large scale. The subsequent sections of this paper are organized as follows. Section 2 presents the idea of percolation and the algorithm behind KMC and justifies their use as a good toolkit for probabilistic design of variability. Section 3 presents a case study on how percolation and KMC together enable the assessment of lifetime variations in an oxide thin film that is used in semiconductor technology for logic and memory devices. Section 4 presents ideas and scenarios where our methodology could be applied to variability design of several technology domains and niche applications. Finally, we conclude Sect. 5 with suggestions for further exploration and development of our design toolkit and summarize the findings of our study.

2 Variability Design Toolkit

We propose here a toolkit for variability design of products/systems/services which comprises of two key components—*percolation* and *Kinetic Monte Carlo (KMC)*, as shown in Fig. 2. Each of these components shall be introduced in the following sub-sections and their context to design shall be discussed.

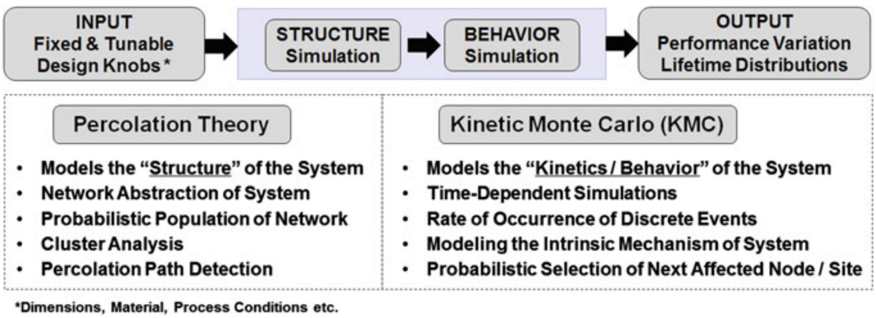

Fig. 2 Proposed methodology for probabilistic design for robustness integrating percolation theory and Kinetic Monte Carlo (KMC) algorithm for stochastic simulation of the "structure" and "behavior" of the system

2.1 Percolation Theory

As the name suggests, percolation in a physical context refers to the possibility of a liquid trickling down through a porous object from one side to the other, where the object is viewed as a *network* of pores which serves as a medium for mass flow. The idea behind percolation theory is to view an object as a "*network of interconnected nodes/bonds/sites*" where the link between neighboring nodes is established with a certain probability (***p***) that could be governed by a model that describes the physical processes occurring in the object (Fig. 3). This could, for example, be processes involving transport (diffusion, conduction, convection), chemistry (bond breaking and bond forming), communication (physical proximity and contact, server-computer connection) etc. At any instant of time, some of these links are formed and some may be broken. The nodes or sites which are connected tend to form

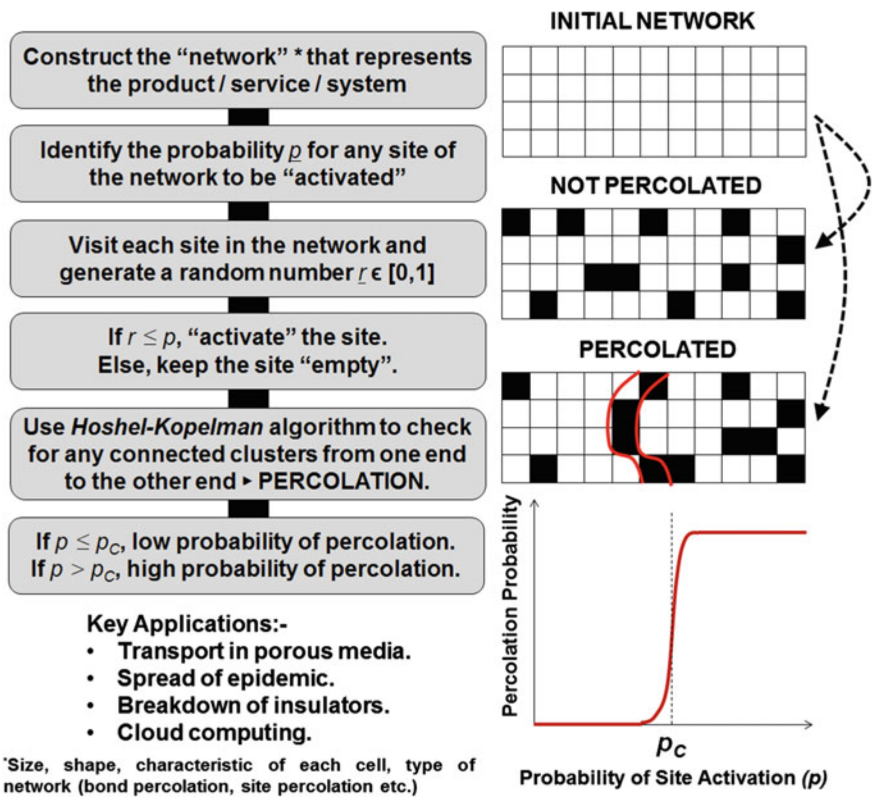

Fig. 3 Construction and graphical flow of the simulation of percolation process, illustrated here for a 2D matrix with cell sites (site percolation). Several other types of percolation frameworks have been proposed in literature

clusters and the object, in context, is said to have percolated if one of these clusters spans the entire object connecting one end to the other, forming a chain link.

There exists a critical threshold of the link probability ($\boldsymbol{p} > \boldsymbol{p_c}$) beyond which there is almost a high certainty of finding a percolation path through the whole network connecting one end to the other [11]. Assuming a product/system/service can be viewed as a network, given a static scenario, the value of $\boldsymbol{p_c}$ can be computed for each network depending on its dimension (2D, 3D etc.), shape of unit cell (site) in the lattice, interactions between neighboring lattice sites (if any) and so on. This deterministic threshold value of $\boldsymbol{p_c}$ can be used as a design metric to evaluate different product design solutions that may have different values of $\boldsymbol{p}$ and $\boldsymbol{p_c}$. The proximity of $\boldsymbol{p}$ to $\boldsymbol{p_c}$ can have an impact on the preference for one of the several proposed design solutions. Here, the interpretation of percolation could be very different, depending on the context of the problem. It could refer to breakdown, leakage, unobstructed material flow, assured connectivity, end-to-end resource distribution etc. Figure 3 presents the summary of the idea behind the use of percolation as a model-based design tool for our work and gives examples of different applications where it may be a relevant approach to use.

2.2 *Kinetic Monte Carlo (KMC) Routine*

While the concept of percolation and percolation threshold traditionally apply to the static context, it is obvious that given a sufficient period of time, any network of sites can get populated by some physical phenomenon (even if $\boldsymbol{p} < \boldsymbol{p_c}$), thereby establishing a percolation path/link from one end to the other. The time evolution of bonds/links in the network can be well represented using the KMC algorithm, the essence of which is shown in the form of a flowchart in Fig. 4.

The KMC approach involves the use of rate ($\boldsymbol{r}$) (per unit of time, for e.g., rate of chemical reaction) to describe the speed at which a process takes place and proceeds by choosing a cell/site in the matrix depending on the fractional value of the rate $\boldsymbol{r}$ for that cell in comparison to all the cells that have not been linked yet, using a random number generator. The cell that is chosen is now considered to be linked and the time step is incremented proportionate to the inverse of the sum of all the cell activation rates of the unlinked cells/sites [12]. This is again followed by the next cycle of cell selection using the same iterative procedure. The algorithm stops execution once the percolation event is detected, i.e. when the first complete link between two ends of the lattice network is formed. The detection of these percolation clusters is carried out using a popular algorithm called the Hoshen-Kopelman algorithm [13].

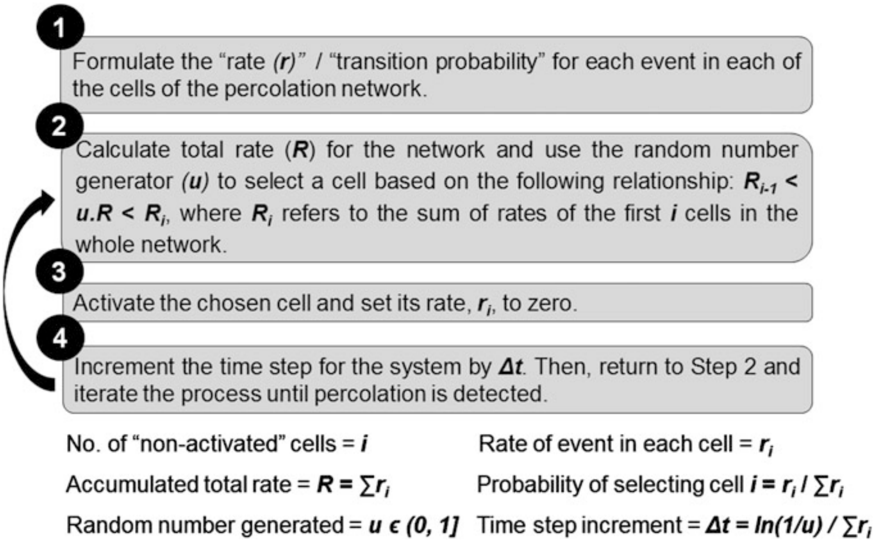

Fig. 4 Algorithm for KMC procedure involving time-increments and network cell (node) activation using probabilistic rules. The internal mechanism of operation of the system is incorporated in the *rate* term

2.3 Variability Assessment Methodology

With the establishment of the percolation network and the KMC routine, the complete algorithm may now be formulated as shown by the flowchart in Fig. 5. The various parameters and tunable factors relevant to the product/system/process being designed are first identified. We then construct the network that best represents the nature of the product/system/process and define the rules for the probability or the rate of the mechanism that is underlying its functionality. For a static context, the percolation process is executed comparing $\boldsymbol{p}$ of every cell to a random number (***rand***) and creating a link at each cell if $\boldsymbol{rand} < \boldsymbol{p}$. After all the cells are considered, we check for the percolation event by examining whether there is any cluster that spans the whole network. In a dynamic context, the KMC algorithm is executed instead and as time goes by, the number of clusters and the average size of the clusters will continue to increase finally reaching percolation at some time t_f. This quantity, t_f, is the time taken for the network to percolate and it can be representative of the lifetime of the product/time to breakdown of the whole network/time to travel/time for full network connectivity establishment etc. depending on the type of product/system/service being looked into.

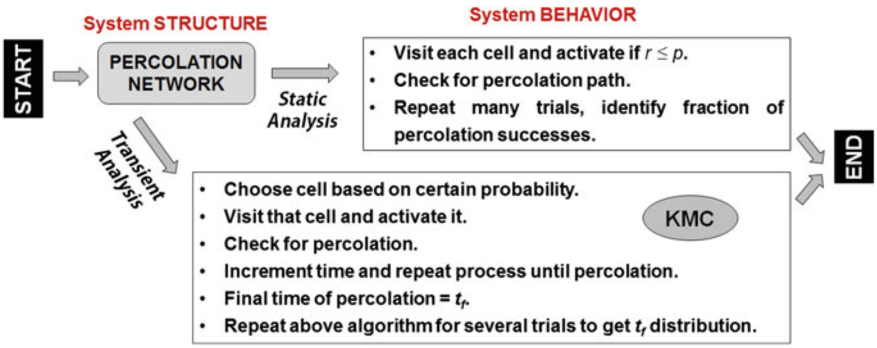

Fig. 5 Overall framework for variability (uncertainty) quantification given the percolation network based abstraction of the product/system/service and its behavioral simulation using KMC algorithm

2.4 *Probabilistic Design for Variability*

Given the stochastic nature of the whole process, the simulation routine described by Fig. 5 should be executed several times for each set of design parameter values. The outcomes from these repeated simulation trials is a discrete statistical distribution of [0, 1] for the static context and a continuous distribution of t_f for the dynamic context. The mean (μ) and standard deviation (σ) of these distributions can then be estimated to gauge the extent of variation, (σ/μ), in the output. The same set of repeated trials should then be performed for different values of the design parameters and for different design solutions as well and in each case, the distribution $\{\mu, \sigma\}$ values should be computed. With all this set of data, we may then carry out a full factorial or fractional factorial design of experiment and use the response surface methodology to identify the most sensitive design parameter that impacts on the variability most adversely (Fig. 6) and gauge the intensity of interactions between different parameters. Once this is identified, the design solution could be modified to circumvent the problem by further concept generation and validation processes. Our probabilistic design approach therefore helps to quantify the expected variance for various design ideas and serves as an additional criterion to evaluate and filter out the design options.

3 Case Study: Thin Film Oxide Breakdown

To illustrate the approach we propose in Sect. 2, we present a case study relating to thin film oxide breakdown (Fig. 7) in semiconductor logic and memory devices. Most modern semiconductor devices comprise an insulating thin film layer of thickness ranging from 1 to 10 nm, referred to as the “gate oxide” that forms a key

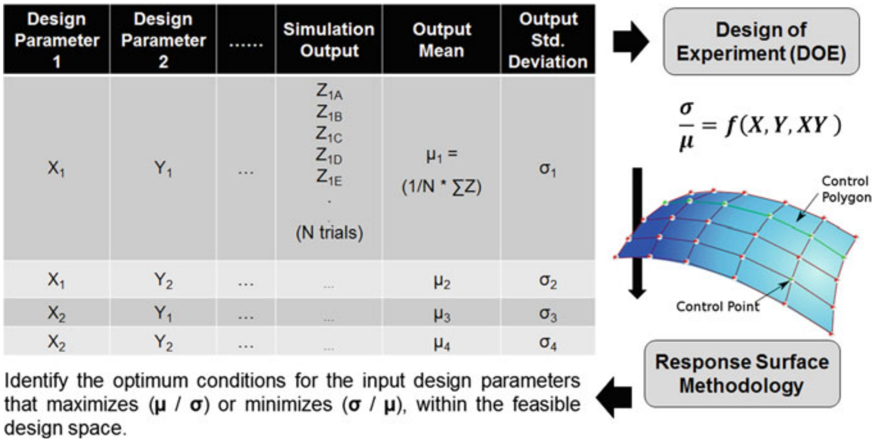

Fig. 6 Experimental design procedure to assess the dependence of the relative spread in output (σ/μ) for multiple design parameters. The output for each set of values for the design parameters involves several repeated KMC simulation trials to acquire sufficient statistics for analysis of means and variance. A response surface method analysis could then be used to identify the optimal input values for the design parameters so as to achieve a robust design of the product/system/service

component enabling capacitive, memristive and transitive action in electronic circuits. It is this property of semiconductor devices that make them capable of binary data processing as well as non-volatile data storage. The gate oxide film is often prone to random defect generation during the operation of the transistor due to the voltage (electric field) stress that it experiences. The dynamics of this defect generation and its evolution to oxide failure (oxide breakdown) is one very good scenario where percolation theory and KMC algorithm can be utilized to understand the impact of different design parameters some of which include film thickness, device area, oxide material, voltage stress, thermal stress etc.

3.1 Abstraction of the Oxide Film Breakdown Process

Since the oxide is inserted to function as an insulator and given the prior knowledge that defect generation is random in the oxide, we may construct a 2D or 3D cell matrix for the oxide (as shown in Fig. 7), where each cell corresponds to a potential location for a defect to be created. This matrix can be interpreted as a network and when several defects are created and some of them form a cluster that connects the two ends of the network, we can interpret this to be a "breakdown" of the oxide as the fully connected path through the oxide is a favored region for high leakage currents to flow, resulting in electrical short and circuit failure. So, the task here is to model the defect generation and clustering process in a percolation network of potential defect sites (Fig. 7).

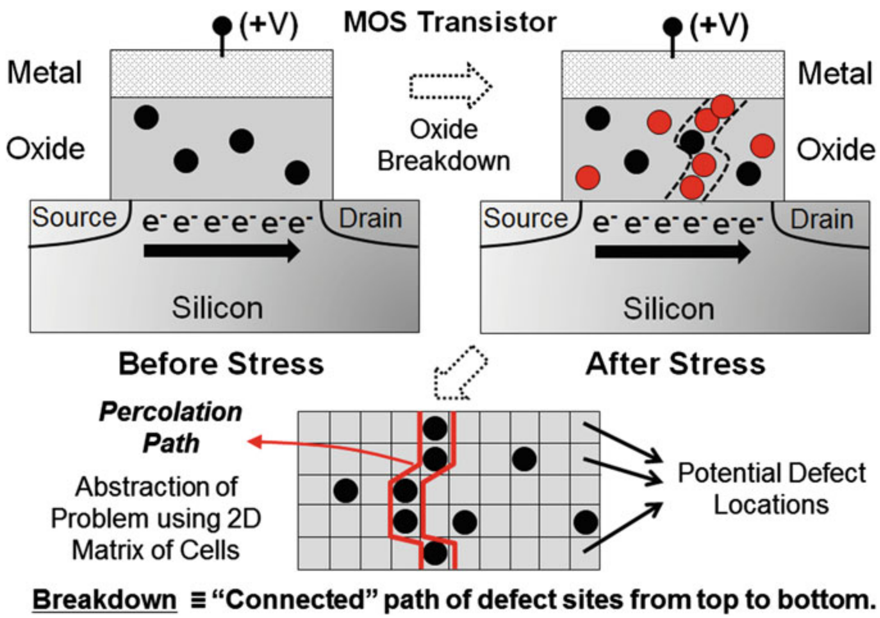

Fig. 7 Schematic of a metal-oxide-semiconductor (MOS) device with an oxide layer that is subject to defect generation during voltage stress. The generation of defects is random in nature and though the region of influence of each defect is spherical (circular in 2D), we can still abstract this problem to a cell-based percolation framework as shown. The *black* and *red circles* in the oxide refer to pre-existing defects and stress-induced defects respectively

3.2 Identifying the Design Parameters

The parameters in the study here are oxide thickness (t_{ox}), defect size (a_0, known to be 0.8 nm from first principle atomistic studies [14]), device area (A_{ox}), oxide material (hafnium oxide: HfO_2, silicon dioxide: SiO_2), microstructure (polycrystalline/amorphous), voltage (V) and temperature stress (T). We will consider a subset of these parameters and vary them using the percolation—KMC framework to investigate their impact on variability of failure times (time to percolate), $\boldsymbol{t_f}$.

3.3 Analytical Model for Physical Mechanism

It is believed that defects in the oxide are generated due to bond breaking of the metal—oxygen bonds or silicon-oxygen bonds, which is electric-field driven and temperature-assisted. The rate of this defect generation ($\boldsymbol{r}$) can be expressed by Eq. (1) [15], where υ is the frequency of lattice vibration, E_a is the activation energy for bond breakage (which is material dependent), k_B is the Boltzmann constant, γ is the field acceleration factor (material constant), ξ is the electric field, V is the applied voltage and T is the temperature (in Kelvin). With this physical expression for $\boldsymbol{r}$, we may tune different design parameters (one at a time) to examine their effect on variance of $\boldsymbol{t_f}$.

$$r = v \cdot \exp\left(-\frac{E_a - \gamma \cdot \xi}{k_B T}\right); \; \xi = \frac{V}{t_{ox}} \tag{1}$$

3.4 Simulation Results and Discussion

The exact algorithm presented in Fig. 5 is used here for the simulation. The impact of three different t_{ox} values of 3.2, 4.0 and 5.6 nm are considered with all other parameters kept unchanged. As shown in Fig. 8a, the variance in $\boldsymbol{t_f}$ drops to lower values with increasing oxide thickness. This suggests that higher oxide thickness values are a preferred way to go, if it is technologically feasible. Another study involved the change in area of the oxide layer by 1–2 orders of magnitude, keeping t_{ox} fixed at 5.6 nm. From Fig. 8b, it is clear that larger device areas also provide for more controlled $\boldsymbol{t_f}$ distributions, even though $\boldsymbol{t_f}$ is lower for larger areas (larger space—more possibilities of percolation for the same voltage stress). If control of variance is the only criteria to satisfy, then a good design for a transistor should involve using the largest device area possible (based on the outcome in Fig. 8b). There are

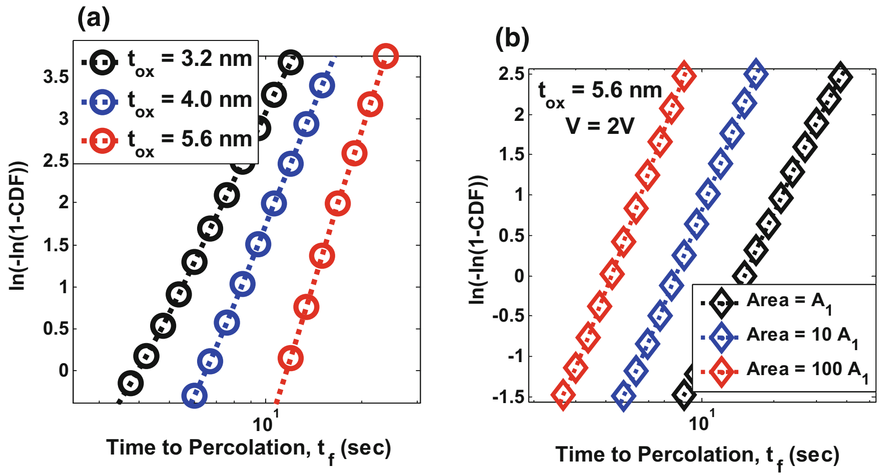

Fig. 8 Weibull probability plots of the time to failure (time to percolation) as a function of **a** oxide thickness and **b** transistor device area at a stress level of 2 V. Higher oxide thickness and larger area structures enable lower spread in the failure time as evident from the slope of the plots above

many more simulations that can be executed for the oxide example here, but we only present two simple cases above as a general illustration of the approach. Since these simulations do not take a long time, we could run a full factorial DOE to examine how variance in t_f is affected by the individual design parameters and also check for the dominance (if any) of some interaction terms as well.

4 Applications of Proposed Methodology

In the previous section, we presented a very simple example on how percolation theory and the KMC algorithm work hand in hand as a good probabilistic design tool to quantify lifetime variability and identify the key design parameters that can be fine-tuned to reduce variations. While the example corresponds to a very niche area of semiconductor technology, the methodology presented in this paper is applicable to several other technology domains and types of problems. Some interesting examples and possibilities in different fields are presented below. This is, by no means, an exhaustive list and the scenarios for which percolation and KMC can be used as effective design analysis tools are manifold. The only requirement is that there be some sort of a *network* representation of the product/system/service that is being designed.

Infectious Diseases—Spread of infectious diseases depends on several factors including the origin location of the disease, the spatial density and distribution of population in the region of outbreak, the rate of spread of disease and its dependence on distance (proximity) etc. If the region of outbreak can be modeled as a network with different nodes/sites and their relative distances from the origin of virus representative of the physical locations, then the spread of infectious diseases can be very well modeled using the percolation + KMC paradigm. Different test scenarios can be simulated and worst case (shortest) time of infection reaching a critical level and spreading to the entire city can be identified so that necessary measures could be taken in advance.

Urban Planning—Representing a city as a network of routes and considering the traffic flow and key hot spots of high urban agglomeration, the flow of vehicles and people could be simulated using the KMC framework and possible impediments to traffic flow can be identified for better planning of roads and transportation rules to avoid congestions.

Communication Networks—Several intermediate stations might be needed before a signal reaches the receiver from the transmitter. In such cases, the transmission station network and its real-time state of performance will determine the reliability and robustness of data transmission without any packet loss. Worst case scenarios for such networks can again be simulated using the percolation + KMC framework.

System of Systems (SoS)—With complex systems and system-of-systems becoming commonplace now, the end-to-end reliability of such systems with network of connections along with built-in standby/load sharing redundancy can be evaluated using the percolation idea with different probabilistic test cases simulated using the KMC.

5 Conclusions and Scope for Future Work

In this study, we proposed a design toolkit leveraging on the popular theory of *percolation* and a generic stochastic algorithm called Kinetic Monte Carlo (KMC) for simulating the statistical nature of adverse events and their worst case scenarios in products/systems/services that could be represented by a ***network*** with certain pre-defined rules of connectivity and probabilistic laws of nature/operation governing the interactions between neighboring nodes/sites in this network. The technical details of the percolation theory and KMC algorithm were discussed and the combined use of these tools for system behavior/process simulation was illustrated through a simple case study on oxide breakdown. Other possible applications in various technology domains where the proposed techniques might be relevant were also briefly discussed.

The strength of the approach here is that the probabilistic rules of connectivity between neighbor nodes/sites can be customized according to the type of problem being solved and the nature of the system under analysis. Therefore, the algorithm is generic and can be used for many more applications for stochastic process simulations, identification of worst case scenarios as well as finding out the right parameters/tunable knobs of the design process which can be tweaked to achieve a more robust design prior to prototyping. The use of such worst case simulations to achieve better design solutions ensures greater societal impact, community acceptance and commercial success of the manufactured product. The only requirement for the use of our design toolkit is that the product/service/system should be representable in the form a multi-node network and the nature of interactions (rate or probability) between the interconnected (neighbor) nodes should follow an analytical model.

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Welding Parameters Optimization in MMAW Assisted Nano-Structured Hardfacing Using Desirability Function Analysis Embedded with Taguchi Method

Abhijit Saha and Subhas Chandra Mondal

Abstract In the assembling enterprises, welding assisted hardfacing has pulled in expanding consideration for its powerful protection against erosion, thermal shock, and abrasion. Nano-particle reinforcements can fundamentally enhance the mechanical properties of the lattice by more viably advancing the molecule solidifying components than micron estimate particles. This paper presents the multi-target optimization of manual metal arc welding (MMAW) process parameters in hardfacing with Nano-technology based electrode. Experimentation was arranged according to Taguchi's orthogonal array. In this paper, tests have been led utilizing welding current, arc voltage, welding speed as input process parameters for assessing numerous responses in particular weld bead width, reinforcement and bead hardness. A mix of Taguchi's robust design idea with desirability function analysis (DFA) has been connected to enhance the process parameters. A composite desirability value is gotten for the multi-responses utilizing individual desirability values from the DFA. In light of composite desirability value, the best possible levels of parameters have been distinguished.

Keywords Manual metal arc welding · Taguchi method · Desirability function analysis

1 Introduction

Welding is a procedure of joining distinctive materials. It is more cost-effective and is a much speedier process contrasted with both casting and riveting. Weld hardfacing procedures are utilized fundamentally to broaden or enhance the service life

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of designing segments and to diminish their cost, either by modifying or by creating so as to deliver a composite wall section. Other preferred properties got may incorporate wear resistance, corrosion resistance, and so forth. As of late, weld hardfacing forms have been created quickly and are presently connected in various businesses, e.g., atomic and steam control plants, weight vessels and farming machines, railroads, and even in air ship and rocket segments.

Yao et al. [1] analyzed wear, corrosion and cracking resistance of some W- or Mo-containing Stellite hardfacing alloys. They concluded that W-containing Stellite alloys have superior corrosion resistance in oxidizing acid and Mo-containing Stellite alloys show remarkable amalgamation of admirable wear resistance and corrosion resistance in dipping situations. Kirchgaßner et al. [2] assessed the wear behavior for pure abrasion and for combined wear of iron-based alloys which are normally joined by GMAW. At long last they inferred that hypoeutectic FeCrC alloys provide significant hardness and for high impact applications, martensitic materials perform best. Wang et al. [3] researched the impact of additional alloy elements on the microstructure and wear properties of the Fe-based hardfacing layers were formed by SMAW. Qi et al. [4] concentrated on the impacts of vanadium added substance on structure property and tribological execution of HCCI hardfacing metal. At long last results demonstrate that the M7C3 and VC type carbides are precipitated from the matrix. Zhou et al. [5] contemplated the impact of titanium substance on microstructure and wear resistance of Fe-Cr-C hardfacing layers were kept on ASTM 1045 steel base metal. In this paper, they found that M7C3 carbide keeps up a high hardness and great wear resistance of the Fe-Cr-C amalgam.

Now-a-days, multi criterion Decision-Making (MCDM) procedures are picking up importance gaining for complex authentic issues as a result of their natural ability to judge particular decisions on various criteria for possible assurance of the best [6]. In the present paper, desirability function analysis embedded with Taguchi method was applied to optimize the welding parameters under concurrent deliberation of numerous weld quality characteristics. The optimization approach begins with the count of individual desirability (d) under concurrent thought of response weighting element and took after by the perception of composite desirability (D).

2 Experimentation

In this study, tubular covered nano-composite based electrode (NanoCarb 110) has been utilized for hardfacing material. Figure 1 shows the SEM-microstructure of NanoCarb 110. Moreover, Fig. 1 also shows dissipated amount of free carbides which is moderately high and almost uniform throughout the surface of Fe-based alloy electrode. Uniformity of the carbide on the surface makes it strong and high

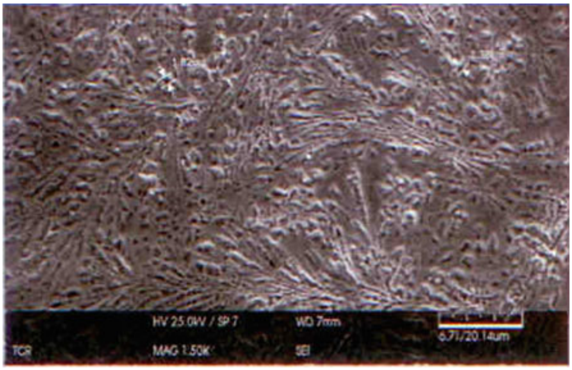

Fig. 1 Nano-microstructure morphology of NanoCarb 110

wear resistant properties at high temperature application. It has remarkable elements, for example, high single layer hardness (>67 HRc), great strength due to firmly pressed nano structure, excellent wear factor (>110), and high temp applications up to 750 °C. The MMAW has been utilized for hardfacing (Fig. 2) over the substrate material (low carbon steel) under negative polarity In this work, twenty-five hardfacing trails were accomplished by changing the welding current (140–160 A), the arc voltage (17–25 V) and the welding speed (20–60 mm/min). Table 1 demonstrates the 25 set of coded conditions used to structure the plan framework and trial consequences of the MMAW assisted hardfacing [7].

The hardfacing execution is by the accompanying estimations. The profiles of the weld beads were followed utilizing an optical profile projector and the various bead dimensions (reinforcement R, bead width W) were measured. At that point, coating performances were measured by Vickers hardness tester via a pyramidal diamond indenter. An average of three measurements was taken from three different positions.

Fig. 2 Hardfacing coating after welding

Table 1 Design matrix and trail results of the MMAW assisted hardfacing

Experiment no.	Design matrix			Experimental results		
	A	V	S	W (mm)	R (mm)	H (H_RC)
1	1	1	1	11.641	2.867	67.6
2	1	2	2	11.822	3.346	69.7
3	1	3	3	11.084	2.936	68.5
4	1	4	4	12.352	2.915	68.2
5	1	5	5	11.480	3.877	67.5
6	2	1	2	11.862	3.691	69.2
7	2	2	3	11.765	3.354	68.4
8	2	3	4	11.883	3.489	68
9	2	4	5	12.004	3.058	68.7
10	2	5	1	12.584	3.107	65.2
11	3	1	3	11.506	2.942	66.8
12	3	2	4	10.198	3.207	69.1
13	3	3	5	11.651	3.671	67.1
14	3	4	1	12.708	3.542	66.1
15	3	5	2	11.097	3.644	64.8
16	4	1	4	11.810	3.580	64.5
17	4	2	5	12.295	3.182	64.1
18	4	3	1	12.701	3.245	66.8
19	4	4	2	12.422	3.367	66.6
20	4	5	3	11.156	3.278	69.5
21	5	1	5	9.798	2.658	68.5
22	5	2	1	12.189	3.758	68.2
23	5	3	2	10.180	3.545	66.5
24	5	4	3	11.401	3.398	67.4
25	5	5	4	12.117	3.340	68.2

3 Multi-response Optimization Using DFA

In this work, a multi-criteria decision making model namely desirability function analysis (DFA) has been utilized for the evaluation of optimal conditions. DFA is a standout amongst the most broadly utilized techniques as a part of industry for the optimization of multiple response processes. It depends on the possibility that the "quality" of an item or process that has different quality attributes, with one of them outside of some "fancied" points of confinement, is totally unsuitable. DFA is utilized to change over the multi-quality distinctiveness into single quality distinctiveness. The steps required in the improvement issue are recorded beneath.

Step 1: The first step is computation of desirability index (d) for every welding response viz., weld bead width, reinforcement and bead hardness. There are three forms (target is best, larger the better and smaller the better) of desirability functions according to the response characteristics. The desirability value varies from 0 to 1. If the desirability value is zero it indicates that predicted value is completely undesirable and the desirability value of one is the idle. The desirability of corresponding response increases as the value of d increases. The one-sided transformation desirability function of maximization for reinforcement and bead hardness as shown in Eq. (1) and minimization of weld bead width as shown in Eq. (2).

$$d = \left\{ \left(\frac{y - y_{\min}}{y_{\max} - y_{\min}} \right)^{wt} \quad \begin{cases} 0 \rightarrow \mathrm{y} \le \mathrm{y}_{\max} \\ \mathrm{y}_{\min} \le \mathrm{y} \le \mathrm{y}_{\max} \\ 1 \rightarrow \mathrm{y} \ge \mathrm{y}_{\max} \end{cases} \right. \tag{1}$$

$$d = \left\{ \left(\frac{y - y_{\max}}{y_{\min} - y_{\max}} \right)^{wt} \quad \begin{cases} 1 \rightarrow \mathrm{y} \le \mathrm{y}_{\min} \\ \mathrm{y}_{\min} \le \mathrm{y} \le \mathrm{y}_{\max} \\ 0 \rightarrow \mathrm{y} \ge \mathrm{y}_{\max} \end{cases} \right. \tag{2}$$

where, d is a desirability function of y, y_{min} and y_{max} are lower and upper limits of response value of 'y', respectively, wt is weight, which can be varied from 0.1 to 10 to adjust the shape of desirability function.

Step 2: The individual desirability are then consolidated utilizing the geometric mean, which gives the composite desirability and is ascertained utilizing condition (3).

$$D = (d_1 \times d_2 \times \cdots \times d_n)^{1/n} \tag{3}$$

where 'n' denoting the number of responses.

Step 3: Evaluation of optimal combination of parameters based on the highest value of Composite desirability.

4 Results and Discussion

The hardfacing execution in this examination was assessed by welding responses like weld bead width, reinforcement and bead hardness. The outcomes got through examinations are exhibited in Table 1. Generally, a bigger estimation of weld bead width, reinforcement and littler estimation of bead width were adequate. The significant consideration was to minimize (favorable attribute) the bead width and to augment (non-helpful trait) the reinforcement and bead hardness. Table 2 demonstrates the individual and composite desirability for each of the test run. Higher the

Table 2 Individual and composite desirability

Experiment no.	Design matrix			Individual desirability (d)			Composite desirability (D)
	A	V	S	W (mm)	R (mm)	H (H_RC)	
1	1	1	1	0.367	0.171	0.625	0.340
2	1	2	2	0.304	0.564	1.000	0.556
3	1	3	3	0.558	0.228	0.786	0.464
4	1	4	4	0.122	0.211	0.732	0.266
5	1	5	5	0.422	1.000	0.607	0.635
6	2	1	2	0.291	0.847	0.911	0.608
7	2	2	3	0.324	0.571	0.768	0.522
8	2	3	4	0.284	0.682	0.696	0.512
9	2	4	5	0.242	0.328	0.821	0.403
10	2	5	1	0.043	0.368	0.196	0.146
11	3	1	3	0.413	0.233	0.482	0.359
12	3	2	4	0.863	0.450	0.893	0.703
13	3	3	5	0.363	0.831	0.536	0.545
14	3	4	1	0.000	0.725	0.357	0.000
15	3	5	2	0.554	0.809	0.125	0.383
16	4	1	4	0.309	0.756	0.071	0.255
17	4	2	5	0.142	0.430	0.000	0.000
18	4	3	1	0.002	0.482	0.482	0.082
19	4	4	2	0.098	0.582	0.446	0.294
20	4	5	3	0.533	0.509	0.964	0.640
21	5	1	5	1.000	0.000	0.786	0.000
22	5	2	1	0.178	0.902	0.732	0.490
23	5	3	2	0.869	0.728	0.429	0.647
24	5	4	3	0.449	0.607	0.589	0.544
25	5	5	4	0.203	0.559	0.732	0.437

composite desirability values better the item quality. Along these lines on the premise of composite desirability quality, the component impact can be assessed and the ideal level for each controllable parameter can likewise be resolved. Figure 3 demonstrates the main effect plot for the composite desirability at various levels of welding parameters. For the most part, the bigger the composite desirability, the better is the multiple qualities attributes. In this manner optimum amalgamation of welding parameters for the various quality attributes ought to be chosen as A1B2C3, namely welding current 140 Amps, arc voltage 19 V and welding speed 40 mm/min, respectively.

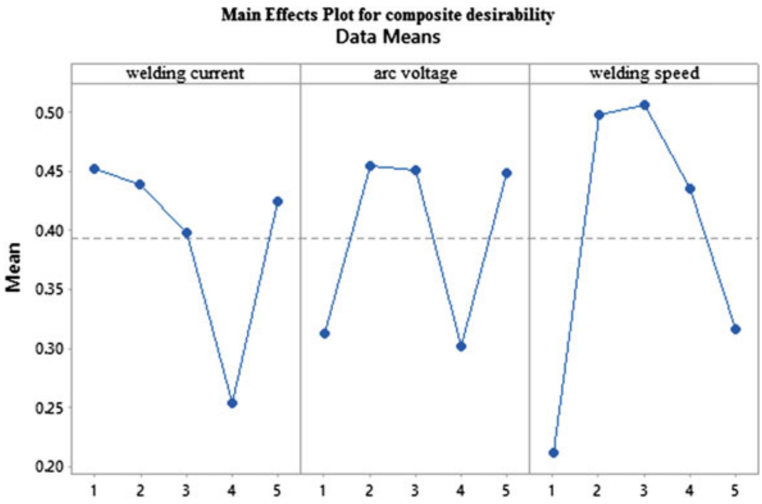

Fig. 3 Main effects plot for desirability analysis

5 Conclusions

The goal of this examination is streamlining of welding parameters in MMAW helped nano-structured hardfacing with multi-response characteristics (weld bead width, reinforcement and bead hardness) utilizing Taguchi technique and DFA. Attentive consideration is important to choose the welding parameters to get an attractive weld quality, and the real key process parameters influencing the bead geometry are arc voltage, welding current and welding speed. In view of the outcomes the accompanying conclusions are drawn.

1. The DFA embedded with Taguchi method is a powerful technique for enhancement of multi-response optimization problem.
2. Optimum combinations of welding parameters for the multiple quality characteristics ought to be chosen as $A_1B_2C_3$, in particular welding current 140 Amps, arc voltage 19 V and welding speed 40 mm/min, respectively.

This examination unquestionably demonstrates a few bearings for future work. In future, this study can be stretched out by creating and examining RSM, ANN procedure and impact of flux thickness on weld globule geometry and HAZ.

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Part IV
Enabling Technologies & Tools (Computer Aided Conceptual Design, Virtual Reality, Haptics, etc)

Exploring Designers' Cognitive Load When Viewing Different Digital Representations of Spaces: A Pilot Study

Rongrong Yu and John Gero

Abstract Do different representations of space evoke the same response in viewers? This paper reports on a pilot study exploring designers' cognitive load as they view different digital representation of spaces to determine the effect of the representations. The results reported in this paper are from a group of year 3 and year 4 architecture students from Harbin Institute of Technology in China who participated in the experiment. The two representational modalities in this study that participants were asked to view were a computer-generated hidden-line perspective and a digital photograph of the same space. Their physiological data were recorded by eye-tracking equipment, including participants' eye gaze trace location and pupil size. The same seven Area of Interests (AOI) were defined in each of the two representations. Results show statistically significant cognitive load change when the AOI focused on changes. The cognitive loads for the two representations were found not to be significantly different.

Keywords Designers' cognitive load · Eye tracking · Computational representation

1 Introduction

During any design process, designers develop their concepts with the assistance of visual representations [1]. With the development of digital design techniques the visual representation of digital models and images are now used broadly. However,

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the effect of digital representations on designers during the design process is not well understood. Do different modalities of representation evoke the same response in the viewer or different responses? With this pilot study we aim to produce evidence-based results about designers' physiological responses and cognitive load as they view different representation modalities of an architectural space.

Previous research has focused on how designers look at scenes using eye-tracking technology, which has suggested some characteristic behaviors. Kaufman and Richard [2] measured the eye fixation time allocated in several pre-defined parts of figures, the results show that the center of gravity is attractive as well as the edges and corners. Weber et al. [3] suggest that, with no a priori model in a figure, the attention would fixate at the center and that while the foreground was common for initial fixations, the eye did not typically scan the edges of interior space or rectilinearly-oriented contours. However, such research focused on comparing different arrangements of objects within a space, rather than different methods of representing the same spatial configuration. There is a lack of empirical evidence regarding designers' cognitive load when viewing different digital spatial representations. This is of interest as architects use multiple kinds of digital representations at different stages while they are designing. Whilst they have life experience with analog sketching and physical model-making, they do not have the same experience to draw on for different digital representations. This research is motivated by this gap in experiential understanding.

This study focuses on exploring designers' cognitive load when viewing different digital representations of the same architectural spaces and is part of a larger study on the veridicality of spatial representations. The results reported in this paper are from a group of year 3 and year 4 architecture student participants from Harbin Institute of Technology in China. The two representational modalities in this study that participants were asked to view were a computationally produced hidden-line perspective and a digital photograph of the same space. During the experiment, architecture students were required to look at each of the images for 20s. Their physiological data were recorded by eye-tracking equipment that measured eye gaze trace location and pupil size. The same seven Area of Interests (AOI) were defined in each of the two representations. The relationship between the pupil size changes and the gaze changes in AOIs was then analyzed and discussed.

2 Background

2.1 Computational Representation

Design representation is a core issue in most design domains including product design, architecture and engineering. With the development of computational modeling digital design representation became possible during the design process. It is claimed that externalizing representations assists designers in both off-loading cognition and providing the possibility to interact with their external representations [1]. For example, BIM technology enables 3D (model check, design view, enhanced reality) and 4D visualization (i.e., the same plus time) [4]. Virtual reality (VR) can produce realistic virtual environments which provide designers with navigation possibilities [5]; augmented reality (AR) can enhance the user's perception by complementing the real world with 3D virtual objects in the same space [6]. These computer representation tools allow designers to more readily explore design ideas and assist with the concept development of their designs. However, there is a lack of understanding of the physiological effect of digital representations on designers.

Oliva et al. [7] studied the representation of the shape of visual space. In their study they critique the isovist theory of spatial perception for leaving out other characteristics of space such as texture, material and color that contribute to the human perception of space. They also propose a model called the 'spatial-envelope representation', which describes qualitatively the character and mood of a physical or pictorial space, represented by its boundaries (e.g., walls, floor, ceiling, and lighting) stripped of movable elements (e.g., objects and furnishing). Then they proposed a formal, computational approach to the capture of the shape of space as it would be perceived from an observer's vantage point [7–9]. The collection of properties describing a space in view is referred to as the spatial-envelope representation. This distinction in the characteristics that contribute to the human perception of space pertains to our research into representations of space that include or exclude some of those characteristics.

2.2 Designers' Cognitive Load Increase Pupil Size

The concept of cognitive load is based on empirical evidence from experiments in psychology and physiology associated with cognitive activities [10, 11]. Cognitive load is the total amount of mental effort involved in using working memory. It has been found that there is a direct correlation between cognitive load and pupillary response. For instances, Hess and Polt [12] suggest that during the solving of simple multiplication problems, change in pupil size is related to mental activity. Just and Carpenter [13] show that different complexities of sentences affect pupil size when reading. Kahneman and Beatty (add to References and insert number here) found pupil size increases when participants remember more digits. Granholm et al. [11] suggest a higher cognitive load is associated with an increase in pupil dilation. Therefore, pupil diameter can be a measurement of mental workload and cognitive process [14]. This allows for this measure to be used to test whether different representations of architectural space entail different cognition loads. Different cognitive loads imply different responses by the viewer.

2.3 Eye Tracking

Early research on eye movement can be traced back to Buswell [15] who focused on the aesthetic impact of photographs of artwork, patterns and sculpture, particularly the layout patterns of advertisements. Kaufman and Richard [2] measured eye fixation times in several pre-defined parts of figures, the results show that the center of gravity is an attractor as are the edges and corners. Gould and Peeples [16] suggest that a subject's interpretation of a figure does not affect eye movements, which means that only "physical attributes" have influence on the eye movements. Torralba et al. [17] suggested that longer fixation durations of eye movements positively correlate with memory performance. Valtchanov and Ellard found that visual information affects the cognitive load of viewers in multiple ways Arnheim [18]. Gero et al. [19] proposed visual attentional guidance through an experimental search task. Results of their study suggest that the context information plays an important role in object detection and observation. They also suggest some parts of the scene attract more attention than others.

While the relationship between eye movement and perception of artworks has been investigated, there has been very little study on the role of eye movement in the perception of three-dimensional architectural space. One of the few studies on this topic was conducted by Weber et al. [3] in which they collected eye tracking data as participants were asked to look at three-dimensional models, or photographs of models, of architectural space. These models were constructed to collect data on the perception of the following architectural issues: empty space; symmetry versus asymmetry; left and right reversed; obliquely-oriented elements; vista; and foreground. The research focused on comparing different arrangements of objects within a space, rather than different methods of representing the same spatial configuration. Their results showed that, with no priori model in a figure, the attention would fixate at the center; while the foreground was common for initial fixations, the eye did not typically scan the edges of interior space or rectilinearly-oriented contours; the objects on the left attract more attentions than the ones on the right. This confirmed the results by Kuchinke et al. [20]. The study also concluded that fixations did not vary significantly when viewing the physical model compared with a photograph of the model, with the exception of the foreground, which attracted greater attention in the physical model. Additionally, their results also suggest that there were significant differences between the fixations and saccades of architects and non-architects.

3 Experiment

We designed a pilot experiment with the aim of measuring physiological differences due to different modalities of representation of architectural spaces. We measured physiological response to two different digital representations of architectural spaces. In this paper we report results from measuring pupil dilation related to eye movement and saccades. In this experiment, 10 third and fourth year architecture students with similar backgrounds at Harbin Institute of Technology (HIT) in China participated in this pilot study. Given the homogeneity of participant cohort 10 participants are sufficient to produce statistically reliable results. The selection of third year and fourth year architecture students was because design students at this stage already have basic aesthetic and design sense, which is appropriate for the current study. During this experiment participants' eye movements constantly changed, which produced large amount of data—up to 6000 eye movement data points were captured for each participant. This extensive data enabled detailed analysis of designers' eye movement and pupillary behavior.

During the experiment participants were initially asked to complete demographic questions regarding their gender, age and first language. Then they were required to look at two images shown on a screen, Fig. 1. Figure 2 shows the two images used: the first one (R1) is a computer generated perspective drawing of a set of architectural spaces, and the second (R0) is a digital photograph of the same spaces when built. The reason for comparing these two representations is that—firstly, the modality of representation may affect the cognitive load of the viewer, secondly, the color in the digital photograph may affect designers' cognitive attention; and thirdly, the complexity level of the areas in the image may be affected by the color.

The participants' eye saccades and fixations data were recorded by an eye-tracking system (Tobii studio) as they looked at the images. Each of the images was shown for 20s with a few seconds for recalibration in between them. Half of participants were first shown R1, then R0. The other half were first shown R0, then R1. After each image session there was a questionnaire session. Data collected included eye fixations, saccades and pupil dilation.

To identify the characteristics of participants' response to the spatial representation, we identified 7 Areas of Interest (AOIs) in the visual scene, Fig. 3. Each AOI defines an area that we wanted to gather data about. AOIs defined the three doorways, the two wall surfaces between them, the terminus of the corridor and the ceiling.

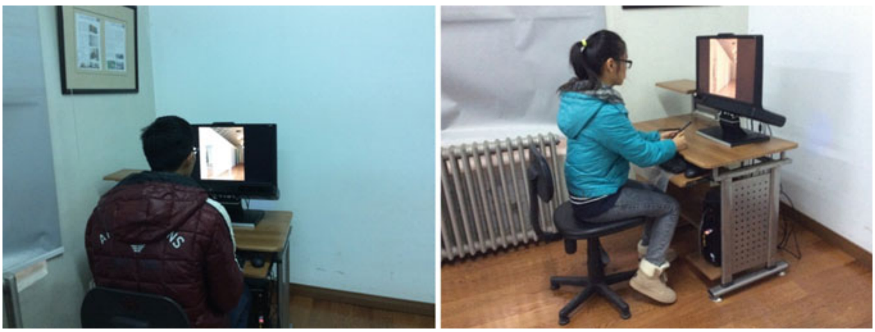


Fig. 1 Two views of the experiment setup

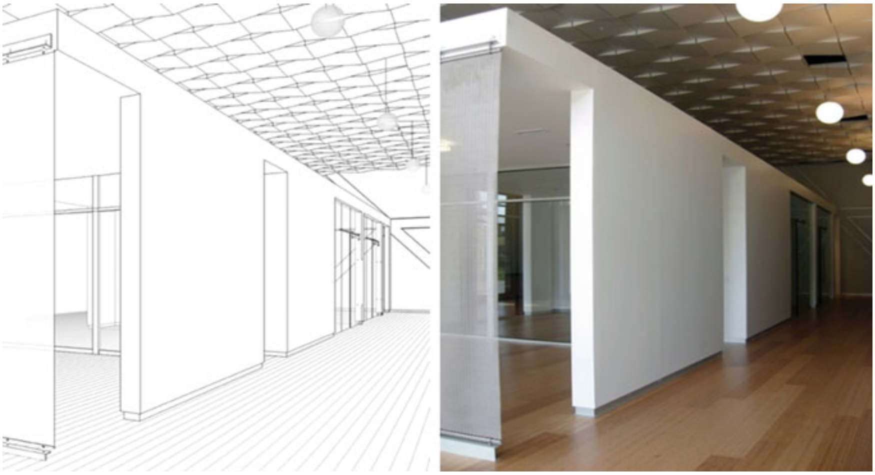


Fig. 2 *Left* Computer generated hidden-line perspective of a set of architectural spaces (labeled R1 in the experiment). *Right* Digitized photograph of the same spaces (labeled R0 in the experiment)

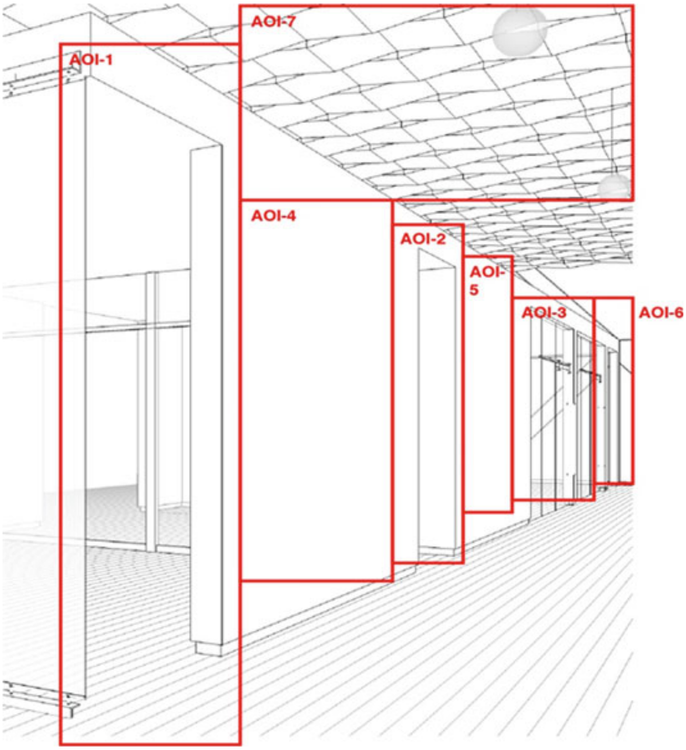
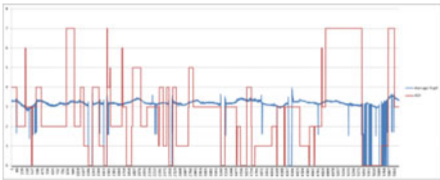
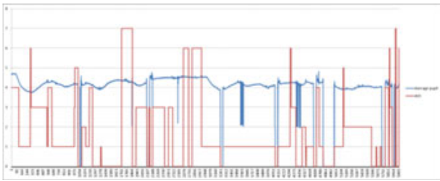
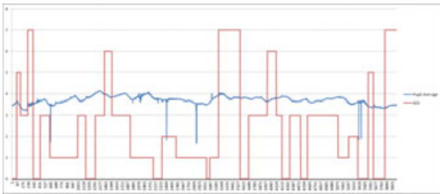
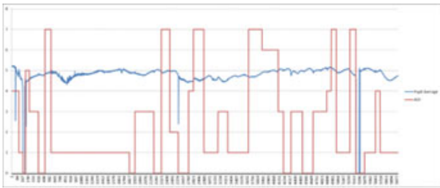
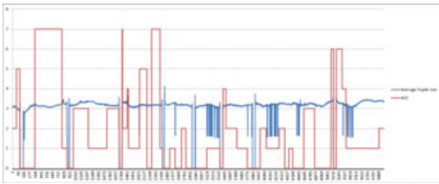
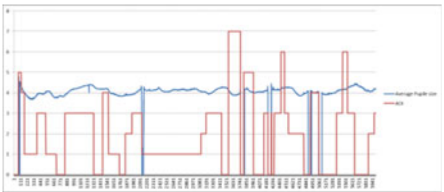


Fig. 3 The seven areas of interest labeled AOI 1 through AOI 7 in R1, they occupy the same positions in R0

Table 1 Plots of AOI focused on and pupil diameter for three of the participants

Student	Images	
1	R1	
	R0	
2	R1	
	R0	
3	R1	
	R0	

The red line is the AOI focused on at that time (the vertical axis is a nominal number whose position has no meaning), the blue line is the average pupil diameter

4 Results

During the experiment, we captured eye movement data for each AOI for each gaze, and pupil size of both eyes. Table 1 shows the pupil size changes with AOI of each participant when they looked at the two images (R1 and R0). The red line represents the AOI focused on, while the blue line represents the pupil size changes. When a participant looked at any location outside the 7 AOIs that was coded as 0. Next, we analyzed the correlation between AOI changes and pupil size changes. The method of analysis is that each time a participant's AOI changes, we measured the mean pupil size of the two eyes for the 30 segments before and after the changes. This gives us four metrics, which are compared using an unpaired t-test, with a threshold of $p < 0.05$ considered as statistically significance.

Table 2 shows the averages of the four metrics for the data of the 7 AOIs in Image R1 and R0. From this analysis, we found on average 84.0% of the pupil size change are significantly related to AOI changes when designers look at the line drawing image (R1). While they look at the digital color photo, this value is 83.1% (R0). We can infer that pupil size change when the AOI focused on changes is statistically significant in both the line drawing images and the digital photo. The pupil size changes are related to their cognitive load, therefore, results confirm that designers' cognitive load are associated with the AOIs they looked at.

From an unpaired t-test of pupil size change of Image R1 and Image R0, there is no significant difference in cognitive load due to representational modality.

From the same pilot study, Table 3 shows the eye movements results for the same 30 HIT students. In comparing Image R1 and Image R0 there were differences

Table 2 Percentage of significant pupil size change when moving from AOI to AOI ($p < 0.05$)

	Percentage of significant pupil size changes Image R1	Percentage of significant pupil size changes Image R0
Student 1	70.2	82.1
Student 2	84.9	75.0
Student 3	82.9	92.1
Student 4	66.7	59.6
Student 5	95.4	92.9
Student 6	76.6	76.3
Student 7	94.4	95.5
Student 8	82.8	85.4
Student 9	95.2	84.3
Student 10	91.3	87.5
Average	84.0	83.1
SD	9.8	10.1
p	0.8386	

Table 3 T-tests of Image R1 compared with Image R0 for students from HIT [21]

	p values						
AOI	1	2	3	4	5	6	7
Time to first view (secs)	0.001*	0.204	0.030*	0.633	0.400	0.353	0.029*
Time viewed (%)	0.028*	0.267	0.009*	0.633	0.154	0.067	0.026*
Fixations	0.003*	0.960	0.873	0.633	0.015*	0.359	0.631
Revisits	0.002*	0.751	0.667	0.633	0.007*	0.820	0.591

*$p < 0.05$

in three of the four eye movement measurements: time to view, time viewed, fixations and revisits. Time to first view, time viewed and fixations were all statistically significantly different when viewing the computer-generated line drawing perspective compared to viewing the digital color photograph for Area of Interest 1, which is the first AOI to be viewed in the digital photograph but is only the third AOI to be viewed in the line drawing perspective. Interestingly, AOI-1 had the highest percentage of time viewed for both modalities, whilst there was a lack of congruence for the other three measures.

Even though the cognitive load of both digital representations is the same there are significant other physiological differences between the digital photo image and line drawing image when being viewed.

5 Conclusion

This paper presents the results of eye-tracking measurements of pupil diameter of architecture students looking at two different digital representations of the same spaces. As expected the results of this study suggest that architectural students' pupil size change is significantly related to changes of their focus area for both the computer generated perspective drawing and digital photograph images. Pupil diameter directly correlates with the viewers' cognitive load. Since the pupil size change is related to human cognitive working load, we can infer that students' cognitive load is related to changes as they focused on different AOIs. However, there was no statistical difference in the changes in cognitive load between the two different representation modalities. Since the earlier result in Valtchanov and Ellard [21] showed significant differences in where they looked and for how long they looked, the results in this paper imply that cognitive load is not directly related to representational modality. This is a potentially important result, if confirmed by future experiments to be generally applicable, as it is unexpected that at this level of cognition the two representational modalities are similar. Since the earlier results have shown that there are significant differences in eye gaze fixations, this result implies that not all cognitive activities are affected by representational modality.

Results of this study contribute to the current understanding of the relationship between designers' cognitive load with their physical reactions, which provides new perspectives for bridging design studies and cognitive science. Future work of this study is to expand the sample size to achieve more statistically robust results, to explore the relationship between students' eye movement and their cognitive design thinking, and to increase the number of representational modalities with the goal of producing an understanding for designers of the implications of the use of representations both for themselves and for their clients.

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Framework of a KE Application Software Development for Emotive Design: A Computational Cognitive Science Perspective

Tanmoy Goswami, Anirban Chowdhury and Sougata Karmakar

Abstract Computational Cognitive Science (CCS) is a new domain of interdisciplinary study to address problems related to human emotions, cognition, and socio-behavioral aspects based on computational and predictive techniques. The CCS addresses computational model development for software application to configure human emotions. People would like to buy a product which has emotional values. Therefore, it's become essential to design emotive product that represent the expected emotive qualities of consumers. Kansai Engineering (KE) is one of the beneficial techniques to design emotive products. The term 'Kansei' is a Japanese word which is referred to sensitivity, sensibility, feeling and emotion. Literature suggested that KE process helps in creativity based product design. Further, creativity is defined as the tendency to generate or recognize new ideas or alternatives that may be useful to solve problems. So far, there is hardly any computer application found which generates creative and emotive design ideas based on KE process. This paper proposed a CCS based framework to design KE computational application. Consequently, the application will help designers to design emotive products in an effective way.

Keywords Computational cognitive science · Creativity · Emotive product · Kansei Engineering

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1 Introduction

People are more interested to buy a customized product now a day. Therefore, it is high time to understand customer's emotional aspects while design a new product. That's why designers need to inculcate many wishes and needs of customers into product which makes the product successful. Designers not only need to consider the technical perspective of products; but also emotional, aesthetic and feeling of individuals. Kansei Engineering (KE) is a valued approach that gives constructive solution in such scenario. The KE based design process will able to pay attention toward human behavior when they observe pictures or stuffs comprising product's features and observe how individual's preferences or cultural origins works to their feelings [1]. One objective for product development in this scenario is to be able to determine the buyer's attentions/feelings of products and translate those emotional characteristics into concrete product design [1]. Computational cognitive science is a new domain of interdisciplinary study to address problems related to human emotions, cognition, and social behavior based on computational techniques. Creativity based KE process is well established methodology to design new emotive products but it is lengthy and time consuming process. CCS deals with emotive software developments [2]. The proposed framework will help to develop a CCS based KE software; which will assist designers to generate creative ideas in short time. In this paper a computational cognitive science based framework was proposed that help system designer to develop the KE application. It is essential to understand about KE process and theories of creativity for product design, prior to elaborate the proposed framework.

2 Creativity

As described by Prof. Herbert A. Simon, design can still be about converting present situations into desired ones. In the domain of design research; design is frequently described as being an activity to frame a planned resolution for a defined objective [3]. The definition of design has continued to modification along with the time. It is well known fact that design and creativity are inseparably related to each other. Creativity is defined as the tendency to generate or recognize ideas, alternatives or possibilities that may be useful in solving problems. It has key role in concept generation, communication of ideas, and design problem solving [4]. Creativity is still one of the most unpredictable components in human intelligent. Creativity is a powerful tool for design process. Many researches have been done on creativity since long time. For example, Geschka (1996) has been studied creativity techniques like brainstorming, visual confrontation, and morphological techniques, which were practiced in Germany or German speaking countries since the 1960s [5]. Creativity techniques are very useful to find out several unique ideas in a short span of time.

3 Kansei Engineering

Kansei Engineering is an established method for translating human emotions into a product design. It is used for improving users' satisfaction on a deliverable by examining the connections between their feelings and design constraints [6]. The emotional aspects are fundamentally considered in Kansei Engineering and User-Centered Design. Conventionally, User-Centered Design has engrossed on practical facets of consumer needs [7], which are normally inadequate for emphasizing user's satisfaction [8]. Therefore, it is essential to move one step ahead of usability in order to recognize customer satisfaction allied with other aspects of product use such as emotions [9, 10]. Kansei Engineering also translating the human feelings into physical product attributes [11]. Kansei is a Japanese word used to express one's feeling towards object, circumstances and surrounding. It is hard to express the meaning of Kansei in different languages. According to Nagamachi, the closest interpretation of Kansei is "psychological feelings" people have with products, situations or surroundings [12]. Kansei is commonly described as sensitivity, sensibility, feelings and emotions. Thus, today the word "Kansei" is being used directly to express these meanings.

Eight types of KE methods had developed; these were KE Type1-Category Classification, KE Type II-Kansei Engineering System (KES), KE Type III- Hybrid Kansei Engineering System, KE Type IV-Kansei Engineering Modeling, KE Type V-Virtual Kansei Engineering, KE Type VI-Collaborative Kansei Engineering, KE Type VII-Concurrent KE and KE Type VIII-Rough Set KE [13].

The KE method comprises of following stages: Domain Decision, Kansei Dimension, Product Design Dimension and Synthesis, to develop Kansei product (Please see Fig. 1). According to this model, domain decision refers the selection of specific domain. This step is mandatory as Kansei is unique in each domain. Kansei Dimension includes 3 steps: identification of Kansei, measurement of Kansei and analysis of Kansei. Product Design Dimension phase is the method of defining significant design features such as colour, size, and shape of the product sample. Finally in the Synthesis stage, study is executed to determine how the design of a product impacts buyer's Kansei [13].

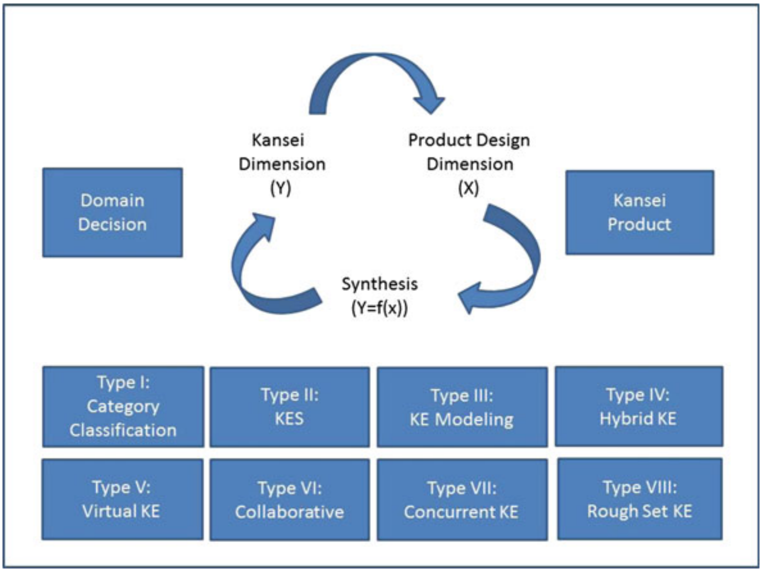

Fig. 1 Process of Kansei Engineering [9]

3.1 Domain Specific Researches Based on Kansei Engineering

Many researchers have already used Kansei Engineering as a root methodology to enhance the emotional aspect of a product or service. Some of the research outcomes are listed in Table 1. Many domains like Food Industry, Life Style Product, Robotics, Automobile, Hotel Industry and Home Decor have been benefited by the application of KE. Please refer Table 1 for related KE words.

Table 1 Domain specific application of Kansei Engineering

Applied domain	Aim of the study	Kansei words	References
Food industry	KE in cuisine design	High fat, salty, savoury, shape, colour, material, exquisite, light flavour	[14]
Life style product	Sunglasses presentation and selection from E-commerce site	Glamorous, sporty, cool, sensual, sleek, gimmicky, modern, bold, trendy, stylish, feminine, flashy, artistic	[15]
Robotics	Design of a humanoid-robot as teaching mediator for autistic children's	Amusing, attractive, depressing, stimulating, responsive, adorable, boring, lively, friendly, understandable, cheerful	[16]

(continued)

Table 1 (continued)

Applied domain	Aim of the study	Kansei words	References
Automobile	Design of an application to study car interior selection	Playful, luxurious, elegant, retro-looking, likable, sporty, Clean-looking, Easy to understand	[17]
Food industry	Design of daily worker evaluation model for SME-scale food production system	Tension-Anxiety, depression, anger-hostility, fatigue, confusion, vigour and friendliness	[18]
Home decor	Innovative alarm clock design made from bamboo	Traditional, clear, creative, exclusive, unique, artistic, natural, interesting	[19]
Hotel industry	Quality services design of on luxury hotel services for tourists	Convenience, welcomeness, confidence, friendliness, attractiveness, elegance, relief, satisfaction, cleanliness, happiness, relaxedness, peacefulness, satisfaction, spaciousness, attention, elegance, modernization, quietness	[20]
Life style product	Design of assistive mobility product for Japanese elderly	Wish, hesitation, surprise, joy, satisfy, fear, sadness, anger, sweet, dizziness, body pain, hot body, annoyance, headache	[21]
All grooming & wellness	Evaluating affective perception of disposable razors design	Beautiful, unfashionable, sportive, unnecessary, simple, light, constant, practical, innovative, serious, Technological, doubtful, lasting, rigid	[22]
Packaging industry	Design of packages for powder shaped fresheners	Bright, beautiful, strange, unique, colourful, interesting, elegant, trendy, modern, simple, look different, eye catching	[23]
All grooming & wellness	Development of balinese aromatherapy product	Unique, attracting, exotic, natural, balinese product, luxurious, artistic, bright, traditional, fashionable, eco-friendly, and transparent	[24]
Home decor	Ceramic product design	Expensive, modern, contemporary, patterned, attractive beautiful, nice, artistic, creative, innovative, harmony exclusive, simple, fascinate, aesthetics, aspiring, inspiring neat, dynamic, limited edition, strong, cosy, stable, safe, healthy, variety	[25]

4 Methodology

A literature survey was conducted using keywords related to computational cognitive science, emotive design, KE and creativity through different search engines (e.g. Google Scholar, Science Direct etc.). KE and CCS process followed and then framework was constructed. Around 126 related papers were selected where 28 papers out of 126 which are directly related to KE and CCS have been thoroughly study to meet the requirements of review process. Finally, a theoretical framework for KE application software design has been developed based on CSS.

5 System Ideation Considering Computational Cognitive Science

Several cognitive theories are available in the literature for emotional product design. Cognitive theories explain the underlying phenomena of emotion generation based on product attributes and their impact on product choice [26].

Based on the literature survey a framework has been developed to conceptualize KE based application software (see Fig. 2) to enhance creative process. In this framework, it is reported that KE process might help to generate creative ideas for emotive design solutions, through permutation and combination rule of creativity.

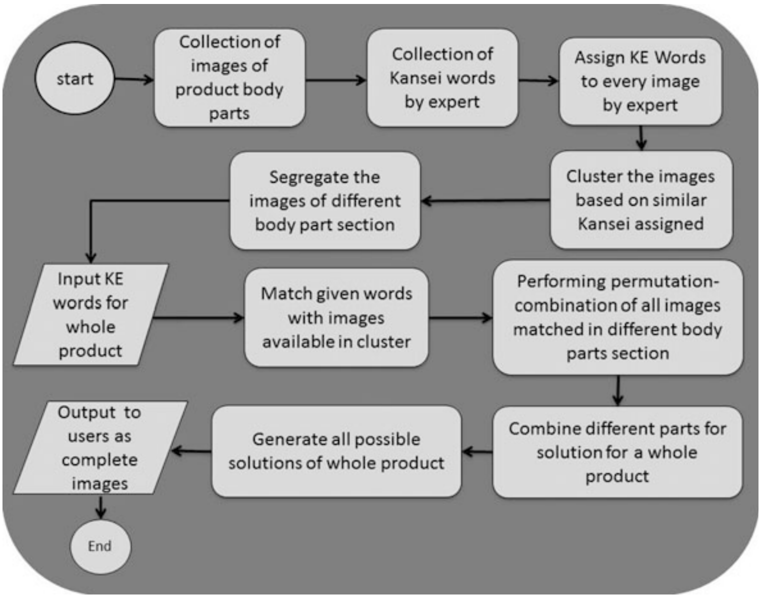

Fig. 2 Steps of development of KE application software

Moreover, it is feasible to develop the KE based application software to generate new emotive product ideas which will help designers to enhance the design process.

5.1 Development Process of CCS Based KE Application Software

The proposed framework of emotive computational system starts with database creation. Database creation stage is actually focuses on collecting product specific images of a defined type of product, for example bikes, cars etc. So, first a product should be defined.

Then the product needs to be divided into fixed no of parts and assign the names for the individual parts. Start to collect the images of every body parts by different means (e.g. from internet, by clicking real pictures etc.). After that, it needs to create new image bank of each body parts of the defined product. Now it needs to collect Kansei words by the experts from that particular product domain. Here after different Kansei words need to be assign to all individual body parts. Finally a cluster will be created of similar Kansei valued images.

In next stage, Kansei words of interest will be taken as inputs from designers. Designers can choose form given list of Kansei words. They can also select multiple Kensai of their choices. In the processing stage, a matching and selection method will be carried out. All the matched product's body parts with the given Kansei words will be retrieved. Now all the product‘s body parts will go through a permutation-combination phase. Final result would be generated as several whole images of product. In final output stage, all possible solutions with the Kansei words will be shown to designers.

5.2 System Framework

The framework of proposed system (see Fig. 3) has four main blocks: 1. Database Creation block, 2. Input block, 3. Processing block and 4. Output Block.

1. **Database creation block** included steps of collecting images of different body parts of a product and collection of related Kansei words. All possible Kansei for the defined product should be collected. The classification based on Kansei words should be done by human factor experts. Database block is primarily responsible to explore maximum options that could be provided to user. This stage has a vital role to play in proposed application framework of emotive product design system. Database could be created such a way that all product attributes are collected. Product attributes could be operated to enrich product personality, product usability to safeguard product choice [27]. Database would be made big enough so that the system should be able to produce more creative

options to the user. The final cluster would be the collection of similar body parts images having same Kansei value.

2. **Input block** is basically used to provide the desires or the needs of users about the product. User should feed the specified Kansai words to the system. Here the system should be taken proper data as input to process it and should generate creative solution for user. User need to be clear about product's emotive value in this block. System would continue its processing as per given input only.
3. **Processing block** is responsible to retrieve all possible options from the database cluster. It should have adequate computational advantages for data processing. System hardware specification should be defined as per the database volume. The prime purpose of the system i.e. to generate several creative design solutions for emotive product should be achieved at this stage. Processing block should retrieve every single image that has been matched with given inputs. At this stage other probable way to create new choices for users must be handled. The shape grammar approach supports analysis and representing new concepts which might help to constructing algorithms that generates new design solutions [28]. Permutation and combination rules could be applied to bring new ideas. Finally, multiple creative design solutions for emotive product should be produced. All different body part should be structured to form the whole product image.

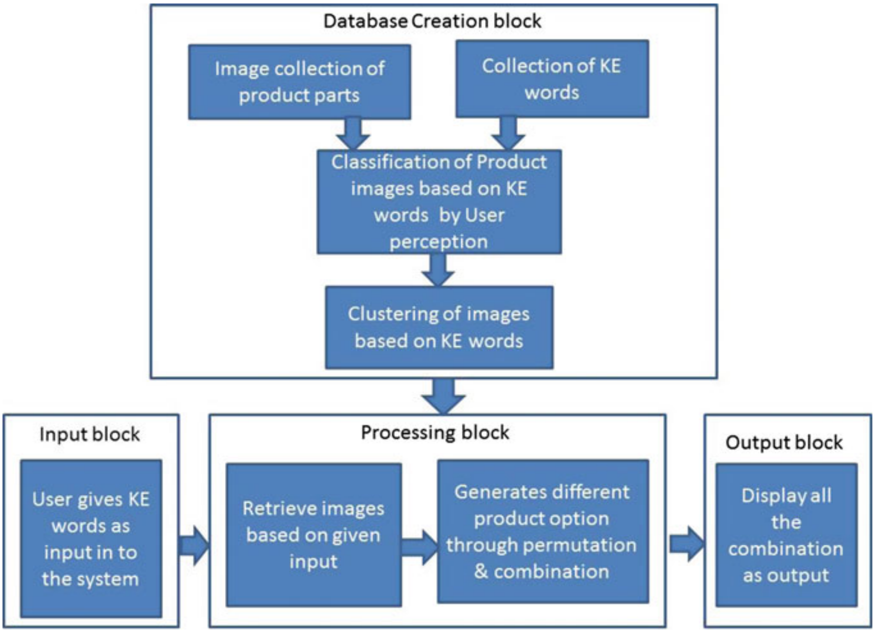

Fig. 3 System framework

4. **Output block** displays all the probable emotive design solutions for the product of interest with the help of graphical user interface. Users can view all the Kansei words associated with complete product image. Users can also take hard printed copy of emotive product images on paper as an output at this stage. Emotive design solutions could be easily produced by the KE application software employing the proposed CCS based framework. This software would help the designers to enhance the emotive quality of product.

6 Conclusion

It can be concluded that the proposed framework would help to develop a CCS based KE application software. The KE application software could predict product parts related to certain Kansei of users; and, the software could generate creative ideas in short time to assist designers. Thus, it would be beneficial to enhance creative thinking of designers. The proposed CCS based KE application can be used for designing products of multiple domains. The computational feature of the application would produce all possible solutions in few minutes with rapid visualization of product appearances. This kind of design software could able to enhance emotive qualities of product such as bike, car etc. It is not only helpful for designers but customers can also use the application to find their suitable emotive product by inserting the Kansei words of their choices. A theoretical framework has been proposed in this paper. However, validation of the proposed framework has not been done with appropriate case study. Construction of required algorithm and validation of this framework is a future scope of this study.

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A Real Time Automatic Ergonomic Measure in Identifying Postural Deviation for the Assessment of Manual Assembly

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Abstract For real-time ergonomic applications, it is essential to track body data and perform real-time data analysis, for detecting postural deviations and possible ergonomic difficulties. This paper presents a setup that uses a body tracking system for automated, real-time postural data collection during an assembly task, for use in ergonomic studies. An analysis of the tracked data in developing a measure for assemblability assessment is also presented. A case study of a standing posture assembly, which involved inserting a threaded bolt into a threaded hole in a peg board, is used for the analysis. During the assembly task, postural data of operators is tracked automatically and analysed for angular variations in time, which is then compared with the benchmarks provided by RULA. The time taken in various postures across the activities is also compared. The results show that variation in the torso angle can be taken as a potential measure for assessing reach difficulty in assembly.

Keywords Body tracking · Assembly · Human posture · Assemblability · Reach

1 Introduction

Assembly is considered a labour-intensive activity, in particular for manual and complex assembly scenarios. Therefore, it is essential that manual assembly work situations be carried out in an ergonomic manner. A large number of work situations

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and the different exposures to be considered in these make ergonomic evaluation extremely difficult [1]. The importance of ergonomics assessment has been studied extensively in literature [2, 3]. Assembly accounts for over 50% of manufacturing costs, where human safety is an important aspect that needs to be considered along with assembly costs. Assemblability techniques help reduce process costs early in design. Assemblability is referred to as the degree of ease in performing an assembly, and is applied by designers to assess and reduce process time, production costs and time to market. Also, it is used in enhancing worker safety [4, 5].

In literature, critical body-postures are identified using video recordings of assembly-execution by human-operators [6]. Existing methods for assemblability assessments rely primarily on manual video-analysis, with its applications in various areas [7–9]. Researchers identify key-frames from these videos, of regions in which the difficulty involved is high, in order to assess the difficulty involved in performing the job. These techniques are generally time consuming; the effort required to assess assembly difficulties can be significantly reduced by automating the identification of critical body postures involved in the task. For automated assemblability assessment, capturing relevant data in real-time is important and technically feasible, but automation of analyzing assembly related difficulties is still a challenging task.

Many techniques could be used for real-time automated body tracking. In this work, automated body tracking has been carried out using electromagnetic (EM) trackers. This paper reports a setup for automatically collecting data in real-time while an assembly is in progress, and a method for ergonomic studies using the body tracking system. Also, the paper presents the results of analysing the tracked data in developing a measure for assessing reach difficulty in assembly.

2 Background

2.1 Working Postures

Adoption of awkward work postures by workers in many work situations and maintaining these postures for prolonged durations, increases the risk of musculoskeletal disorders (MSD) [10, 11]. Such postural deviations have been linked to several kinds of pain and its associated issues dealing with worker safety. In order to gather information for assessing difficulty encountered by operators, it is therefore necessary to track the operators' body postures during assembly scenarios. Identification of the operators' critical body postures have been carried out in earlier studies by the use of video recordings of assembly processes [6]. It is generally recommended to ensure that awkward postures for prolonged durations are avoided, and assembly is made easier, with improved product quality and safety of the worker. Various studies such as those reported in [6] show that working posture is an important criterion for identifying assembly difficulty.

2.2 Automated Data Acquisition

Several methods including Electro-Magnetic (EM) trackers can be used for automated data acquisition. In EM trackers, various body segments can be tracked automatically. The emitter, which is known as source, generates three mutually perpendicular electromagnetic fields that are detected by the sensors. The sensors, which are fitted on the body, measure field attenuation and send these details to a computer. The triangulation principle is incorporated to find their distance. For this study, EM trackers are selected as these are cheaper in comparison to other techniques with similar functionality. Further, these trackers have advantages like large working volume, good resolution, convenience in use, and no line of sight problems.

3 Experimental System

3.1 Details of System Usage

A system of eight EM trackers has been used to instrument the upper body and arms of the operators involved (Fig. 1). Each tracker is programmed to report its 6-DOF Position & Orientation with respect to the electromagnetic source. Position is reported as a 3×1 array of Cartesian coordinates; orientation is represented as a 3×3 rotation matrix.

The eight trackers are placed on the body at eight locations: One on vertebra C7 at the base of the neck, one on the head using a helmet, and three on each arm: On the top surface of the hand, on the forearm along the Ulna, and on the upper arm in the gap between the biceps, triceps and deltoid. These locations are chosen as the closest to the bone structure in order to avoid errors due to skin and muscle movement.

The arm is modelled as a 7-DOF system with 2DOF on the shoulder, 2DOF on the Elbow and 3DOF on the wrist. The sequence for rotation is modelled to match the body's natural movement and described in Table 1. Each joint is separately calculated from the rotation matrix of the trackers on the links that form the joint. (e.g.,

Table 1 Description of the joints tracked by the system

Joint	DOF	Sequence of rotation	Frames
Shoulder	2DOF	Flexion, abduction, (skin error)	YX(Z)
Elbow	2DOF	Rotation, (skin error), flexion	Z(X)Y
Wrist	3DOF	Pronation, ulnar deviation, flexion	XYZ
Torso	3DOF	Rotation, flexion, lateral bending	ZYX
Neck	3DOF	Flexion, lateral bending, rotation	YXZ

Fig. 1 Electromagnetic tracking system that was used for the experiment

Fig. 2 Home and calibration position used for analysis

Wrist rotation is calculated by taking the rotation matrices of the forearm and hand, and elbow rotation is calculated by taking the upper arm and the forearm).

The rotation at any joint is defined as the relative change in orientation of the distal link with respect to the proximal link. It is displayed to the user in terms of Euler angles with one angle for every DOF at the joint. In order to account for variance in the placement of the trackers across subjects, each experiment is started with a calibration procedure. First, the subject is asked to stand in the 'home position' shown in Fig. 2, which is the reference position with respect to which all angles are measured [12], and is chosen to coincide with the neutral position for ergonomic assessment of assembly operations using RULA [13]. The computer program captures the values of all trackers at this position and assigns these as zero values for each individual tracker. This operation, known as Boresight, ensures that the reported angles of every joint are reported with respect to the ergonomic home position.

Boresight is followed by capturing 3 positions (Fig. 2, snaps 2–4) at the extremes of the shoulder and elbow movements, which are used by the program as reference values to interpolate and correct errors due to skin/muscle movement at the joints.

3.2 Prerequisite Steps

In this study, thirty subjects (20 male and 10 female) have been involved, with an average age of 27. The subjects are graduate students in Engineering or Design. Each subject is briefed about the study; and in particular, its goals. The subjects are asked to provide their personal data, viz., name, age, gender and hand preference. Following this, stature height, maximum working range (i.e. workspace) in terms of reach, and the range of motion for various body segments of the subject, are measured.

3.3 Setup

The set up comprises a set of threaded bolts and a peg board with threaded holes at various locations. The subjects are asked to perform an assembly process which involves inserting a specific bolt into a specific hole (Fig. 3). During this process, the body of the subject is tracked using Polhemus-Liberty™ Trackers 1–8. The trackers are fitted onto the subject's body, as explained in Sect. 3.1. The experimental set up is shown in Fig. 3. The design of the experiment has been such that at least two of the reach points (i.e. the two holes at the farthest distance) are beyond the workspace of the subject while standing upright. The position of the holes where the bolts are to be inserted are kept at three distinct distances from the

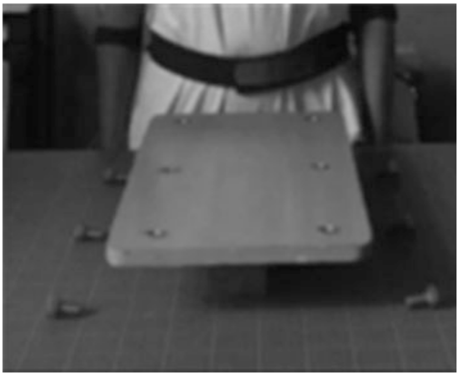

Fig. 3 Working setup of an assembly used for assemblability study

subject, such that the difficulty increases progressively in terms of the subject's reach. The experiment is video recorded; feedback from the subjects are obtained to understand which parts of their body felt strenuous.

The assumptions or provisions made in the experiments are as follows: (a) Negligible inaccuracies due to skin movement, and the inherent errors of the system, are not taken into consideration; (b) the experiment is conducted in an environment made free of metals, and the subjects are asked to not to carry any metallic objects while they perform the task, in order to avoid any interference to the tracker from magnetic metals; (c) lower part of the body, viz., legs and feet, are not tracked, as the experiment involves only the upper part of the body above the waist.

3.4 Experimental Procedure

The authors' hypothesis is that the torso angle variation plays an important role in identification of reach difficulty. The experiment is carried out in the following sequence: (1) trackers are attached to the subject in various positions as explained in Sect. 3.1; (2) calibration of the values to the home position is undertaken as explained in Sect. 3.1; and (3) the subject performs the experiment as instructed (Fig. 4). In order to ensure the variation in terms of subject's reach, the holes are located such that at least two of the reach points are beyond the workspace of the subject while standing upright.

A continuous stream of data is gathered by the trackers on the postures of the subject while he/she individually performs the assembly. The data generated is automatically fed into a computer program to compute and store the angles of each joint. The stored values indicate variation in various body angles, along with time as one entity. Each joint angle for a body segment is represented in a tabular form as θ_1, θ_2 and θ_3. A sample output of the streamed data from an experiment is shown in Table 2.

Table 2 Sample output data of automatically values of various body postures

Time as recorded in device in millisec	Right upper arm angle in degrees			Left upper arm angle in degrees			Right lower arm angle in degrees		
	θ_1	θ_2	θ_3	θ_1	θ_2	θ_3	θ_1	θ_2	θ_3
1150360.00	0.81	0.61	0.94	4.33	5.18	4.14	3.77	−3.00	−0.44
1150480.00	−1.01	2.50	−1.77	3.38	5.84	6.17	10.98	−9.74	−0.14
1150610.00	−2.65	4.69	−5.51	−0.75	6.22	6.44	20.39	−18.44	−0.74

Fig. 4 Experiment on reach difficulty

4 Output, Results and Discussions

4.1 Output of Tracked Data of Various Subjects

In this study, variation in torso flexion angle is considered to be the most critical angular variation among all angle variations in the body segments, and as a significant angle for study in the designed experiment. For experiments that involve other tasks or areas of difficulty, variation in other postural angles might be more significant. The distribution of torso angle variations across different subjects is plotted for analysis in Fig. 5. This figure shows the time variation in the X-axis, and angle of torso flexion variation in the Y-axis.

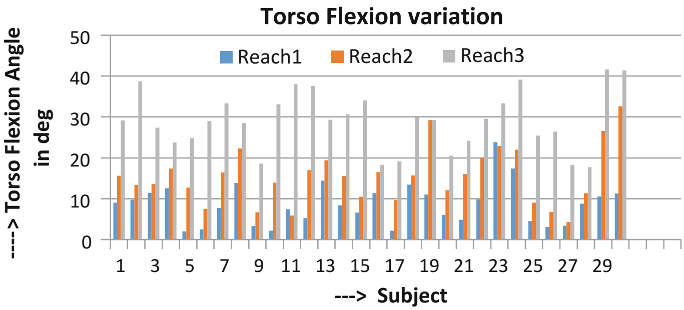

Fig. 5 Torso flexion variation for various subjects

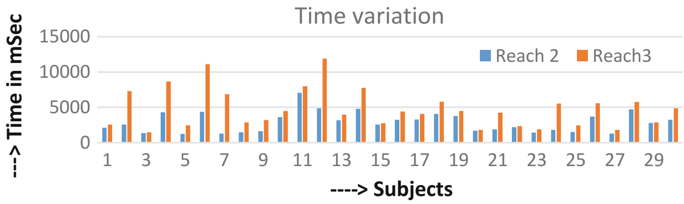

Fig. 6 Time variation of various subjects

Figure 5 shows the various reach points which the subject attains while performing the insertion of a bolt into the hole at that point. The blue, orange and grey bars represent angular values for the torso at the start of Reach 1, Reach 2 and Reach 3 positions respectively. At Reach position 1, the minimum angle reached among the 30 subjects is 2°, whereas the maximum angle reached is 24°. In a similar manner, at Reach positions 2 and 3, the minimum angles reached are 4° and 18° respectively, while the maximum angle reached are 33° and 42° respectively.

Figure 6 below shows the time variation for reach 2 (which is at the maximum workspace of the subject) and Reach 3 (which is beyond the workspace of the subject) positions. The blue bar indicates the time required by a subject to complete the task of tightening the screw at Reach 2; the orange bar shows the time required by a subject to complete the task of tightening the screw at Reach 3. Among the 30 subjects, the minimum and maximum time taken by a subject to perform the activity at Reach 2 are 1225 and 7050 ms respectively. Also, the minimum and maximum time taken by a subject to perform the activity at Reach 3 position are 1475 and 11925 ms respectively.

4.2 Results and Discussion

Figure 5 indicates that variation in torso angle is the highest for Reach 3 (grey bar) position, and higher for Reach 2 (Orange bar) than for Reach 1 (blue bar). When a subject maintains the position of the body at an angle larger than the normal, he/she should undergo greater strain in carrying out the activity. From Fig. 5, it can be seen that Reach 3 (grey bar), which is placed beyond the workspace of the operator, the normal angular limit for a torso (>20°) is violated for 75% of the subjects. It means that most of the subjects performing the activity at Reach position 3 are also most strained at this situation, compared to at reach 1 and 2. In another sense, this also indicates that torso would be a significant indicator of, and a potential measure for assessing reach difficulty.

Figure 6 shows the time variation at Reach 2 and 3. At Reach 2 or Reach 3, the activity performed by the subject are the same i.e. inserting the bolt into the threaded hole; however, the time taken to carry out the task at these two points, in most cases, are not similar. This, we argue, is due to the fact that the subjects are more strained at Reach 3 compared to at Reach 2.

From this study, it is observed that, for the experiments above on inserting bolts into threaded holes in a pegboard, the torso of the body predominantly moves and shows a clear relationship with reach difficulty: torso angle progressively increases as the reach difficulty of the task is increased. All other movements, in other segments of the body observed, are due to movements in torso.

It can be noted from Fig. 5 that reach-specific difficulty can be identified from the notion of change in angular movement in the torso. From Fig. 5, torso movements, irrespective of the subject involved, are progressively higher from one stage to the other as one goes from Reach 1 to Reach 2 to Reach 3. These locations are indicators of location-specific difficulty associated with torso. Along these locations the subjects' difficulty level increases as the distance to reach increases, in spite of the same task being done at each reach point. So, the level of difficulty after reach point 2 is more than at the previous reach point; at Reach 3, the difficulty is higher in comparison to that at Reach 2. The difficulty at the various locations increases progressively as the distance increased, and so does the angular deviation from the ideal position. The difficulty at Reach 3 is found to be the highest; at this location, the subjects reach at least 18° (which is just below the normal); most attain an angle that is much beyond the normal range of angle (20°) that is comfortable for a person to maintain, with the maximum angle attained being 42°.

The other limb movements (like head, wrist and arm) are not considered for analysis in this study, since the movements of such limbs are due to other sub tasks needed to attain the specific goal of the experiment.

The similarity of results of the experiment across the subjects involved indicates that—(1) torso flexion is a significant indicator of limb movement for reach difficulty; and (2) time taken by the subjects is higher when they are more strained. These results of the study could be used as an initial basis for further studies in other assembly scenarios and could potentially be used for simulation for real time assembly. The data could be further analysed for identification of other kinds of difficulty, such as vision and dexterity involved in an assembly task.

5 Conclusions

The research work reported in this paper analysed various results from an experiment designed for automated assessment of reach difficulty in an assembly performed by 30 subjects, the body postures of whom have been tracked using electromagnetic trackers. Torso angle variations at various stages of the assembly and the relative time taken to complete the stages are analysed. The analysis indicates that torso angle variation has the potential to be used as a measure for detecting reach difficulty in manual assembly operations.

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Role of Human Computer Interaction in Building the User Interaction Layer for Citizen Facing Government Websites

Suchitra Pyarelal and Amarendra K. Das

Abstract The E-Government Systems built for Government to Citizen (G2C) services are with the objective of providing quality services, in the minimum possible time. The user experience of a citizen begins from the time of receiving the information about a service and its benefits and accessing the service through multiple channels to the final interaction with the system itself. The end-to-end experience of the interaction that the citizen has with the system can be termed as the human-system or human-computer interaction (HCI). The different stages combine to form the user experience. This paper highlights the present challenges in the existing Government Websites, focused for those under the Government of Assam and the efforts being taken by the Government of Assam in 'Standardization of Websites'. It takes into consideration many important aspects but key among them being: the role that the interaction nature of citizens play while designing such citizen-facing websites: what are the deeper problems in the system that is preventing its wider usage; how the citizens interact with the system and their experience in terms of usability, usefulness and the level of satisfaction; are the interaction patterns of the service delivery to the users adequate. Are the services being provided in the right manner; do the citizens get what they look for in the minimum time with minimal efforts. Since there are many departments within the Government of Assam, how does one resolve the question that the user is within the Government of Assam website and not out of it? The principles for establishing a generic framework for building effective, interactive and usable systems are brought out in this paper so that these can be embedded during the design stage life cycle of systems.

Keywords Citizen centric website · Usability · User experience · User satisfaction. human computer interaction · Standard website · Framework

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1 Introduction

The Indian Government has laid considerable emphasis in adopting e-Governance at all levels by leveraging the Information and Communication Technology (ICT). The National e-Governance Programme (NeGP) in 2006 marked a major step towards setting the stage for e-Governance. The vision of the NeGP was to “make all Government services accessible to the common man and to ensure efficiency, transparency and reliability of such services”. To this end, the E-Government systems are with the objective of improving the quality of the services delivered and delivering them in a timely manner. Citizens being by and large the largest beneficiaries of e-Governance, the majority of the E-Government systems centre around delivery of services to the citizen. eHealth, ePanchayat, eMunicipality, eDistrict are to name a few of such systems that were taken up for execution as Mission Mode Projects (MMPs) [1].

Citizen satisfaction is considered synonymous with good and effective governance. By drawing up the ‘Framework for Citizen Engagement’, an important step was taken by the Government for deeper engagement to ensure citizen centricity [2]. Yet another major step was the drafting of the “Electronic Service Delivery Bill” that requires public authorities to deliver all public services electronically within a maximum period of eight years [3]. E-Governance Standards based upon the policy on Open Standards have been prescribed for integration and interoperation of E-Government systems [4]. The “Digital India” launched by the Government in 2014 aims to take the e-Governance to the next level. The three pillars of the Digital India programme are “E-Kranti-Electronic delivery of services”, “Information for all” and “Reforming government through Technology” is indicative of the thrust laid on effective and efficient Citizen centric E-Government Systems.

Even after the promising strides made in the area of e-Governance, studies on the outcome of the impact of e-Governance indicate that the reach and benefits have not fully been realized, even after years of the systems being in place. The fact that India does not figure in the top 100 countries of the UN E-Government Development Index 2014 [5] is an indication to the overall impact of e-Governance. The recent UN E-Government Survey 2014[1] puts India at 118th position with an E-Government Development Index (EGDI) of 0.3834. For India, the results of three components of EDGDI, Online Service Index (OSI), Telecommunication Infrastructure Index (TII) and Human Capital Index (HCI), are 0.5433, 0.1372 and 0.4698 respectively. OSI measures online presence of the Government and online services available to the citizens. TII measures the status or availability of various Telecommunication Infrastructures in the country through which the citizens can access online services and HCI measures the education level of the citizens that will help them in accessing the online services.

[1]The UN e-government survey is the report in the world that assesses the e-government development status of the 193 UN member states.

The aim of E-Government systems targeted at various stakeholders[2] is to promote good governance and to bring in more efficiency, transparency and accountability. The overall ease with which the end user can avail the services from an E-Government system directly co-relates to its usefulness and thereby its effectiveness. According to the survey conducted by European commission, reduction in time and flexibility in access to electronic services are the motivating factors in electronic services (Javier et al.) [6]. While the low penetration and adoption of e-Governance can be attributed to several factors such as lack of adequate ICT infrastructure, low level of computer literacy and insufficient capacity building among a few of them, there arguably exists inherent drawbacks in the way the E-Government systems have been built.

In the digital medium, websites still remain as the primary source of information for citizens. This paper focuses on E-Government Websites of Government of Assam that are citizen facing. The issues and challenges in Websites of the Government of Assam that front-end the information and services delivery to citizens are evaluated. Initial studies of the existing websites of the Government of Assam had brought forth several issues and challenges being faced by the citizens. Apart from the content not being updated, low user friendliness of the websites was an equally important issue. The methodology adopted by the Government of Assam for addressing the challenges in the existing websites is detailed in the paper. Factors for building effective, interactive and usable websites and the need to embed them during the design stage of the system development life cycle itself are highlighted. The resulting 'Standardized Website framework' developed for Government of Assam Websites that provide the technology, information and process framework for Government Websites is detailed. Citizens are sometimes referred to as the end-user in this paper and the two are used interchangeably.

2 Study of the Existing Government Websites

The approach taken to understand the issues in the existing websites, needs and expectations of the end users of the Government websites used more than one method. The multi-method research tracks are outlined in this section.

Around 29 of the existing Government of Assam websites were studied to get a preliminary understanding of the status and issues. What are the deeper problems in the websites that are preventing its wider usage; Are the required information and services being provided in the right manner? Do the citizens get what they look for in the minimum time with minimal efforts? Issues related to the content, its non-availability, accuracy and low level of intuitiveness were the major findings. It was found that most websites did not comply to the Guidelines for Indian Web Site

[2]Stakeholders -G2G- Government to Government, G2E-Govt to Employees, G2B-Government to Business, G2 N-Government to Non-Profit Organizations.

Fig. 1 The website of a single department, one accessed from assam.gov.in and the second with direct URL

Table 1 Results from the study of the existing websites

Sr. No.	Findings
1	Inconsistent websites
2	Incomplete and inadequate information
3	Information for citizens are minimal
4	Many links were broken
5	The site had too many images and photos

(GIGW) [7] released by the Government for web site usability and standardisation. Information that was available on the websites was found limited largely to the functions of the department, important documents and details of officials. The information that citizens looked for was possibly not kept in mind, as most websites were found lacking in information on their citizen centric services. Furthermore, few departments while having their own website are also linked from the State Portal of the Government. It was found that two websites exist for one department, each one completely different from the other in terms of content, interface and information. In cases such as the one depicted in Fig. 1, authenticity of information becomes a challenge (Table 1).

2.1 *Quantitative Analysis*

A quantitative survey was done in the initial phase. The survey was done online with a sample size of 500 respondents. A cross section of users comprising of Students, Journalists, Service Holders, Retired Personnel, Academicians and Self-employed were selected as respondents. The respondents were asked about the parameters viz: visual appeal, user friendliness, relevance of information, whether information is up-to-date, whether information is comprehensive without having to visit the department, user expectations from Government Websites and to identify the areas of improvement (Table 2).

Table 2 Key findings from the quantitative survey

Sr. No.	Findings
1	Information on the website to be up to date
2	There is a need to categorise information
3	Images on the Websites to be good quality and resolution
4	Fonts to be eye-friendly
5	More Visual appeal required
6	Sites lack professionalism
7	Too many photos in the website that was distracting
8	Links that did not work were present in the website
9	Sites were not bi-lingual
10	Needed to highlight success stories
11	Smart phone compatibility
12	List of publications to be made available
13	Navigating the site to be made easier
14	Availability of all notifications, Assembly Q&A, Inquiry reports
15	Necessity of 'Search' button

2.2 Qualitative Analysis

A deeper understanding as to Why were the websites not providing the basic information sought by the citizens? Why was the content not being updated? What was the process adopted in the website development? Were the requirements of the end users of the website kept in mind while designing? Was any feedback gathered on the experience of the end users of the website in terms of usability, usefulness and level of satisfaction; are the interaction design of the information and service delivery to the users adequate?

The answers to the above could be obtained from only the Government departments who were the owners of the department websites. Consultations with the departments were therefore considered necessary. Focus Groups of Nodal Officers were identified in every department. From several interactions and discussions had with the Department Nodal Officers, it was apparent that most of them were not fully aware of their own department website. The key findings are listed in the Table 3.

3 Analysis of the Findings

3.1 User Needs (Table 2: 3, 10, 14)

In the Government, evaluation of effectiveness is seldom carried out by keeping user as the centre. User satisfaction as being the least used metric in e-Government

Table 3 Summary of findings from consultations with departments

Sr. No.	Findings
1	Involvement of department in the website design, content preparation and regular content updating was limited to one or two officials in the department. The development was generally outsourced to an external hired agency. The website requirements provided by the department essentially translated the working of the department. This resulted in websites having only the details and functioning of the department
2	There were no consultations or collaboration with the entire department during the design of the website. This resulted in two issues. One, many of the department users were not aware of their own website. Second, the information and content from all sections of the department was not covered in the website. Website did not represent the information and content of the entire department
3	The user needs and expectations were not studied or even kept in mind while most of the department websites were being designed
4	Content in the website was not categorized based on the user needs
5	A Government department has the Main administrative department and its constituent organizations. The websites of the main department and its constituent organizations are developed in silos. There is no information sharing between them. This results in redundancy of information as the same information required for both the websites are uploaded separately
6	There was no institutional mechanism for the Website Management. No single person in the department was made responsible. Periodic review of the websites was also not being done

studies directly impacts the usefulness and ease of use of e-Government websites (Javier A et al. [6]). The 'intention to use' is emphasized in the updated Information Systems success model proposed by De Lone and Mc Lean (2002, 2003) [7]. The Global Information Technology Report considers usability and citizen participation as the key parameters for evaluating the effectiveness of e-Governance providing citizen web sites [8]. The 'Framework for Citizen Engagement' [2] advocates the participation of users through information sharing, collaboration and consultative participation. The target end users which could be citizens, business community, NGOs, Government departments need to further be classified on the diversity with respect to age, requirement, ICT skills and expertise, language and network access. Differently-abled user community has to be considered as an important user group.

User needs to be kept as the foremost factor in the design of Government Websites. As users are diverse and different, their needs are also varied.

3.2 *User Experience, User Interaction and Usability of Site (Table 1: 4, 5, 11, 13)*

The user experience of a citizen begins from the time of receiving the information about a service and its benefits, accessing the service through multiple channels to the final interaction with the system itself. The end to end experience of the interaction that the citizen has with the system (can be termed as the human-system or human-computer interaction (HCI)) which are in stages, combine to form the user experience. In this, the actual interaction with the system for obtaining the services, is considered as the longest stage and play an important role in determining the effectiveness of the system. Garett in his book 'Principles of User Experience' [9] has rightly described websites as a self-service product where user is all alone when facing the website. There are no user manuals or representatives to guide the user. Here it is the experience of the user that will be the only factor that will determine if the user will come back to the site. The model proposed by Kumar and Mukherji [10]of e-Government adoption considers citizens to be the focal point of e-Government services .

When efforts are being made for improving the front ends, very little, so far, seems to be really specific to e-government HCI as observed in the studies made. The Guidelines for Indian Web Sites [11] are mainly for web site usability and standardization. How the user interacts with the system, the interaction nature, usability of the interfaces are areas that require expertise in the field of Interaction and User Experience design.

Experts on User interaction design are required

3.3 Information Content (Table 1:1, 2:1, 3:4)

Accuracy and Authenticity of information available on the websites were among the factors that resulted in the low usage of the websites. This along with trust and usability are factors that affected the adoption of the e-Government. Kumar et al. (2007) [10].

Responsibility for Information Content in a website should be the collective responsibility of the department. Periodic review of Website content is required.

3.4 Information Architecture (Table 2:1, Table 3: 4)

Information Architecture (IA) of a website refers to the design of the structure and organization of the website. To provide a satisfying user experience, government websites must have a well organized structure or IA. User should be able to find the information in the minimum possible time. Information content on the website has to be under proper and meaningful classification.

Categorizing the content as per the target user group and under meaningful menu options.

3.5 Information Management (Table 3:5)

There exists information that can be shared between departments. Such information is at present being uploaded in each website leading to information redundancy and duplication of efforts. At times, there is inconsistency in the information due to the varied sources from which it is uploaded. The information that is required to be provided by all departments can be standardized. An integrated website for departments and its constituent organization will make it easier to share and manage information.

Responsibility for Information Content in a website should be the collective responsibility of the department. Periodic review of Website content is required.

4 Methodology Adopted by the Government of Assam

4.1 Establishment of Institutional Mechanism for Websites

An Institutional Mechanism was established for the long-term sustainability and management of the websites. A Website Development cell was set up with IT and Domain experts. Every department had designated Responsible Officers, Content Managers, Master Trainers, Website Administrators with defined roles and responsibility as a part of the Website Governance Structure. Regular and Periodic review of content, enforcement mechanism of the Website Standardization guidelines was made a part of the responsibilities of the Responsible Officer [12].

4.2 Constitution of an Expert Committee with Experts Drawn from Department of Design, IIT Guwahati

The Government of Assam constituted an expert committee for guidance on Design, Usability and Human Interaction Aspects of Government Websites. This committee had experts from Department of Design, IIT Guwahati.

4.3 'Standardized Website Framework' for the Government of Assam Web-Sites

The SWF comprised of Technology, Information and Process requirements for the end-to-end development of Standardized Websites. Toolkits were developed for each area of the SWF viz: Identifying User needs, Content Grouping, Drawing up the Website Information Structure, Standards and Guidelines for Websites.

User Needs

During the workshops held for the Department Content Managers, the first activity was to identify who the target users were of the website. At the first level, the users were identified as Citizens, Business community, NGOs, Other Departments. At the next level, the Citizen users were further classified based on various parameters and groups viz: age, region, computer literacy level, students, Job seekers, Employers, Pensioners etc. The needs and expectations of each user group were then determined. Toolkit 2 of SWF provides the step by step activity involved [12].

Information Content

In the entire process of developing websites, very little importance was given to con-tent planning and its readiness. The existing websites lacked in good content. Content identification and planning activity was given importance from the start of the development. Identification and Grouping of content was the next activity Standard content required in all the websites were identified. Content related to all areas of work within a department were required to be identified and grouped. Toolkit 3 of SWF describes the methodology for Toolkit 3 of SWF describes the methodology for Identify and Classifying Content for Websites [12].

Information Architecture

When a citizen visits a Government of Assam department website, the assurance that he or she is at the right place is the first step towards a good user experience. This can be made possible by means of an identifying header for the Government Websites. Next, a citizen would expect every government website to provide a minimum set of in-formation viz, whom to contact, how to lodge grievances and give feedback. This set of information that is expected to be available across all website can be referred to as 'Standard Content'. Going a step further, a citizen would expect that the Standard Con-tent is always at a particular place on all the Government websites. This brings the need for a uniform placement of 'Information' across the websites. As we take a step further, citizen would look towards finding a specific type of information under certain categories. Under the link of 'About the Department', it is expected that the Vision, Mission, Citizen Charter are available. Hence there is a need to read, understand and evaluate the expectations of user. All this brings to the need to bring some amount of Standardization with respect to information, content and placement. Toolkit 4 of SWF describes the steps for establishing the Website Structure [12].

4.4 Capability Building

A Series of Content and Master Trainers Sessions are organized for each department. Content Mangers representation were required in each work area of the department. This ensured that information of entire department was considered. Further, updating the website was now the responsibility of the entire department. Capability building of minimum two Master Trainers within the department was done.

4.5 Validation

Validations of the Standardized Framework was done with the development of six department websites as pilot websites. The website development was outsourced to an external agency. At each phase of the development, the expert committee had reviewed the website design and structure. The initial prototype underwent several versions based on the review and suggestions of the expert committee. Some of the key recommendations with respect to the User experience and User Interaction are as follows:

1. Different views for Target user group
2. Site to be made simple and clutter free
3. Colour contrast of the website
4. Logo colour and its placement
5. Grids to be present
6. Positioning of the portlets
7. Colour code should be intuitively provide the linkage
8. Tab Menus should have clear separators
9. Font size of the text
10. Size, Colour and Text Department and Sub department names (Figs. 2 and 3)

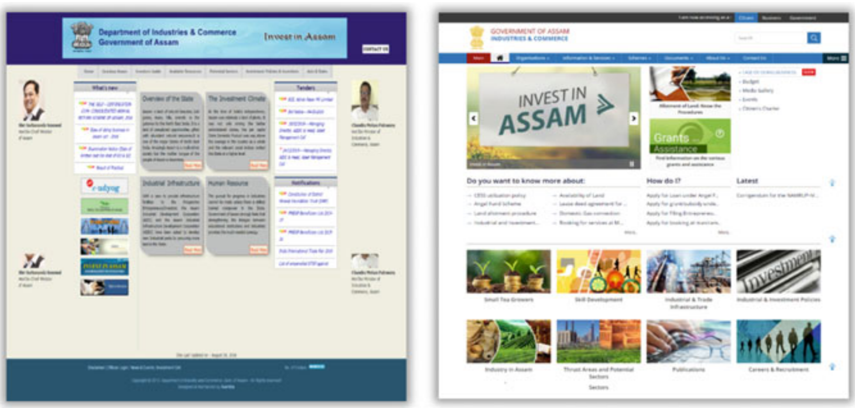

Fig. 2 Website of industries and commerce (before and after)

Fig. 3 Website of directorate of employment and craftsman training (before and after)

5 Conclusion and Recommendations

Usability (Seamless interaction), Utility, Efficiency, Appeal are key factors influencing adoption of e-government services by citizens [7]. From our study of the websites and preliminary research done with users, that usability aspects were considered at peripheral level of the websites only. Modelling and understanding the users' interaction experience is an important challenge in the design stage [2]. An interface that met all the diverse requirements of users became a key challenge during the development of Standard Website Interface. This was mainly because of the fact that the interaction requirements of websites cannot be generalized.

The critical review and suggestions by the experts from the Department of Design, IIT Guwahati on Website usability, User experience, Visual aspects of the website developed by resulted in greatly transforming the citizen interface. In the design of the Standard website, we used common user design principles and build context based designs after a complete understanding of the type of users their needs and requirements.

Designing the user experience for e-government systems require balancing the human needs and interaction design [1]. Ongoing advances in HCI, cognitive science, psychology and neuroscience will help in identifying the behavioral aspects of the user and redesign to their specific needs Jraidi et al. [13].

What is significant is, while several research studies and efforts are being carried out on the supporting technology areas, very little is being done on the improvement of effectiveness of the E-Government systems itself. Areas of importance are the design methods, tools for building usable, consistent and reliable user interfaces [14].

The measure of Usability and Interaction is not easy to predict especially when it comes to citizen centric systems. Hence the research and studies need to first simulate the model of HCI with the Websites. Design practices for diversity of users and design patterns for seamless access need to be evolved. How these can be dovetailed into the life cycle development is what needs to be evolved? Techniques for user participation, end user usability evaluation tool for studying the interaction patterns at different points during the design cycle of the E-Government system. Methods to develop usability evaluation models based on the target age group, level of computer literacy.

HCI tool kits need to be developed along with guiding polices that can form a part of SWF that will serve both the E-Government Websites designers and development community.

We recommend that HCI for E-Government Systems should be made an integral part of the Digital India Programme. Sustained research will be required to make the next generation of citizen facing interfaces more useful, usable and universal.

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Virtual Ergonomics Evaluation of a Design Concept of Manual Powered Portable Paddy Thresher Suitable for Hilly Region Agriculture

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Abstract In the north-eastern states of India, paddy threshing is mostly carried out by traditional methods (such as bullock treading; beating by hand; crushing by foot, etc.) which require an enormous physical effort. These discomfited situations expose workers to many risk factors from ergonomics viewpoint. Therefore, it has been perceived that there is a necessity for systematic design and development towards low cost, manually operated, portable thresher considering the contextual need and topo-geographical conditions. The present research demonstrates the development of a concept CAD model of a portable pedal operated paddy thresher and evaluates the model through virtual ergonomic assessment. For virtual ergonomic evaluation of the CAD model of the thresher, customized digital manikins (5th, 50th and 95th percentile models of both male and female) were created in DELMIA software. These manikins represent anthropometric dimensions of the Assamese agricultural worker population. Postural comfort evaluation in virtual environment revealed that the proposed model was found to be acceptable. Following virtual ergonomic evaluation, it is expected that the development of real physical prototype would certainly be cost effective, user-friendly and efficient for small and marginal farmers in the rural area.

Keywords Anthropometry · Human factor · Posture · Threshing · Digital human modeling

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1 Introduction

With the development of farm mechanization, improved farm implements and machinery came into use for various farm operations with the aim to increase the productivity of land with the rationalization of labor through timely operations, efficient use of inputs, improvement in the duality of produce, resulting in reduced drudgery of the farmer. Mechanization of various tools and technique used for production, transportation and processing of agricultural products is a need for sustainable development of agriculture [1]. It is well perceived that using CAD based design approaches will extrapolate the advancement of farming, thereby boosting the rural economy, improving the competitive farm's ability, and finally raising the farmers' economy. To date, the conventional design in agricultural gradually transformed into modern digitized design tools. Application of CAD has made the design of farm machinery intuitive, flexible yet convenient.

Computer-aided Design (CAD) and Digital Human Modeling (DHM) (specialized CAD software for virtual human representation) technologies endow unique opportunities to integrate human factors proactively in product design and research. Enhancing agricultural productivity and farmer's incomes through improvement in the design of farm tools/machinery and their interaction with user compatibility can assure by the adoption of modern technologies like CAD and DHM. The literature review revealed an extensive number of studies shifted from conventional design methodologies to advanced techniques in diverse fields. Today, a paradigm shift is taking place in the field of engineering design, where with the help of DHM, researchers have a preliminary focus on interfacing the human with the machine to achieve better man-machine compatibility. DHM has a comparatively late entry into agricultural engineering set-up. The application of DHM in agriculture setting is most widely used for the off-road vehicle only, especially for tractor cab. The digital human model has capabilities to create a specific population attributes which facilitate designers to build tractor cabs suitable for operators of varying body dimensions. It provides the developers with a biomechanically correct CAD realistic representation of the human body, i.e. manikin, which can be simulated of driver's posture and motion behavior [2].

In the developed countries, however, harvesting and threshing of rice have almost entirely mechanized, and this has resulted in a remarkable reserve of time and labor. Furthermore, the increased income of the farmers from higher paddy yields has provided additional encouragement for mechanization. However, cultivation in hilly terrains is still carried out with traditional hand tools or bullock drawn wooden implements. In fact, The Northeast Region (NER) of India is still in the early stages of evolution as far as mechanization is concerned. Th farm mechanization in Northeast states has not taken up the required shape, possibly due to terrain, cultivation practices and economic condition of farmers as well as weak promotional efforts from the governmental and private organizations. Moreover, in NER, non-availability of improved farm tools and implements along their repairing facilities are also one of the major restrictions in the growth of mechanized farming.

Therefore, the present paper demonstrates the virtual ergonomic evaluation process to confirm whether the proposed design of pedal operated paddy thresher would be acceptable to prospective users and satisfy their needs in a real scenario without compromising comfort and efficiency.

2 Methodology Followed

The present research focused on the design and evaluation of an ergonomic paddy thresher in a virtual environment with due consideration to an anthropometric database of Assamese farmers' population. The development and assessment in a virtual environment have numerous benefits like shorter design time, reduced redundant changes, lower manufacturing costs, better quality, increased output, enhanced safety leading to heightened morale.

2.1 Creation of Digital Human Models and Rendering of Comfort Posture

State-of-the-Art of digital human modeling has been widely and commonly used within the product development process since its early stage up to the product production and delivering [3]. For evaluating human-machine interaction considering anthropometric diversity by creating human models, also known as manikins, of different sizes and proportions, is essential. In the present study, anthropometric data of Assamese population were compiled and referred to for ergonomic design and subsequent evaluation of a CAD model of the conceptualized paddy thresher. The digital human mannequins were built to accommodate the target range of Assamese farmer populations in the present study, using the anthropometric database for each selected representative in the DHM simulation system. A total of six digital human models (5th, 50th and 95th percentile for both male and female) were created to represent smallest, average and largest dimension of target population respectively (Fig. 1). Comfort postures rendered over the digital human manikins.

2.2 Generation of Digital Prototype of Pedal Thresher

Mechanical design feature of DELMIA (V5R19) digital human modeling software was used to generate the CAD model of the proposed thresher. After finalization of the various dimensions of the proposed model, 2D diagram was constructed. Using 2D layout, 3D solid model was created with CATIA (Fig. 2). Following development of the CAD model for individual parts, all parts were assembled for the

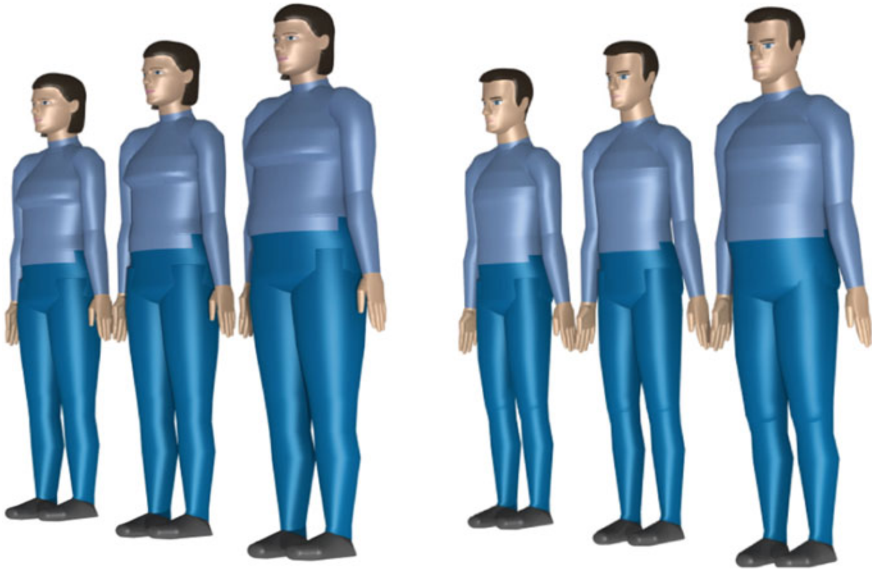

Fig. 1 5th, 50th and 95th percentiles male and female custom-built digital manikins

preparation of 3D model of the thresher. The thresher redesigned in a way to suit a wider range (5th–95th percentile) of operators. 3D CAD model of the machine was created and analyzed in a virtual environment with the help of DHM to test its efficiency and usefulness.

Here, it is worthy to mention that the concept model of the thresher also considered other features (apart from anthropometric compatibility) as given below:

(a) grain shield for reducing spread of dusts/husks and thus respiratory protection; (b) chain gear' mechanism instead of 'four bar linkage' mechanism, to simplify power transmission system; (c) adjustable pedal height with variable range of movement to satisfy the user with varying lower limbs' heights; (d) attachable wheels for translocation of the thresher within short distance; (e) substantial reduction in overall weight of the thresher by modifying the design and selecting lighter materials; (f) easy assemble/disassemble of components (i.e. cylinder, grain shield, frame and power transmission mechanism, etc.) for comfortable carrying at different terrains and during transportation.

2.3 Virtual Product Development

The ergonomic design of agricultural tools and equipment using CAD-DHM dictate the designer for improved comfort, safety, and productivity. Undoubtedly, these tools have enough potential to improvise the product development challenges, thus

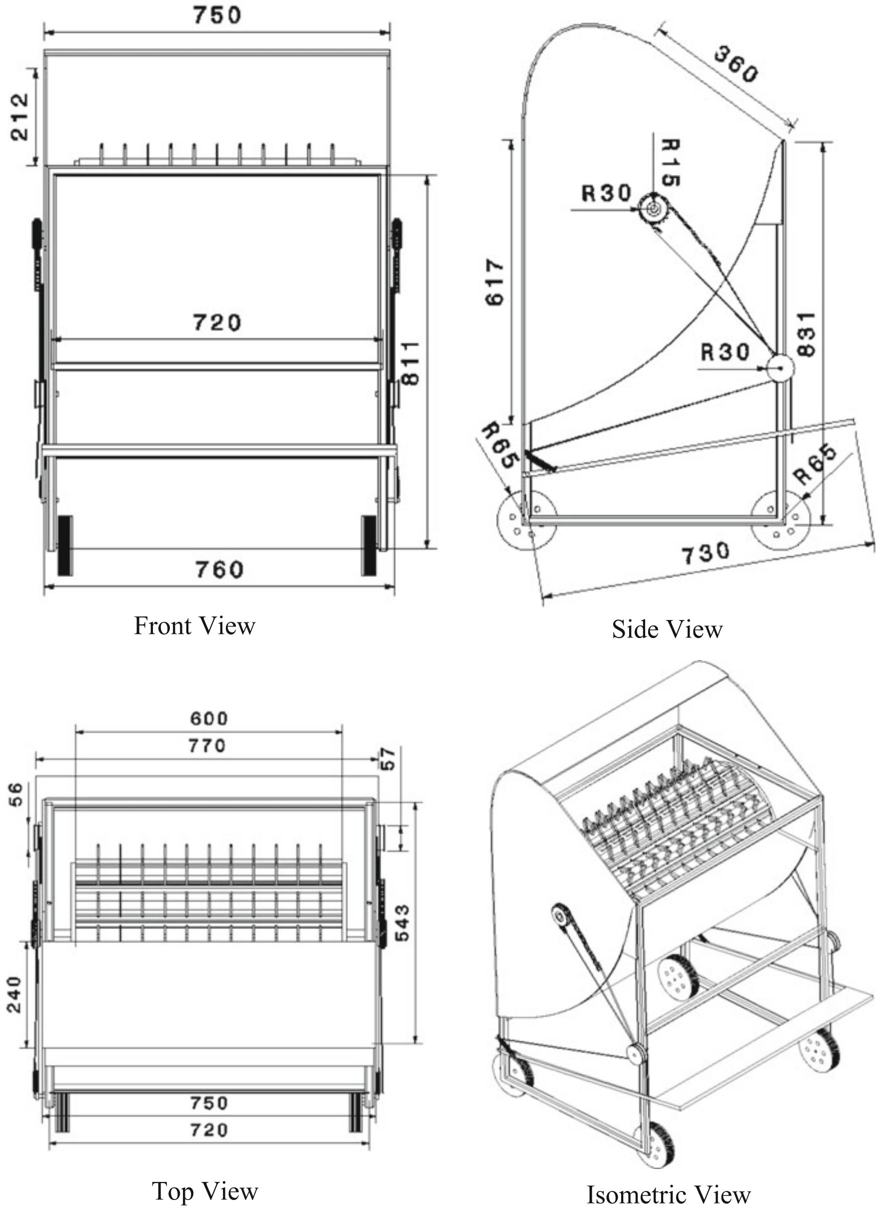

Fig. 2 Detailed dimensions of developed pedal thresher (All dimensions are in mm)

exercising control over the entire process of virtual design and analysis of the product before its physical launch. These techniques allow changes in the initial phase of the design stage, thus reducing the chance of ergonomic problems in development stage before creating the actual prototype.

2.4 Interfacing Digital Human Models with the Virtual Paddy Thresher

Precise interfacing between digital human models of Assamese farmers and CAD model of paddy thresher featuring selected working postures were achieved using ergonomic design and analysis function in DELMIA. Work activities of modified and existing paddy threshers were evaluated using DHM representing 5th, 50th, and 95th percentiles male and female agricultural workers to pinpoint the postural load.

3 Concept Product Evaluations

The conceptualized pedal operated paddy thresher was evaluated for finding its suitability to the intended user population in performing necessary activities.

3.1 Working Posture Assessment

The research application of Digital Human Modeling (DHM) is emphasizing on the necessity of using this technology for design and analysis of farm tools, featuring an amalgamation of ergonomic guidelines along with other engineering design considerations. The proposed model of the pedal thresher was found anthropometrically compatible for all manikins (5th, 50th and 95th percentile male and female) used for evaluation (Fig. 3). The above finding indicates that the design concept of the proposed thresher would accommodate a broader range of the targeted user (agricultural workers of Assam) starting from the 5th percentile female (representative of smaller body dimensions) to the 95th percentile male (representative of higher body dimensions). The postural comfort analyses in virtual environment revealed that the proposed model was advanced.

3.2 Biomechanical Analysis

Mechanical load on the lumbar spine is considered as a contributing factor to many of the lower back anomalies [4]. The compressive forces on L4–L5 lumbar spines, due to the mass of a body plus load acting on hand and trunk, have a safe/cut off limit of 3433 N with the maximum permissible limit of 6376 N, as recommended by the National Institute of Occupational Health [5]. A safe limit of 500 N with 1000 N as the maximal allowable limit was suggested by University of Waterloo ergonomic research group towards joint shear [5]. Spinal compression forces were evaluated for existing and developed paddy threshers. For the developed thresher,

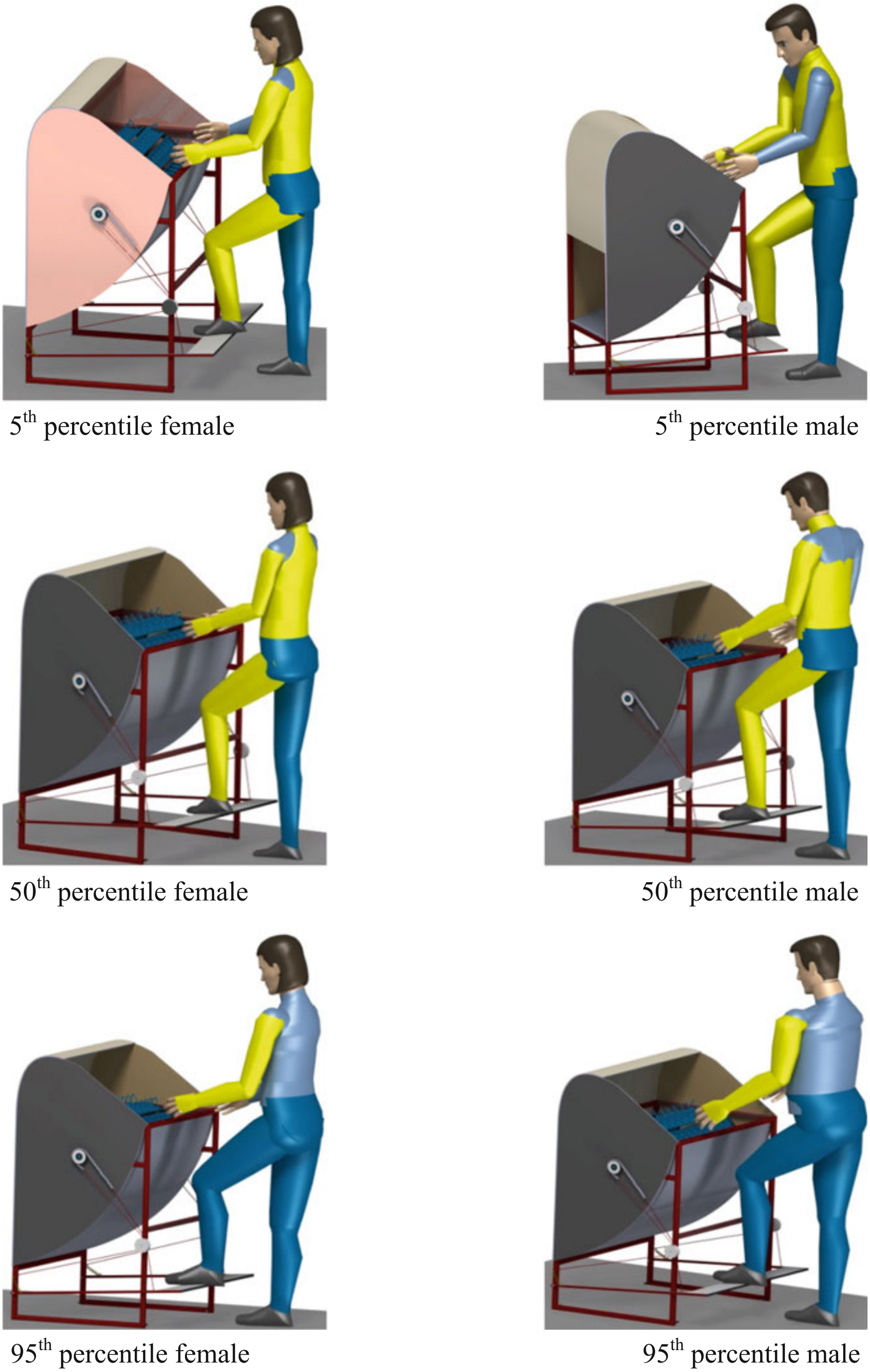

Fig. 3 Posture analysis while using 5th, 50th and 95th female and male manikins for proposed pedal operated paddy thresher

L4–L5 Compression strength of 5th, 50th and 95th percentile male were 873 N, 1057 N and 1790 N respectively, whereas, for female, readings were 858 N, 861 N and 1065 N respectively. The absolute values of the L4–L5 compressions were found to be within acceptable limits.

4 Discussions and Conclusion

While designing various agricultural hand tools and equipment for NER, little attention has been given to the users' competencies and limitations [6, 7]. The importance of the present piece of research is to standardize the various design parameters of paddy thresher suitable for targeted user population. With the existing paddy thresher, one has to apply greater force [8] in a maintained awkward posture, which is highly susceptible to the risk of muscle injury. To address these issues, various human factor aspects of a CAD model of pedal thresher were evaluated in DELMIA with virtual manikins. CAD and DHM technologies have made it possible to identify key design issues behind difficulties which may be encountered by workers in performing their tasks, in the early phase of the design process. These also allow for configurations and design changes in the virtual design stage (before making the actual prototype) and can reduce the risk of human-machine incompatibility problems [9]. The essential function of DHM software is a realistic display of anthropometric data and simulation of design challenges and processes, such as visibility, reach analysis, posture analysis, seat design and comfort [10–12]. Designers can subsequently utilize a human model in engineering design and analysis capabilities for improving the workplace and control of human-machine interface virtually [13] to ensure enough clearance and space to a person for their ease and comfortable movement within the workplace.

Globally, a wide range of applications and benefits offered by DHMs technologies are steadily harnessing by most of the industries, to radically substitute and streamline its traditional processes of design, increase the productivity and efficiency. However, this technological revolution in agricultural sector is still in its infancy. Some of the researchers used DHM for tractor cab design and evaluation [14, 15]. The application of DHM in the agricultural industry is no doubt getting momentum particularly in tractor and power tiller design such as tractor operator's workplace for operator cabs, seat position, seat height, visibility, adjustments for brake reach and linkages, etc. Although, nowadays agricultural machinery manufacturers are aware of the fact that emergent DHM technology offers many benefits like testing and design configurations without real human subjects and expensive physical mock-ups; less workforce and timely processing; improved productivity and reduced production cost. However, in many instances, the initial investment for purchasing software and developing the infrastructure are quite expensive and challenging for manufacturers to adopt. Therefore, efforts are needed to ensure greater access to these technologies. These technologies offer a number of potential benefits to design both agricultural machinery and work environments to meet the needs of human operators. There seems to be an imperative need for effective collaboration among designers, engineers, researchers, scientists, and entrepreneurs for their extensive adoption of these modern technologies through organizing workshops, training, seminars, conferences, etc. It is expected that advancement in design and proactive ergonomics analysis through DHM technology in the agricultural sector would deliver a knowledge-based approach to key stakeholders who are interested in agricultural engineering and ergonomics in farm machinery/tool design or agricultural workplace evaluation. The present research article motivates the readers to access the vast scope of DHM technology in the agriculture sector for transforming agricultural modernization from stagnation to growth.

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Demonstrating the Effectiveness of Olfactory Stimuli on Drivers' Attention

Monica Bordegoni, Marina Carulli and Yuan Shi

Abstract More than one million people die per year on world's road. Researches have identified drivers' cognitive aspects as the major cause of human errors in 80% of crash events. Driver-Assistance Systems (DAS) have been developed to detect data about vehicle, environment and driver, and to communicate information usually through the senses of vision and hearing. But, the growth of in-vehicle devices increases the visual and auditory demand of the driver. This research aims at investigating whether olfactory stimuli can be used to elicit drivers' cognitive aspects. An experimental framework has been set up, and testing sessions have been organised. The analysis of the data collected from tests shows that olfactory stimuli are more effective in increasing some subjects' physiological parameters than the auditory ones. Therefore, smells may be used as a DAS, for increasing drivers' attention.

Keywords Olfactory stimuli · Drivers' attention · Driver-Assistance systems

1 Introduction

Nowadays, approximately more than one million people die per year on world's road. Since the 70s, several studies have shown that human factors are the largest contributing factors (more than 90%) to the traffic crashes and fatality.

Recent researches have identified drivers' cognitive aspects, which include the management of attention (i.e. distraction and inattention), as the major cause of

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human errors in 80% of crash events [1]. Among the reasons of inattention, there are fatigue, traffic stress-rage and boredom. For instance, driving in monotonous environments may cause boredom to the driver because of the diminished impulses received by the stream of sensorial stimuli, which result in a reduction of the brain activation level. Two important factors that influence the drivers' cognitive and emotional aspects are the arousal level, which is the degree of physiological changes represented in a continuum axis ranging from drowsiness and exhaustion to excitement and tension, and the valence, related to defining emotional responding from anger and sadness to happiness [2]. Thus, it is important to address the development of countermeasures to manage the arousal level and the valence for maintaining the optimum driving performance.

Driver-Assistance Systems (DAS) have been developed to detect data about the vehicle, the environment and the driver, and to communicate information to the driver, usually via the senses of vision and hearing. Unfortunately, the recent growth of in-vehicle devices potentially increases the visual demand of the driver. Besides, auditory signals used to call the users' attention to dangerous events can be confused with other similar ones commonly used for different alerts.

In order to overtake these problems, other sensory channels could be used to influence the cognitive aspect of the drivers. In particular, smell is a fundamental sense in humans. Since it is much more irrational and linked to visceral emotions than the other senses, smell can impact on various aspects of humans' psychological state, and can induce activation or relaxation states in people.

This research aims at investigating whether olfactory stimuli, instead of auditory ones, can be used to elicit and influence cognitive aspects of drivers.

2 Related Works

2.1 Driver-Assistance Systems—DAS

In the last decades, DAS has become a fast growing area in the automotive industry. Among others, research activities regarding "Driver Drowsiness Detection" and "Driver Monitoring" systems are the most important ones. Some different methods are used for detecting drivers' fatigue and drowsiness. Vision-based detecting method is one of the most used. Eriksson and Papanikolopoulos [3] proposed a method to detect driver's fatigue analyzing the eyes' positions from ordinary videos. Pathade and Gohokar [4] present a detection system of driver fatigue using a camera that monitors driver's eye and head movements.

Concerning other methods, Lee [5] introduced a driver's fatigue monitoring system that uses a data fusion approach based on several data types. Zhang [6] based his detection algorithms on the PERCLOS (PERcentage of eye CLOSure) to detect driver's fatigue in realistic driving conditions.

In the marketplace, the first drowsiness detection system was integrated in a Lexus car in 2006. It used a camera placed on the steering column to detect the drivers' eye movements [7]. Besides, both the Ford Driver Alert system and the Volvo Driver Alert Control use a forward-facing camera and sensors to monitor the car position on the highway, and its movements between the lane markings [8]. The Mercedes Attention Assist learns the user's driving characteristics and monitors the steering movements [9]. Even if these detection methods are variable, usually the response mechanisms are similar. Auditory alarms are the most widely used, but some systems use also visual signals to warn drivers.

2.2 Physiological Measurements of Attention Level

Physiological measurements have strong correlations with the arousal level in people. As previously mentioned, the arousal level is the degree of physiological changes (from drowsiness and exhaustion to excitement and tension) and several methods have been used in different research areas. The most used physiological measurement is the monitoring of the Skin Conductance (SC). It has been demonstrated that SC could indicate the psychological and physiological arousal [10]. Specifically, when the user receives a stimulus, this causes an arousal, which could create a peak in the SC values. The peak amplitude may be correlated with the strength of the stimulation. SC is the most widely studied property of Electrodermal Activity (EDA) [11]. Also, bio-signals have been used to detect consumers' preferences [12] and attention during advertising visualization [13].

Monitoring the driver's performance by using physiological signals could offer the most direct indication of early onset of sleepiness and distraction. In addition, this method can also be considered as an excellent platform to share data with other vision-based driver's assistance applications [14].

2.3 Olfaction and Scent Simulation

Olfaction was one of the primordial senses at the origin of humans, since it is devoted to acquire and analyze smells in the air in order to recognize dangers, identify food and support social communication [15].

The process of olfaction involves many regions of the human brain. In short, some of them (the cerebral cortex, the thalamus, and the frontal cortex) manage the conscious part of this process, which concerns the identification and measurement of the olfactory stimulus. In the opposite, the limbic system governs the unconscious and emotional components of perception and, together with the hippocampus, the human olfactory memory. Due to this structure, an olfactory stimulus can evoke memories and unconscious responses at the emotional level even before it is consciously perceived and recognized.

For these reasons, smells can increase the attention level and are deeply evocative [16]. Also, research works demonstrated that smells can induce activation or relaxation states in people due to the fact that they can impact on heart rate or skin conductance [17].

Specifically, Meamarbashi [18] demonstrated that peppermint odor improves the physiological and exercise performance. Raudenbush et al. [19] found that both cinnamon and peppermint odors improved participants' scores on tasks related to attentional processes, visual-motor response speed, virtual recognition and working memory. In the driving context, Yoshida et al. [20] found out that peppermint enables driver to be in full alert state for 9 min on average.

For what concerns scents simulation, in the ICT and Virtual Reality fields, several studies have focused on the development of systems for delivering odors. These systems, named Olfactory Displays, are controlled by a computer, and generate scented air that is eventually smelled by the users. Various techniques and technologies are applied to the development of Olfactory Display [15], which are used for scent simulation in real or virtual environments [21, 22]. Unfortunately, all these systems are often very limited and not precisely controllable for what concerns the number and type of scents that can be generated, the quantity and quality of scents to emit. In order to address these shortcomings and to improve the currently available systems, the authors started developing Olfactory Displays that are more performing and fully controllable [23].

3 Research Hypotheses and Experimental Framework

The research presented in this paper aims at investigating whether olfactory stimuli, instead of auditory ones, can be used to influence the cognitive aspect of the car drivers. Specifically, the hypothesis we make is based on the fact that driving in monotonous environment might cause boredom to the driver, and so his/her attention level could decrease. This is obviously a condition to avoid. And, in fact, drivers' cognitive aspects, which involve the management of attention, are the major causes of human errors in 80% of crash events [1].

Driver-Assistance Systems developed so far usually communicate information to the driver via the senses of vision and hearing. Unfortunately, in the car environment, these senses are already subjected to high demands, and these stimuli can be underestimate or considered as annoying. Indeed, although auditory stimuli are useful, their repetitive use is affected by habituation [24]. They can also be ineffective if interfering with noise, music or other auditory alarms [25].

In order to overcome these problems, the hypothesis we make is that the introduction of olfactory stimuli, instead of those commonly used, can be used for eliciting the drivers' attention level. Indeed, olfactory stimuli can impact on various aspects of humans' psychological states, and can induce activation or relaxation states. Moreover, olfactory stimuli have been proven to improve the attention level for a long time period [20], due to the fact that they impact both on humans' conscious and unconscious levels.

In order to demonstrate our hypothesis, an experimental framework has been set up and experimental testing sessions have been performed. The authors decided to carry out two separate testing sessions simulating a very monotonous car trip and presenting, in the first session, auditory stimuli, and in the second one olfactory stimuli. A within-subject method, with a population of 15 subjects, has been used. During the testing sessions the subjects' physiological data were acquired, so as to collect objective data about subjects' behaviors. Due to practical and safety reasons, it has been decided to use the experimental setup of the i.Drive Lab (http://idrive.polimi.it/), an interdepartmental Laboratory of Politecnico di Milano hosting a driving simulator, where studies about the interaction between driver, road infrastructure, vehicle and environment are performed [26]. The experimental framework consists of a multisensory environment including:

- the seating-buck of the i.Drive Lab for simulating the driver's seat, including Porsche steering wheel, pedals and gear;
- the Optoma active stereo-projector and a wall screen of the i.Drive Lab used for displaying a video reproducing a monotonous car trip;
- a wearable OD developed by authors [23], for presenting olfactory stimuli, and commercial in-ear earphones for presenting auditory stimuli;
- the BioGraph Infiniti system for acquiring the subjects' physiological data (Skin Conductance, Blood Volume Pulse, Heart Rate and Respiration Rate).

3.1 Acquisition of Physiological Data

The BioGraph Infiniti system has been used for the acquisition of physiological data. The system includes various sensors connected to an encoder, and a software tool (the BioGraph Infiniti Software), which captures and analyzes raw data from sensors and converts them in charts. In particular, in the experimental framework the authors have used:

- a BVP sensor, which is a blood volume pulse detection sensor housed in a small finger worn package, to measure heart rate and provide BVP amplitude, BVP waveform, Heat Rate and Heart Rate variability feedback;
- a Skin Conductance sensor, which measures the conductance across the skin, and which is normally connected to the fingers or toes;
- a respiration sensor, which is sensitive to stretch. When strapped around a person's chest or abdomen, it converts the expansion and contraction of the rib cage or abdominal area into rise and fall signals displayed on screen.

3.2 Experimental Framework Setup

The experimental framework consists of the seating buck where subjects seat and live a driving simulated experience. A video of a monotonous car trip lasting 10'24" was shown. Due to the fact that no data about drivers' attention level after periods of time are univocally known, the duration of the video has been defined in order to allow subjects to deeply relax and, consequently, analyze their possible physiological reactions. The video was made by recording a real car trip on a highway connecting two Italian cities (Pavia to Milano). 15 subjects were asked to carry out two different driving testing sessions, which were complemented with olfactory or auditory stimuli. Specifically, during a driving experience some olfactory or auditory stimuli were delivered. In the experiments the peppermint scent has been used as olfactory stimulus. The reason is that this scent has proven to enhance motivation, performance, and alertness in driving [19] and to stimulate arousal [27]. Each olfactory stimulus has been delivered for 5 s, which is an average time sufficient for reaching humans' olfactory apparatus. Regarding the auditory stimuli, it has been decided to use a cellphone ring, an alert tone commonly used for mobile phones as well as in car environments. Each auditory stimulus lasted 800 ms, which is the duration of one ring of a standard cellphone ring. Then, we defined both the olfactory stimulus and the auditory one as "threshold values". In both testing sessions, two stimuli (auditory or olfactory) were produced after 5 and 7 min from starting driving.

The subjects were students and professors of the Design and of the Industrial Engineering Schools of the Politecnico di Milano. Their average age is 30, and 40% of them are female. In order to reduce the influence of culture-specific experiences, which may significantly influence odor perception [28], all subjects were Italian. Subjects were voluntary and did not receive monetary compensation. They were not informed about the topic of the research and were not aware of the presence of auditory or olfactory stimuli in the multisensory virtual environment. Each subject was received alone, and the sequence of the two testing sessions (olfactory and auditory) has been randomly assigned. Consequently, in 6 cases the testing session with the auditory stimuli has been performed before than the one with the olfactory stimuli, while in 9 cases the sequence was the opposite. Moreover, in order to avoid cross contamination effects, the testing sessions with the olfactory stimuli and those with the auditory ones have been performed in different days, and any possible external stimuli have been avoided.

Firstly, subjects were asked to fill in a questionnaire for gathering their background information and for checking if they are smoker, suffer from allergy or have a cold. Then, subjects were made sit on the seating-buck, wear the in-ear earphones, the wearable Olfactory Display and the BioGraph Infiniti sensors. After a period of relaxation, they were asked to watch the video (Fig. 1). After a period without any stimuli, olfactory or auditory stimuli have been delivered. During the driving experience, the subject's physiological data were acquired.

Fig. 1 Subject during a driving testing session

4 Analysis of the Results

In order to carry out the analysis of the collected data, they have been grouped according to the used stimulus. Then, for each subject, the data collected in the two testing sessions have been analyzed and compared. Specifically, for each testing session a chart has been produced using the BioGraph Infiniti Software. Each chart maps the line graphs and means of the Skin Conductance, of the BVP, of the BVP Heart Rate, of the Respiration Rate and of the HRV (Heart Rate Variability). On the whole, the trends of the lines in these charts show that the use of both auditory and olfactory stimuli produced physiological reaction in subjects. In fact, usually the lines are quite flat in the periods in which no stimuli are presented, while peaks can be seen just after the introduction of a stimulus.

After this preliminary analysis, the authors carried out an in-depth analysis of the SC data [10]. The SC is the most widely studied property of Electrodermal Activity (EDA). EDA includes both background tonic (Skin Conductance Level: SCL) and rapid phasic components (Skin Conductance Responses: SCRs), which result from the sympathetic neuronal activity [11]. Then, the raw data gathered by the BioGraph Infiniti software have been imported into Ledalab, a Matlab-based software for the analysis of SC data (http://www.ledalab.de). According to the literature [29], authors decided to consider only the SCRs part. Indeed, SCRs generally increase when a person is aroused [29], while SCL is the general tonic-level EDA which relates to the slower acting components and background characteristics of the signal. Moreover, among the different features of SCRs, the authors used Amplitude for better analyzing SCRs variations. The peak Amplitude of SCRs, measured in µS [11], is calculated by computing the difference between skin conductivity before the SCR onset and the skin conductivity at the peak of the SCRs. According to [30], the onset of a SCRs is expected to be between 1 and 3 s after the stimulus onset. Figure 2 shows an example of the obtained chart concerning the Phasic Driver.

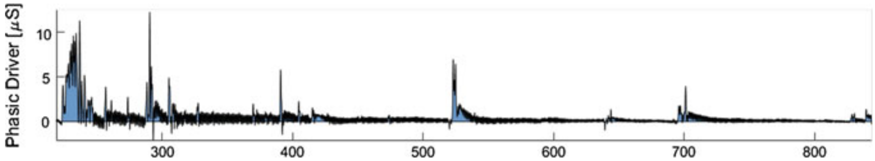

Fig. 2 An example of chart developed by using the Ledalab software

Also in this case, the trends of the lines in the Phasic Driver charts are similar to those observed in the BioGraph Infiniti ones. In 18 cases (62%), the Phasic Driver of subjects has variations during stimuli. Specifically, considering these 18 cases, in 4 cases variations occurred with auditory stimuli, while in the remaining 14 cases, variations occurred with olfactory stimuli. Concerning the amplitude of the variations of the Phasic Driver, in 24 cases (80%, 12 subjects out of 15 in total), the testing sessions with the olfactory stimuli present variations higher and stronger than those of the sessions where the auditory stimuli were delivered. Subsequently, the average values and the values for each stimulus of the SCRs amplitude have been computed, in order to stress the variations amplitude. The values are shown in Table 1.

The analysis of these data showed that, comparing the percentages of the variations in the two testing sessions, in 21 cases (70%) it is higher in the testing sessions with olfactory stimuli. Also, it is worth reporting that the second stimulus is less effective than the first one in 24 cases (80%) with auditory stimuli, and in 20 cases (66,7%) with the olfactory ones.

Also, subjects were asked to evaluate their perceptions of olfactory or auditory stimuli. On the whole, subjects considered their boredom level higher during the sessions with auditory stimuli, the auditory stimuli as more disturbing, and the olfactory stimuli as more pleasant. Also, subjects rated the testing sessions as very engaging. Finally, subjects were not aware of the fact that olfactory stimuli impacted on their attention level.

5 Conclusion

It has been proven that cognitive aspects of drivers are one of the major causes of human errors in 80% of crash events. Some DAS systems for monitoring drivers have already been developed and integrated in vehicles. Several methods are used for this purpose, but usually the response mechanisms consist in auditory alarms or also visual signals to warn drivers. Unfortunately, the recent growth of in-vehicle devices has increased the visual and auditory demand of the driver, and these warnings can be underestimate or considered as annoying. Consequently, other sensory channels could be used to elicit cognitive aspects of drivers.

Table 1 Average Value (AV) and values for stimulus 1 (S1) and stimulus 2 (S2) of the SCRs amplitude

Testing session	Av	S1	Variation (s1—av) %	S2	Variation (s 2—av) %
A1	0.22	0.50	127.27	0.01	−95.45
O1	0.34	1.89	455.88	1.42	317.65
A3	0.22	0.70	218.18	0.66	200.00
O3	0.23	3.17	1278.26	0.32	39.13
A4	0.06	0.13	116.67	0.02	−66.67
O4	0.07	0.50	614.29	0.20	185.71
A5	0.07	0.11	57.14	0.05	−28.57
O5	0.11	0.45	309.09	0.37	236.36
A6	0.13	0.85	553.85	0.02	−84.62
O6	0.13	0.95	630.77	0.93	615.38
A7	0.12	0.02	−83.33	0.04	−66.67
O7	0.26	0.60	130.77	0.17	−34.62
A8	0.25	1.29	416.00	0.90	260.00
O8	0.45	1.08	140.00	2.19	386.67
A9	0.78	2.33	198.72	0.02	−97.44
O9	0.25	1.58	532.00	1.03	312.00
A10	0.07	0.01	−85.71	0.01	−85.71
O10	0.07	0.12	71.43	0.30	328.57
A11	0.11	0.62	463.64	0.05	−54.55
O11	0.09	0.15	66.67	0.59	555.56
A12	0.13	0.05	−61.54	0.01	−92.31
O12	0.03	0.18	500.00	0.17	466.67
A13	0.16	1.05	556.25	1.20	650.00
O13	0.29	2.76	851.72	1.37	372.41
A14	0.08	0.13	62.50	0.11	37.50
O14	0.21	0.75	257.14	0.26	23.81
A15	0.22	1.06	381.82	0.32	45.45
O15	0.64	2.49	289.06	0.42	−34.38
A16	0.49	2.54	418.37	1.12	128.57
O16	0.46	1.82	295.65	2.12	360.87

The research presented in this paper aims at investigating whether olfactory stimuli, instead of auditory ones, can be used to influence the cognitive aspect of the drivers. For this purpose, an experimental framework has been set up and experimental testing sessions have been performed.

The analysis of the subjects' physiological data collected in the testing sessions shows that, in comparison to the relaxation state, olfactory stimuli are effective in increasing some values of the subjects' physiological data more than the auditory ones. Specifically, the analysis of the Phasic Driver shows that in 80% of the cases the testing sessions with the olfactory stimuli present variations higher and stronger in comparison to those of the testing sessions with the auditory stimuli.

Future studies will be carried out for testing different kinds of scents, as well as their intensity and persistence, although olfactory perception is quite subjective and related to people's background and it is difficult to define standard thresholds and limitations. Also, on the basis of the presented preliminary results, future studies will involve a bigger number of participants, in order to enlarge the sample size and achieve a grater statistical significance.

In conclusion, the research here presented demonstrates the possibility and the effectiveness of integrating Olfactory Displays in car interiors for assisting drivers in maintaining their optimal driving performance.

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ICT Technology for Innovating the Garment Design Process in Fashion Industry

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Abstract The Italian fashion industry is nowadays subject to radical transformation; therefore, it needs to remain competitive and, at the same time, innovate itself, in order to strengthen its position in the global market. An important opportunity of innovation can be the introduction of ICT technologies in the garment design process, which today is based on traditional methods and tools. Moreover, this innovation could be particularly important for online sales, in order to reduce the customers' doubts during purchasing. The research presented in this paper describes a framework for designing clothes as realistic 3D digital models and for allowing customers to evaluate the designed clothes by using realistic virtual mannequins of their bodies instead of the standard ones. A case study will be presented in the paper. The obtained results show that the framework can innovate the traditional garment design process and it could have a huge impact on fashion industry and customers behaviours.

Keywords Virtual prototype · Design process · Cloth simulation · Body scanning · Motion capture

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1 Introduction

Fashion is one of the most important industrial sectors in Italy, and it is based on long tradition, knowledge and expertise. Nowadays, similarly to other sectors, it is subject to radical transformation, due to the rapid evolution of the fashion global market. Therefore, it needs to remain competitive and, at the same time, innovate itself, in order to strengthen its position on the global market.

In this scenario, an important opportunity of innovation can be the introduction of ICT technologies in the garment design process. Indeed, up to now, the Italian fashion industry refers to a traditional design process, based on artisans' knowledge and skills, and ICT technologies are only integrated in few phases (as for instance, the development of cutting layouts) of the development process. On the other hand, the extensive usage of ICT technologies can represent a competitive advantage, as demonstrated in other design sectors (furniture, lighting, automotive, etc.).

Moreover, this approach could be particularly important for online sales. In fact, this strategic area is not really exploited because of customers' doubts during the purchasing. While for other goods (e.g. computer, household appliances, and furniture) customers can evaluate their characteristics by checking their technical and functional features and by considering their aesthetics, for clothes they can only make hypotheses about the wearability on their body, and the fabric behaviours according to a declared "standard size".

The research presented in this paper describes a framework for designing clothes as realistic 3D digital models. The novelty of this approach concerns the combination of a set of existent IT applications (e.g., Microsoft Kinect, Blender and Clo3D), which have been integrated in order to create a unique workflow for garment design. The framework allows customers to evaluate the results through realistic virtual mannequins. Specifically, virtual models of clothes can be designed and interactively modified in a 3D environment starting from 2D sewing patterns, which are today the most used tools in the fashion industry. Furthermore, different fabrics, prints and finishing effects with realistic behaviours (facings, hems, etc.) can be applied to the virtual clothes.

Then, customers can evaluate the designed clothes by using realistic virtual mannequins instead of the standard ones. These mannequins are accurate reproductions of the body and movements of customers, since the framework integrates systems for the acquisition of body shape and movements. In an envisaged scenario, both the shape and movement acquisitions can be performed in few minutes in specifically equipped shops.

A case study developed by using the framework will be presented in the paper.

2 Related Works

2.1 Garment Design Process in the Fashion Industry

The design process in the fashion industry can vary depending on the category of products to develop (haute couture or ready-to-wear). However, in general, the process begins with the collection of information and inspirations and, then, the conceptual phase, which consists in the definition of the type of products, and the generation of the first ideas of products. Therefore, designers create some first sketches, in which information about materials, finishing etc. are also integrated.

In the following phase patterns are developed from scratch or, more typically, by modifying existing ones. A pattern is the graphic representation of the structure of a cloth, and it is at the base for the next phases of the design and manufacturing process. Through these first patterns it is possible to create the physical prototype of the cloth and, in an iterative process, modify the prototype and the patterns up to the definition of the collection.

Then, some phases are required before the manufacturing process. Specifically, in the grading phase the patterns of the cloth in all sizes are developed, while in the placement all the developed patterns are placed on the fabric in order to reduce the scrap during the cutting. Finally, we have the production phases constituted by tissue preparation, cutting planning and execution, sewing and finishing, which includes operations, such as adding details, and ironing.

The phases of patterns creation (or modification), grading, placement and cutting planning and execution have been converted from "on paper" to digital, and are now widely supported by 2D CAD/CAM systems (e.g., Lectra Modaris—www.lectra.com). However, no changes or optimization strategies concerning times and costs have been introduced in the traditional design process.

2.2 Methods and Tools for 3D Shape Acquisition and Body Motion Tracking

A full virtual clothing design environment requires the acquisition of customer's body. Three steps are required: 3D body scanning, motion capture and 3D rigging to link the skeleton of animation to the 3D body model. Regarding 3D customer acquisition, many commercial solutions are available with different costs depending on their precision, accuracy and operating principle [1]. In this research work, we mainly focused the attention on low-cost devices. Consequently, a marker-less motion capture system based on four Microsoft Kinect v2 devices has been exploited as tool for acquiring the customer's body together with Skanect (http://skanect.occipital.com/, Skanect), which exports the 3D model in an OBJ file.

Another technology concerns motion capture to acquire customers' movements. Two different solutions have been considered. The first relies on the use of two

Microsoft Kinect v2 sensors together with iPiSoft (http://ipisoft.com/) to track and elaborate data and come up with usable results. It permits to export a BVH file, which contains all information and data relative to both the skeleton and associated animation. The second solution implies using the optical motion capture system Optitrack (https://www.optitrack.com/). This system allows capturing the human movements by means of specific cameras that are able to follow the position of spherical infrared-reflecting markers located onto the customer's body.

For the last issue, Blender (https://www.blender.org/), an open source 3D modelling and animation application, has been used to manage body animations and automatic association of an animation to the 3D human avatar [2]. Blender is also used to export/import 3D models in several animation format, such as BVH, C3D and DAE. These formats are the most common to manage motion capture in several commercial Mocap systems, such as iPiSoft and Optitrack.

2.3 Virtual Prototyping of Clothes

Virtual Prototyping (VP) is widely used in the design process and in other application fields, from engineering to medicine, and has already proven its effectiveness for the evaluation of the design solutions of new products [3, 4].

In recent years, in the fashion industry, the impact of VP is growing and more and more companies are using software for the development of virtual prototypes of clothes. Systems for creating virtual prototypes represent a significant change in the design process by reducing the number of 2D drawings, the cycles of the design process and allowing the definition of patterns directly from the 3D cloth. By using these tools, indeed, it is possible to create in a very easy and fast way the 3D model of clothes starting from 2D patterns, and then modify it, apply textures and finishing effects and so on. These 3D models are realistic representations of clothes, because they simulate the real behaviours of pieces of fabrics affected by different kind of cuts, seams, finishing effects in order to verify the real behaviours of clothes, the wearability and, also, the aesthetic appearance. Usually these possibilities are obtained through the numerical simulation of fabrics. The main advantages are the reduction of costs and times of the design process and of the number of physical prototypes necessary for the collection. These systems have initially developed and validated in the academic world [5–7].

Today, on the market there are several tools for the 3D modelling of clothes. The most important ones, according to their characteristics and distribution, we have Optitex (http://optitex.com/solutions/odev/), Brow |z| wear (http://www.browzwear.com/), Lectra (http://www.lectra.com/en/fashion-and-apparel), and CLO3D (https://clo3d.com/).

3 Research Hypotheses and Experimental Framework

The research presented in this paper describes a framework for designing clothes as realistic 3D digital models. The framework allows customers to evaluate the results through realistic virtual mannequins.

The authors focused on the definition and development of an "automatic process". In this process, virtual prototypes of clothes, in different sizes, are developed by designers while, on the other hand, it is possible to easily and quickly acquire the body and movements of customers. Then, these elements are integrated into a unique virtual environment.

As a result, the phases of the process can be divided into two main areas: *acquisition of body and movements of customers and file processing* and *development of virtual prototypes of garments and integration of customers' virtual mannequin*.

These phases are graphically summarized in Fig. 1 and are detailed in the following paragraph, in which one of the practical examples developed by using the framework will be presented.

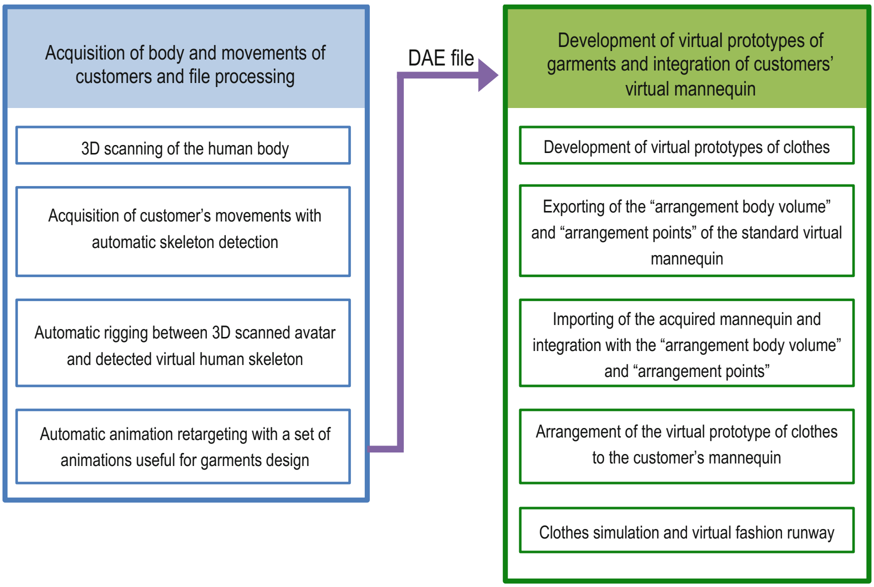

Fig. 1 Structure of the experimental framework

4 Case Study

The above-described framework has been defined via several experiments in which each part has been developed separately. Then, the authors decided to perform an experimental case study in which all the phases have been carried out sequentially to simulate the complete process. Specifically, the body and the movements of a customer (a man) have been acquired, the virtual prototype of a shirt has been developed on a standard mannequin and, finally, it has been put on the acquired mannequin.

4.1 Acquisition of Customer's Body and Movements

Firstly, customer has to maintain the T-pose for 2–3 min, in order to acquire his/her body shape, and then to walk for a while in a room to allow the system to acquire his movements. In both cases, the acquisitions were performed using the Microsoft Kinect v2 sensors together with iPiSoft solution already presented in Sect. 2.2. Then, we executed the "3D rigging" between the customer's avatar and the detected virtual human skeleton and the "animation retargeting" with a set of animations useful for garments design, such as position of arms and shoulder.

Automatic rigging and automatic animation retargeting are crucial issues and ad hoc software modules that permit to automatically executed these operations. They have been implemented by using the open source software Blender.

The 3D rigging prepares the mesh for animation by organizing the mesh points in vertex groups. Animation retargeting allows translating an animation from a skeleton to another one, which can have either the same or different set of bones. This is necessary when the skeleton of the acquired human avatar is different from the skeleton used for animation and occurs when the animation is acquired with marker-based motion capture system, such as Optitrack.

Figure 2 shows the procedure based on Blender that permits the automatic association of an animation to the 3D model of the human body. First, the acquired skeleton is linked to the 3D human avatar in the correct position. Then, the vertex groups are generated and populated according to the position of each vertex to the nearest bone of the skeleton. When the automatic 3D rigging is completed, the skeleton can be moved and the 3D human avatar is animated accordingly (Fig. 2a).

The procedure generates a DAE file containing both animation and 3D mesh (Fig. 2b). The generated DAE file is the input for 3D environment for clothing design (Fig. 2c).

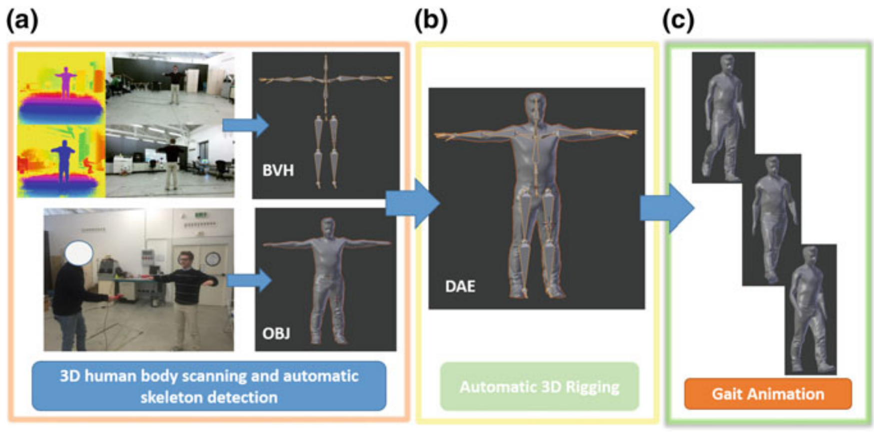

Fig. 2 Main steps of the first phase of the experimental framework

4.2 Development of Virtual Prototypes

The operative workflow of the second part of this process consists in the following main steps:

- Development of virtual prototypes of clothes (in different sizes);
- Exporting of the “arrangement body volume” and “arrangement points” of the standard virtual mannequin;
- Importing of the acquired mannequin and integration with the “arrangement body volume” and “arrangement points”;
- Arrangement of the virtual prototype of clothes to the customer’s mannequin.
- Clothes simulation and virtual fashion runway.

Concerning the virtual simulation of clothes, among the commercial software for cloth simulation, the authors selected CLO3D as the most appropriate one for the purpose of this research work. One of the most important characteristics of this software is the real-time simulation of the cloth behaviour (not only aesthetically, but according to the characteristics of the fabric and cuts). CLO3D allows the creation, importing and modification of patterns; then, it is possible to put the cloth on a virtual mannequin and start the simulation. Each pattern can be modified in 2D, and it is possible to define some different characteristics of the cloth, such as the kind of fabric, of sewing, of texture, the hems, the presence of buttons, of different layers of fabrics and so on. Finally, it is also possible to create a virtual runway show. Thanks to this tool it is possible to save time, mainly for what concerns the first part of the process, in which many modifications of the patterns can be necessary before reaching the desired result.

Then, in the first step of this second phase, the authors developed the virtual prototype of a shirt on a standard mannequin of CLO3D. Specifically, the virtual mannequin (a woman) has been modified in a man, and its height and other body sizes have been changed in order to be similar to those of the acquired customer.

Specifically, the patterns of the shirt, in a .dxf file, have been imported in CLO3D. Then, the patterns, displayed in the 2D part of the CLO3D interface, have been sewn (in 2D) and then put on the virtual mannequin by using the “arrangement points”, which are specific features of the standard virtual mannequin in CLO3D. By using these points, the software is able to recognize the front and the back of the garment and the torso and the back of the avatar.

Therefore, the authors started the simulation, in which the various patterns are sewn together and adapted to the mannequin, also according to the characteristics of the selected fabric (in this case cotton). The described procedure is the same normally used in CLO3D and the results, with two different colours, are shown in Fig. 3.

The following step concerned the exporting of the “arrangement body volume” and “arrangement points” of the standard virtual mannequin, in order to use them for the acquired mannequin. It has been verified, in fact, that the imported mannequins from the DAE file do not automatically incorporate these features, which have to be specifically created. The “arrangement body volumes” are graphically represented as green cylinders, while the “arrangement points” are blue points (arrangement points are shown in Fig. 4b). CLO3D needs the setting of these features in order to easily fit the developed cloth on the human body. CLO3D allows increasing or decreasing their number, but we have exploited the standard ones during this case study in order to demonstrate the ease of use of the proposed method.

Subsequently, the DAE file generated in the first phase of the process was imported as avatar to replace the standard one. In the following, the authors

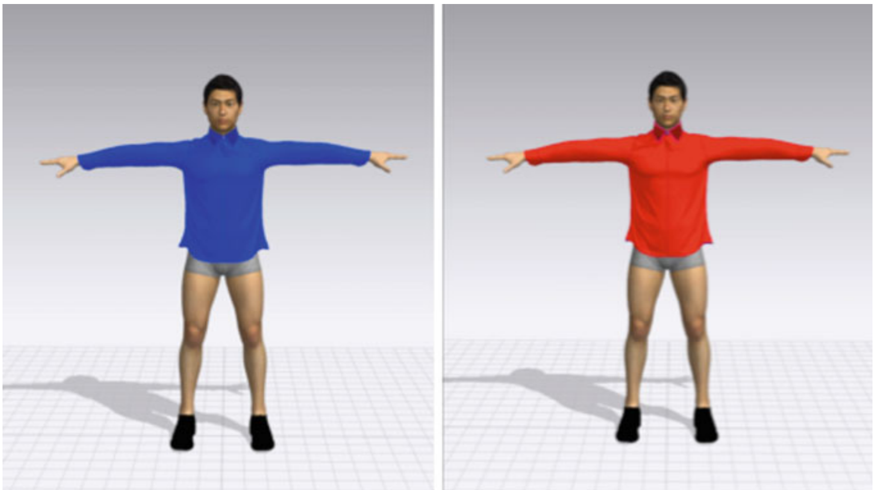

Fig. 3 The shirt on the standard mannequin

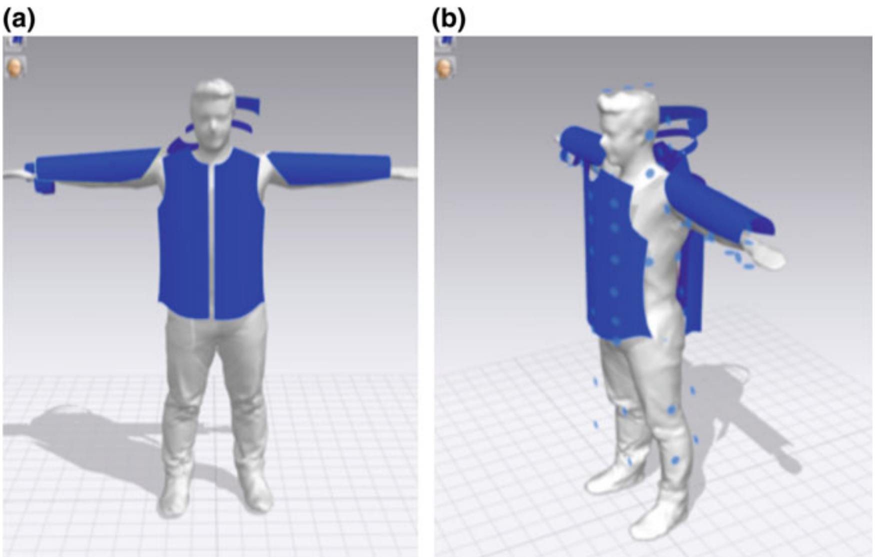

Fig. 4 The shirt patterns attached to the attachment points of the acquired customer

re-imported and associated to the mannequin the “arrangement body volume” and “arrangement points” previously exported. Then, the previously simulated shirt, which had lost the reference points, has been put onto the virtual mannequin of the customer (each pattern of the shirts has been attached to a specific imported attachment point, see Fig. 4a, b). As a result, the simulation of the garment on the

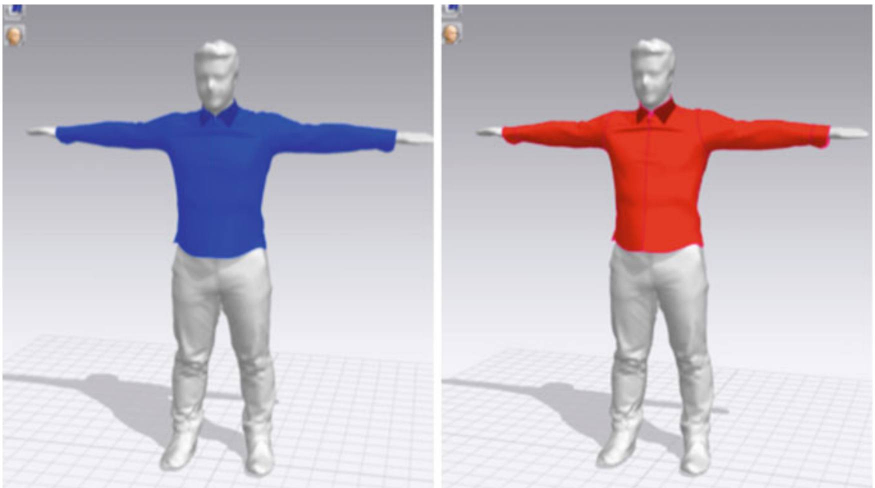

Fig. 5 The shirt on the acquired customer

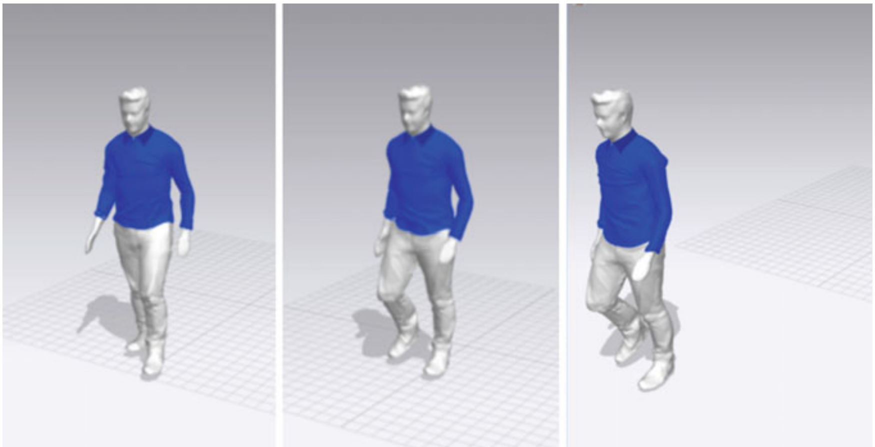

Fig. 6 The final virtual fashion runway

imported mannequin was started and the virtual prototype of the shirt on the virtual mannequin of the customer has been automatically generated (Fig. 5).

Finally, since the DAE file also contains the movements of the customer, the authors started the virtual fashion runway, in which the virtual mannequin performs exactly the captured movements and wears the shirt (Fig. 6).

5 Conclusion

Fashion is one of the most important industrial sectors in Italy, but it is subject to a significant transformation caused by the evolution of the fashion global market. Even if it is still based on traditional processes and on tailors' knowledge, it needs to innovate to remain competitive in the global market. This is also related to the new possibilities given by the online sales, by using which, it is possible to reach customers everywhere and at any time. However, many customers are not comfortable in buying clothes online, due to the fact that it is difficult to evaluate their quality and also their wearability on their body.

The research presented in this paper focuses on the introduction of Virtual Prototyping methods in the garment design process both for innovating and optimizing it and for allowing customers to evaluate clothes through realistic virtual mannequins of their bodies.

Specifically, the paper presents a framework for acquiring customer' body and movements, for creating virtual prototypes of clothes and for integrating these two elements in a virtual environment through a case study.

The results obtained are both methodological and practical. The framework will innovate the traditional garment design process used in the fashion industry and it could have a huge impact on fashion industry and customers behaviours.

Indeed, by using this framework, fashion companies will be able to create their own collections faster, also reducing design process timing, costs, and the number of prototypes to be made. In addition, customers will easily obtain their realistic virtual mannequins, with realistic movements, for performing online purchases in a more reliable way.

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Art of Designing an e-Art Gallery

Anupam Chandra and Praveen Uchil

Abstract This paper provides insights into the design research process and outcomes of an art gallery website designed by a design studio. Our research indicated that artists often do not exhibit their art work in popular virtual art galleries, not only because intermediation of art curator tends to be cost intensive but also because appropriate art curators are difficult to find. Our research is aimed at developing support for providing value for works of artists through developing an artist friendly website wherein artists can sell their art without the aid of art curators. Physical art galleries design the art display environment for the users in a unique way by providing them a soothing experience of connecting to the art through lighting, space and ambience. We attempt to transfer the same experience virtually to the user. Through multiple methods such as competitor analysis and interviews with art enthusiasts, artists and art curators, we identified certain issues with existing art galleries on the web and jotted requirements for the novel art gallery design. We present the evolution of a new art gallery design including information architecture, wireframe and implementation. We discuss the novel features of the new design such as an art value calculator that helps artists to estimate the value of their art without the aid of an art curator. We will also discuss the issues faced with employing design research methods such as card sorting and interviewing, and then provide certain suggestions for improving specific aspects of these methods.

Keywords Virtual art gallery · e-commerce website · Art-curation · Web-application design process

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1 Introduction

Artists for a while have this pain of being exploited by not getting paid fairly. Also, art buyers have the problem of spending exorbitant amounts to buy artworks from art galleries. Both sellers and buyers are unhappy with the current system, but due to lack of an alternative they are bound to use the conventional system.

Traditionally, artists are considered to live in their own world, disjoint from the social world; hence they need an intermediary source to market and sell their artwork. This eventually led to the rise of art galleries and art-curators. This convention was so blindly followed, that curators and art galleries became the unsaid owner of the art for sale. Typically, for majority of sales, art galleries charge commission of more than 60% of the value of the art [1]. This offered a good potential to design a product, which would reduce these unnecessary costs and eventually be beneficial to both art sellers as well as buyers.

With advancement in web media, online art galleries are emerging, but they are not yet efficient enough to solve the purpose of fair art trade.

The objective of this study is to find gaps between an artist and an art buyer and try to make a seamless channel between the two, along the lines of designing this web-application based on new age design language.

2 Methodology

2.1 Research Methodology and Data Collection

Initial literature survey indicated that research concerning art e-gallery designs has been scarce.

In the following section, various methods used for data collection and the outcomes of those methods are described.

2.1.1 Competitor Analysis

The objective of competitor analysis is to know about a competitor so the firm's competitive strategy can be formulated to take into account the competitors' likely actions and responses [2].

Competitors can be classified as follows: (a) The ones who satisfy the same set of customer needs and (b) The ones whose resource base, technology, operations, and the like, are similar to that of the focal firm [2].

Competitor analysis is aimed at identifying strategy of competitors and their likely actions and responses and to estimate the financial and personal outcomes of the competitor's strategic choices [2].

A list of 16 competitors was listed in a pug-matrix where all their strengths, weaknesses and unique selling points were compared. The motive of this analysis is to find loopholes in the existing system that can be treated as an opportunity.

2.1.2 Identifying Users

An online survey was conducted of over 100 users having interest in art. They were asked to share their interest in art and motivation to do art, hindrance in fulfilling their interests and their ideal approach of exploring art. As per their responses, the following categories were created:

Focus group (artist/art-enthusiast/buyer):

- User group 1: Users who have basic education and who continuously upgrade themselves with trending technology. These are the users who are technologically aware and have strong verbal and written communication skills.
- User group 2: Users who have the bare minimum education but comfortable with web products. Due to some reason they lack education, which also affects their communication skills, they are good learners and they make themselves comfortable with technology.
- User group 3: They are highly educated, but are not comfortable with the latest technology. These are the users who have developed themselves in some conventional practice and still want to stick with it.
- User group 4: They are excellent in their domain but lack sufficient education, which affects their communication skills. They also have poor exposure to technology.

Non-focus group (Anyone else except focus group).

The non-focus group has also been included to record the usage pattern of a random visitor having minimum or no association with art. Analysis of the behavior pattern of the non-focused group helps to predict the unconventional use cases, which will help the design process to avoid unexpected failures [3]. If the goal is to convert a normal visitor to a recurring user, who over a period of time may end up as a member of a focus group, the platform has to be designed considering the general usage pattern.

2.1.3 Individual Interviews

Contrary to the conventional method of following a standard questionnaire, users were asked to share their story of some incident related to our topic. In individual interviews, an interviewer talks with one user for 30 min to an hour [4]. Individual interviews allow the interviewer to probe the user's attitudes, beliefs, desires and experiences.

As per the availability of subjects, interviews are conducted over telephone and in person. Separate sets of questionnaires have been created for 30 artists, 15 art enthusiasts, 10 buyers/collectors, 2 curators and 5 random visitors.

The goal of this exercise is to motivate the interviewee to narrate their story in a more personal way rather than simply answering a list of questions.

2.2 Strategy Building and Defining Scope

2.2.1 User Persona Creation

Personas are fictional characters created to represent the different user types that may use the product in a similar way [3]. All interviewees' responses were collated to create **seven** user personae.

In persona creation, the demographic and psychographic profile has been captured. Where demographic (age, gender, marital status, education, employment and region of residence) profile gives the idea of social influence; psychographic (likes, dislikes, beliefs, introvert/extrovert, learning pattern and lifestyle) profile captures the behavioral pattern of the user [5].

Out of 62 subjects interviewed, seven personae were created which were further grouped as artists, art enthusiasts and art buyers. These personae will act as the reference of user's behavioral pattern and expectation with the product for rest of the design process.

2.2.2 User Journey Map

A user journey map tells the story of the user's experience from initial contact, through the process of engagement and into a long-term relationship [5]. A user journey map is constructed using the data obtained from user interviews. It indicates user feelings, motivations and questions for each of the interactions.

During the interview sessions, subjects were asked to share their experience journeys in the existing scenario of online galleries. The journey has been divided in three consecutive phases as (a) uploading artwork, (b) exhibition and (c) sale.

With three target users, the following bar chart focuses only on the pain points of the user journeys and height of the bar represents in direct proportion the intensity of frustration and dissatisfaction at a specific process/task (Fig. 1).

2.2.3 Requirement Analysis

During interviews, all interviewees were asked about their likes and dislikes regarding the existing medium (virtual or physical) they were using for showcasing art (in case of artists) and/or exploring art (in case of art enthusiasts). They were

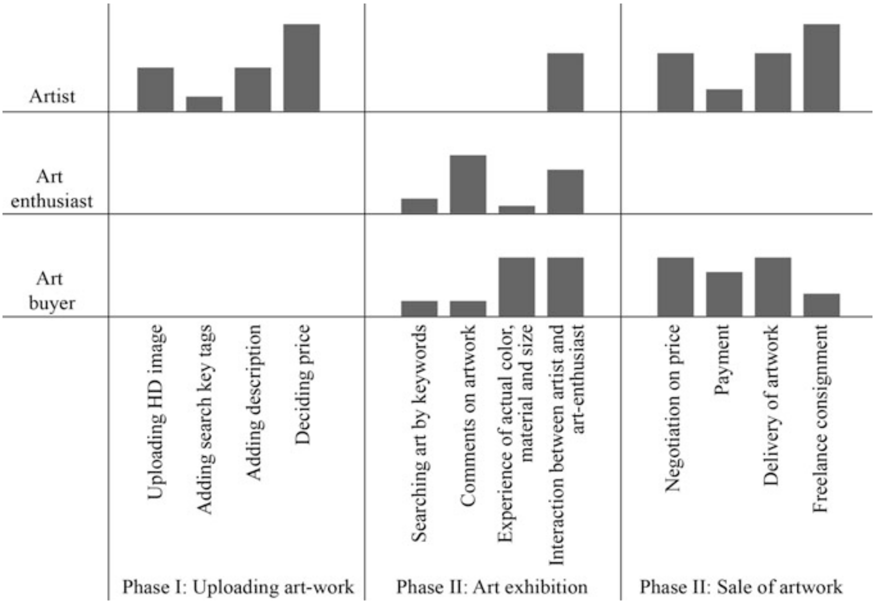
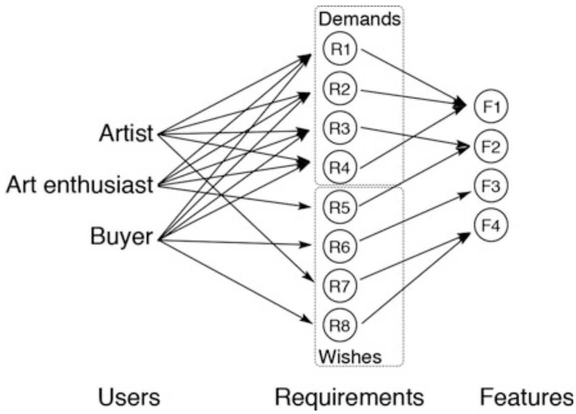


Fig. 1 User's pain point in experience journey map

also asked which practice they thought was an ideal one to fulfill their interest. Noted requirements have been further segregated into "demands" and "wishes", depending upon the intersection of requirements from various group that gave rise to the final set of product feature-set.

For example, an art-enthusiast wants to explore the compatibility of an artwork with different environments and a buyer wants to visualize whether a painting will match his/her wall or not. These are two different requirements that can be fulfilled by a single feature of virtual trial (Fig. 2).

Fig. 2 Mapping of user's requirement and product feature set



2.2.4 Defining Information Architecture

In information architecture, flow of information and navigation among the various states of a system are decided [6].

A focus group was conducted with twenty users, where they were asked to club similar cards from a deck of 70 cards, with each card having a text related to an art gallery or an e-commerce website.

Twenty subjects (users) have been further divided into two equal groups. The first group was asked to participate in an open card sorting exercise where participants could create their own names for the categories. This helped to reveal not only how users' mental model for classifying the cards worked, but also to identify the labels they used for each categories. The second group was asked to participate in the closed card sorting exercise, where participants were provided with a predetermined set of category names. They then assigned the index cards to these fixed categories. This helped to reveal the degree to which the participants agree on which cards belonged under each category [7].

2.2.5 Minimum Viable Product (MVP)

A minimum viable product has just those core features that allow the product to be deployed, and no more. The product is typically deployed to a subset of possible customers, such as early adopters that are thought to be more forgiving, more likely to give feedback, and able to grasp a product vision from an early prototype or marketing information [8].

Following MVP strategy a mock website was created, where artists can upload an image of their artwork and add description to it and art-enthusiasts/buyers can view all artwork from various artists at a single place (virtual art gallery). Art enthusiasts/buyers can explore the artwork displayed in the gallery and get all the details of an art and the artist. There will be links for contacting the artist and purchasing artwork online but all these links are not active, instead clicks are recorded to measure customer interest.

Users can create their profile but access to most of the profile specific features will be disabled for MVP.

3 Insights from the Study

3.1 Art Galleries Do More Than Selling Art

Art galleries are found rendering superior aesthetic experience as compared to e-art galleries. Art place is not considered only for selling and buying artwork, but also a place to go to meet people of similar interests and exchange ideas and build a

Fig. 3 Motive of audience while visiting an art-gallery

community and socialize. Patrons and students alike come to see a show and then talk about it with peers the next day. People get excited about going to a gallery, meeting an artist in person and experiencing a work of art. With time it also becomes a matter of social reputation to visit an art gallery and buy something from there.

An online survey has been conducted over 50 art-enthusiasts about their expectations while visiting an art-gallery. The result appears as a pyramid shown in Fig. 3. There are three prime motives while visiting an art gallery:

- Meeting people of similar interest is common among all type of visitors (other artists, art-enthusiast and buyers) and it forms the base of the pyramid.
- Inspiration for their personal work for visitors who themselves are artists or related to the creative field.
- Business motive, either buying artwork or hiring artist for freelance work. A common pattern was observed with the approach of visitors with business motive, i.e. if the artist is experienced, then the number of buyers will be more as compared to contract assignment, but reverse with novice artists. So in the following pyramid, the position of buying and contract work will swap according to the experience of the artist.

3.2 Price Estimation

Estimating the price is the biggest challenge every artist had faced at some moment of time. Selecting an optimal price tag adds value to the work and helps the artist to look more professional in the market.

Generally, artists decided the price tag depending on the previous sale, but for a novice artist, there was no reference price available. In absence of curator, the problem became even worse and artists ended up with a price much below a deserved value. This action acts adversely by leaving the impression that the artwork was not worthy of sale, hence it was cheap.

If there is a reference price matching the contemporary market, then this problem can be minimized. To serve the same, a price calculator was proposed, which takes few inputs from the artist and calculates a base price as per market standard (Fig. 4).

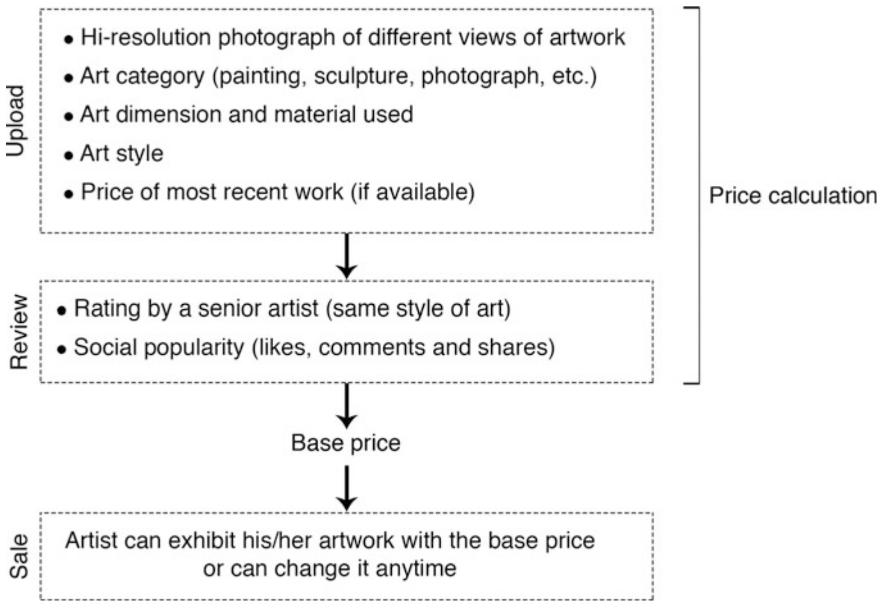


Fig. 4 Price calculation process

Once the user uploads the artwork with required information, it will be sent to some senior artists of similar art style and category for review. It is also shared on social-sites to evaluate its popularity. Depending on the artwork's detail and response in review, it takes a week to a month to calculate the base price. This base price will act as a reference and artists have the flexibility to either use the same price tag for sale or can change it according to their wish.

3.3 *Product Realization Helps the User to Make Decision*

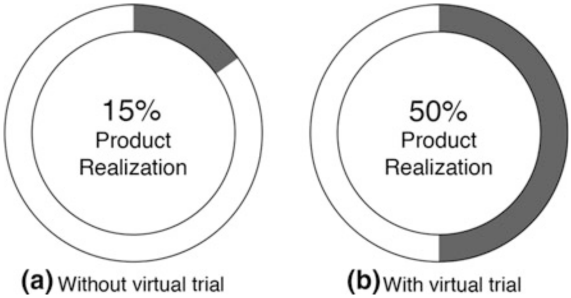
It was observed that in art galleries, before people buy a piece of artwork, they are interested not only in the underlying art language but also in the durability of medium, the constituent materials and the time of painting. Challenge for an e art gallery would be to showcase perceived durability, which is beyond the capability of online data available (i.e. touch and feel).

To make a user more confident, virtual trial is in practice on furniture, spectacles, and fashion apparels e-commerce sites. Even one of the competitors has already introduced virtual trial on art-gallery.

In virtual trail, augmented reality technology is used, wherein a user can select a painting on his/her smartphone and place it virtually on the wall of his/her room and can also change the projection of light and reflection on it. A human silhouette of

Fig. 5 Virtual trial

Fig. 6 A/B testing result



6 ft height will act as a reference to adjust the dimension of the painting, so that the user will be able to get the exact realization of the actual product (Fig. 5).

A/B test was conducted over 40 users to check their ability of product realization and final satisfaction while exploring an artwork online with and without virtual trial. In test-specimen A, users can only zoom-in the image of the artwork whereas in test specimen B, apart from zooming-in feature, users can also check the compatibility of the artwork in the environment. As a result of this test, there was an increase of 35% of user's satisfaction and confidence on product realization with virtual trial feature (Fig. 6).

4 Conclusion and Directions for Future Work

Our research identifies online art galleries as more than selling and buying artwork, it is more of an environment which a physical gallery visitor experiences. Visiting an art gallery, meeting the artists in person and buying the artwork from an exhibition/auction appears to be a matter of social status rather than one of personal interest. That is the reason why renowned artists dominate this area.

The study was focused on developing a platform where artists (esp. new) can easily showcase their artwork without involving any art-gallery or curator. The proposed platform is an online art gallery, where the artist, art enthusiast and buyers all meet at a common platform and can directly communicate with each other. As far as the role of curator is concerned, it can be minimized by moving the artwork to social media sites for promotion and by introducing an art calculator, which can predict the appropriate price of an artwork for sale.

Following points are open for future work

- Proposed art e-gallery will be globally available on Internet. Buyer's approach to art and willingness to value a piece of art by paying the right price varies from country to country and culture to culture.
- Research needs to be sought on enhancing specific feature of the online galleries such as enhancing the uploaded image quality of the artwork on the website. Addition of a video clip where the artist himself/herself describes the artwork.
- Converting a simple e-marketplace to an auction ground.

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A Study on Product Display Using Eye-Tracking Systems

Yukari Nagai, Tomo Fukami, Satoshi Kadomatsu and Akemi Tera

Abstract We investigate a relationship between the product display and the purchase decision using an eye-tracking system. It is possible to get quantitative data of saccade and gaze plots from an eye movement detector. We make clear that a display of goods is related to the consumer's thinking process when a consumer decides about the purchase, using this method. We conclude that eye movement can be an important index as a result of data from this experiment, as well as the accompanying interview and questionnaire survey, when a display of goods influences consumer's product purchase.

Keywords Eye-tracking system · Gaze · Saccade · Product display · Package design

1 Introduction

There are two methods of displaying main products. One, main products are put on the upper left side of the shelf because people tend to look at the upper left side of the shelf first, then the upper right, the lower left, and finally the lower right (law of Z). Two, main products are put at eye level where people can see and pick up products easily (Law of Golden Line). Many shops are trying to make attractive displays by

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using these methods. Product displays can be said to influence consumer purchase decisions [1].

However, a recent study of product displays using eye-tracking systems shows a tendency that differs from the conventional laws of eye movement. The study reports that people tend to look at the upper left first, then the upper right, lower right, and finally the lower left. It also illustrates the tendency of human eyes to move from up to down [2]. And the other study reports that during seeing the design, the cultural background of consumer has, has an influence big [3, 4]. Also it is reported that packaging design influences the decision process in several phases [5]. Therefore, further research is required.

2 Goal

This study aimed to find the relationship between product displays and purchase decisions by using eye-tracking systems. Data collected and analyzed by eye-tracking systems determine the effect of product displays on consumers and reveal consumers' thought processes during purchase decisions. In addition, the study seeks to identify the characteristics of products selected by consumers out of several alternatives.

3 Methodology

In this study, eye-tracking systems follow eye movement while looking at plastic bottles of tea lined up on a display shelf. We obtain time progress of the eyes movement during seeing a display by eye-tracking data, a questionnaire and an interview together, and analyze them. The experiment uses two types of display images. Twelve different types of plastic bottles are chosen out of the ones sold in the marketplace.

This research was carried out by strictly observing the guidelines set by JAIST's Life Science Association regarding the use and storage of personal information. In carrying out the experiments. Consent was obtained from the participants for the use of such information.

3.1 Eye-Tracking Data

We use Tobii X-120 for obtaining eye-tracking data [6]. The eye movement is measured for analysis in order to capture it as digital data [7–9]. The eye-tracking systems enable researchers to obtain quantitative data about eye movement (In which direction did the eyes move?) and gaze dwell (For how many seconds did the eyes stay on the product?) (Fig. 1).

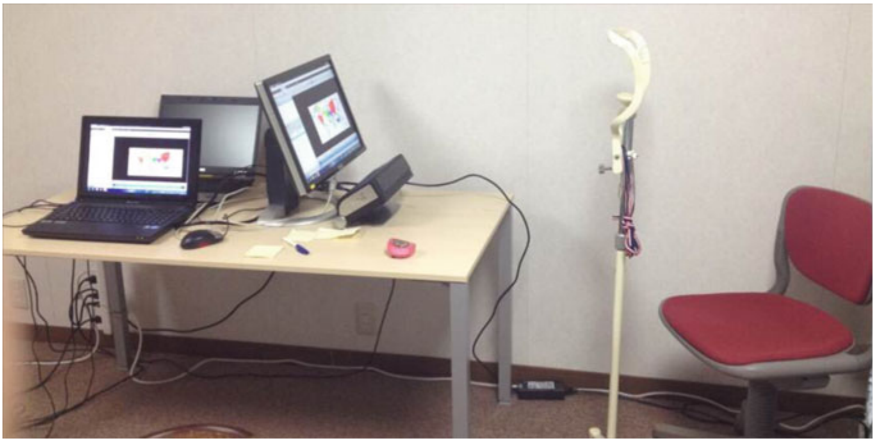

Fig. 1 Experimental set-up

3.2 Interviews and Questionnaires

Interviews were conducted to obtain detailed data, which illustrate consumers' thought processes not provided by the following questionnaires. Referring to the data provided by the eye movement measures, interviewees are asked about their eye movements before their purchase decision.

In addition, in the following questionnaires, they are asked about plastic bottles of tea. The questions are mainly about the reason they chose one product out of 12 kinds of plastic bottles and the important reasons for choosing the product.

3.3 Participants

Participants were 30 people (16 Japanese, 14 foreigners), who are students and staff of the Japan Advanced Institute of Science and Technology. We divided them into two groups (See Table 1).

Table 1 Participants

Group/numbers	Japanese			Foreigner			Total
	Male	Female	Total	Male	Female	Total	
Group A	4	4	8	5	2	7	15
Group B	6	2	8	0	7	7	15

3.4 Subject of Research

From an investigation, we chose 12 kinds of very popular tea (see Fig. 2), and performed an experiment.

3.5 Procedure

After preliminary explanation, we conducted measurement of eyeball movements (calibration), an interview, and a questionnaire.

After calibration, we had each participant choose the goods that they would like to buy, and then we measured their eyeball movements.

We interviewed them while viewing the eyeball movement data (heat mapping and gaze plot).

Participants completed a questionnaire about the goods they chose.

Concerning the measurement of eyeball movements, we initially showed a white picture for 5 s, and then a picture of the showcase until each participants chose goods. Figure 3 shows an arrangement of plastic bottles for groups A and B.

Fig. 2 12 kinds of plastic bottle of Tea

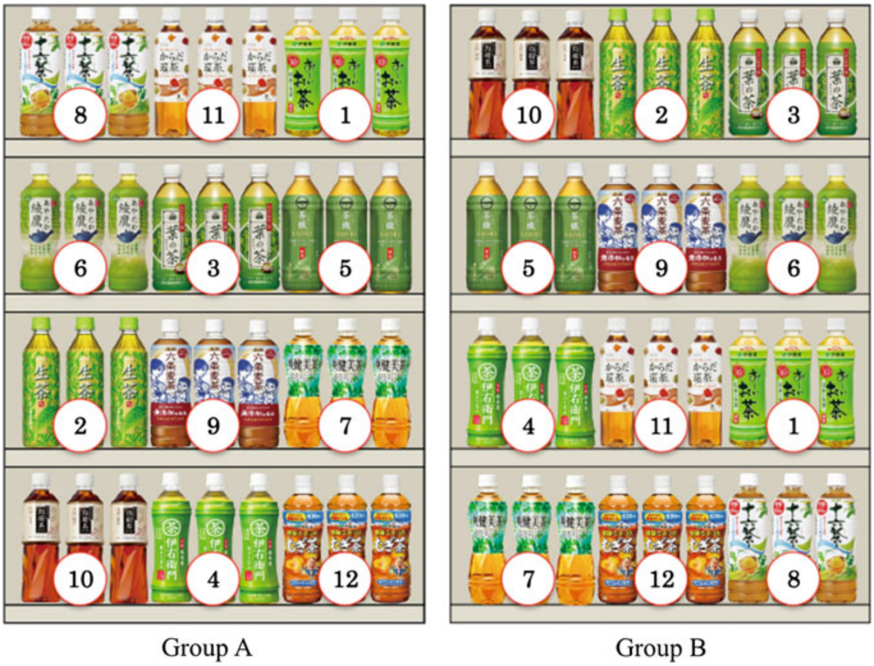

Fig. 3 Arrangement of plastic bottles (group A and group B)

4 Result

4.1 Interview

Choice (Evaluation) of the products:
Table 2 shows the number of the participant who chose each plastic bottle. “No. 6” arranged in the high location got high evaluation by group A, and “No. 7” arranged in the low location got high evaluation by group B. As a result it has a high possibility that it was chosen by influence of other elements, not only the display of goods.

During the second half, most of the participants performed an eye movement “to decide.” Participants each answered, “I looked at the beginning leisurely, and the end wasn’t seen so much.”. And the reasons that they gave for their choices are “package,” “previous experience,” “the taste,” “celebrity and commercial,” and “arrangement of goods.”

Table 2 The number of pet bottles participants choose

Group A (order)	Product (No)	Participants	Group B (order)	Product (No)	Participants
1	No. 6	5	1	No. 7	4
2	No. 1	2	2	No. 6	2
	No. 4			No. 8	
	No. 7			No. 9	
	No. 9			No. 10	
7	No. 10	1		No. 11	
	No. 5			No. 12	
	No. 11		8	No. 1	1
	No. 12		9	No. 2	0
10	No. 2	0		No. 4	
	No. 3			No. 5	
	No. 8			No. 3	

4.2 Eye-Tracking Data

Heat Map:
Figure 4 shows the heat map of the participants of groups A and B. The color signifies the total length of the time of their fixation, a red color means a long fixation and a green color means a short one.

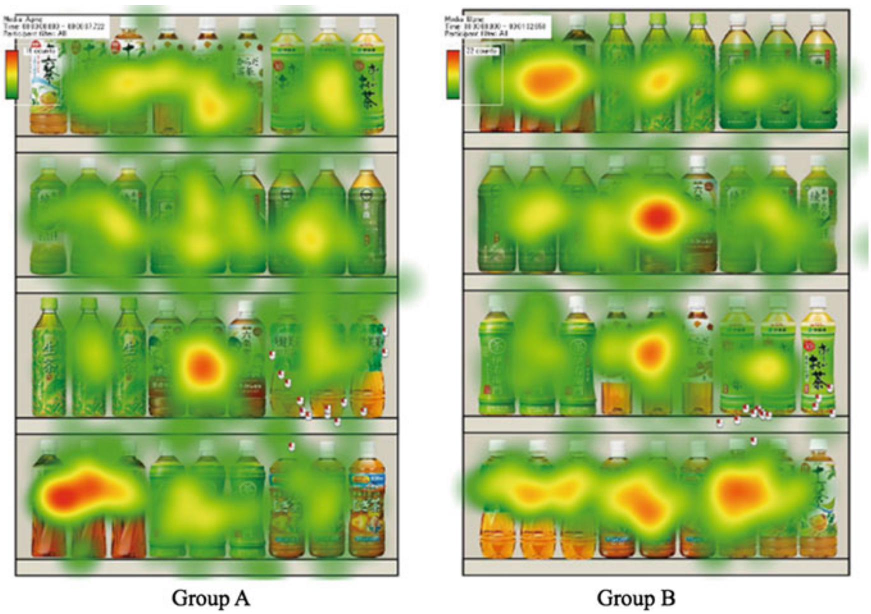

Fig. 4 Heat Map of the participants of groups A and B

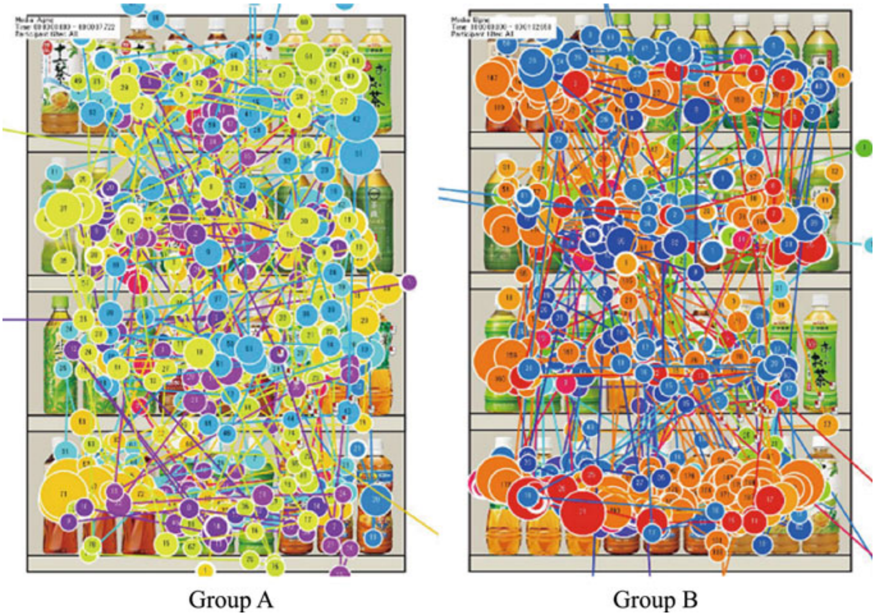

Fig. 5 Gaze Plot of the participants of groups A and B

Gaze Plot:
Figure 5 shows the gaze plot of the participants of groups A and B. The size of each circle signifies the length of the fixation, and each line signifies the saccade line.

Figure 6 shows the extended indication of gaze point. We can see that each circle has each number. The number in the circle, indicating the length of the time for gaze point, expresses an order of the gaze point. We can see the trace of the eye movements of each participant clearly by searching this.

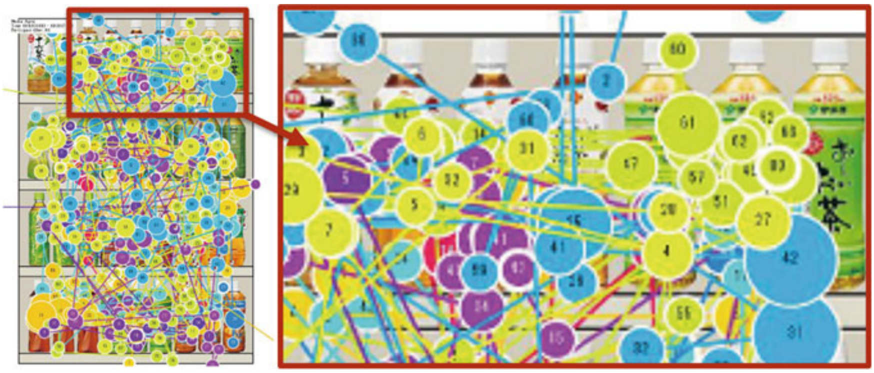

Fig. 6 Extended indication of Gaze Plot

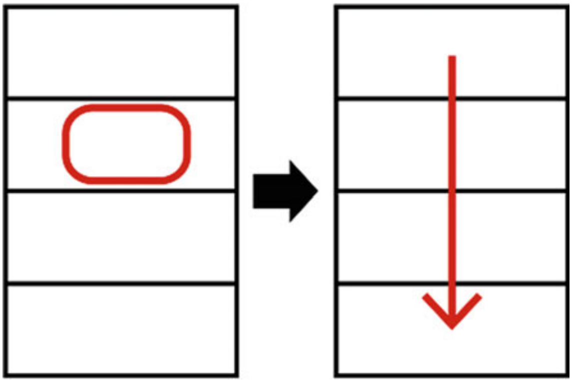

Fig. 7 The model of the eye movement when making a purchase choice

Length of the time to choose:
Twelve participants chose the goods they would like to buy within 10 s. The main reason for their choice was the idea that it "has been always accepted." Eight participants chose in more than 20 s. Their main reason was "the location of the goods."

4.3 Line of the Eye Movement

Eye movement to grasp the whole shelf was confirmed as another frequent movement just before participants finally decide to purchase a product. First, participants unconsciously look at the golden line of the display shelf. Then, they looked at the display shelf from top to the bottom consciously. Participants each answered, "I looked at the beginning leisurely, and the end wasn't seen so much." Figure 6 shows the model line of eye movement during purchase choice (Figure 7).

4.4 Comparison of Japanese and Foreigners

The Japanese were most influenced by "the taste" and "the package design." They were not influenced by "the location of the goods." We suggest that they tended to emphasize "the taste" because the Japanese had sufficient knowledge of the quality of the goods.

Foreigners were influenced by "the location of the goods" much more than by "the package design" or "the taste." We suggest that because they had little knowledge about the goods, foreigners tended to emphasize "the package design" and "the location of the goods."

5 Conclusion

This study aimed to find the relationship between product displays and purchase decisions by using eye-tracking systems. We obtain time progress of the eyes movement during seeing a display by eye-tracking data, a questionnaire and an interview together, and analyze them. The experiment shows that the product display is one index influencing when consumers purchase products. Although taste and package design are also important indexes, product display can be an important index to ensure purchase of a product out of many alternatives of the same taste and package design.

As the future's work, it's necessary to make an experiment by other target things to investigate influence of a display of goods more in detail.

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Embedding Design Descriptions Using Lattice Structures: Technical Requirements, User Perspectives and Implementation

Amar Kumar Behera, Alison McKay, Hau Hing Chau, Alan de Pennington and Mark A. Robinson

Abstract Commercially available engineering design tools typically operate on native data formats and support individual designers creating design descriptions which are shared within product development teams and across supply networks. The use of such tools results in a multiplicity of design descriptions. For example, a CAD system may be used to create a design Bill-of-Materials (BoM), which is a form of design description, but different BoMs are needed for downstream processes such as manufacturing and servicing. Conventional approaches to the integration of design descriptions is through the use of data exchange technologies or a common underlying meta-model to support, ultimately, a single, shared digital design description. These approaches have architectural elegance but their real-world feasibility is limited by the heterogeneous environment in which they must be implemented. The research reported in this paper challenges this thinking and explores the feasibility of embedding design descriptions into each other. We report early results exploring the feasibility of using lattice theory, where lattices are in the form of partially ordered sets, to embed multiple design structures into a given design description.

Keywords Lattice structures · Design descriptions · Software prototype · Robot

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1 Introduction

The process of designing using commercial engineering design tools results in design descriptions that are shared within product development teams and across supply networks. The result of using these tools results in a multiplicity of design descriptions [1]. Design descriptions include shape models, bills of materials (BoMs), assembly mating structures and function structures. In particular, a number of different types of BoMs may be used [2] such as engineering, manufacturing, packaging, shipping and servicing. The management of BoMs is crucial to ensure consistent interpretation of product geometry specifications across different departments of a firm and maintain interoperability among different engineering systems [3]. Current approaches to manage and integrate engineering information, such as that present in separate BoMs, involve using product lifecycle management tools that process product-related meta-data [4] to enable the coordinated sharing of digital design descriptions. However, despite having a logical, core architecture that defines these meta models, the heterogeneity of information resources within an organization presents a significant barrier to the use of meta models for the efficient management of product data [5]. The research reported in this paper is exploring a different approach that preserves the heterogeneity of different design descriptions while allowing necessary relationships to be defined between them [6]. The relationships are defined using embedding, where one instance of a mathematical structure is contained within another [7], implemented using lattice theory. Methods of formal concept analysis provide a mathematical means to capture conceptual knowledge within a formal framework [8]. Lattice theory is one of these methods that can be used to represent concept hierarchies [9], where nodes in a lattice represent concepts as sub-concepts and super-concepts [10]. In this research, the nodes in a lattice are used to represent parts in a BoM that enables the exploitation of two properties of lattices. Firstly, for a given collection of parts, there is a complete lattice that contains every possible combination of parts, i.e., every possible BoM for the given collection of parts. Secondly, given two BoMs, there is a unique biggest lattice (the supremum) that contains both and a unique smallest part (the infimum) that is part of both.

This paper reports results from the development of a software prototype that enables embedding of BoM design descriptions using lattice structures. The prototype allows a design BoM to be extracted from a CAD model, in the form of a STEP AP214 file, and translated into a lattice that is visualized using a Hasse diagram. This lattice is a sub-lattice of a complete lattice that includes all possible assembly structures for the given collection of component parts in the assembly. The lattices generated by the software contain the individual parts and sub-assemblies as nodes of the lattices. Different BoMs, such as—“as shipped” and “as disassembled”, can be defined as sub-lattices of the complete lattice. Each component part and subassembly, together with the whole assembly and an empty node, form the complete lattice. New design structures can be defined by selecting the required nodes, and relationships between them, in the complete lattice. Our vision is that a user will be able to create a desired BoM by selecting the required nodes and tracing through the lattice to arrive at the final assembly description of the product. Case studies that have been created to test the software prototype are used to illustrate technical requirements, user perspectives and implementation requirements for the implementation of lattice-based embedding.

2 Methodology

A prototyping methodology, involving the development of software prototypes based on lattice theory concepts, was used. Two software prototypes have already been built: one demonstrating the feasibility of representing BoMs from CAD systems using lattices and a second demonstrating the feasibility of embedding one lattice-based BoM into a complete lattice. Figure 1 illustrates the structure of the software prototypes. The first two prototypes (StrEmbed-1 and StrEmbed-2) are written in Perl version 5. StrEmbed-1 parses a STEP AP214 file, generated from the SolidWorks hierarchy view of an assembly, and generates a corresponding lattice. The lattice is implemented in a file format that can be imported into and visualised using a Java-based applet LatDraw [11]. StrEmbed-2 embeds the aforesaid lattice onto a complete lattice that is based on the number of component parts in the hierarchy view. A further prototype, StrEmbed-3 will allow alternative BoMs to be defined in terms of the complete lattice. For example, if an assembly from a CAD file

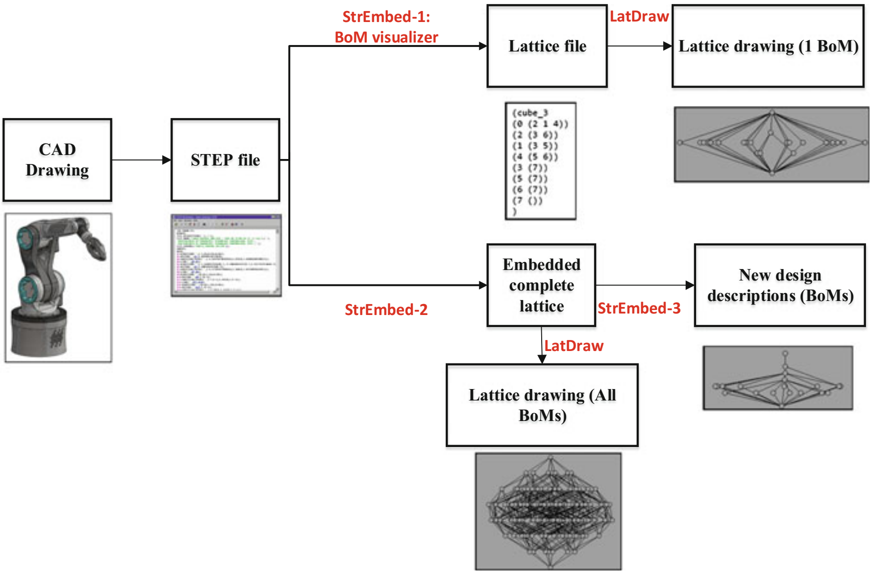


Fig. 1 Software and development architecture for the three software prototypes

represents a view as designed, additional BoMs could be created to represent the same product in its “as built”, “as shipped”, or “as in service” forms. StrEmbed-1 and StrEmbed-2 were used in experiments to generate BoMs for a case study robotic arm.

3 Embedding Using Lattice Structures

The underlying concepts of lattice theory that were used in the software prototypes to implement embedding are discussed in this section, followed by technical requirements and details of how the prototypes address these requirements.

3.1 Lattice Theory

The relevance of lattices as representation schemes for the geometrical modeling of shapes is discussed in a number of early works such as by Stouffs et al. [12] and March et al. [13]. Lattices are appropriate for representing design structures such as BoMs because they are partial order sets in which any two elements have a unique greatest lower bound and a unique least upper bound [14]. The presence of partial order in lattices is useful as it establishes a one-to-one correspondence with the structure in typical product descriptions, which consist of parts (sub-assemblies and components), thereby establishing a hierarchy where multiple parts may be present at a specific level of abstraction or design description.

An example of a complete lattice for a product consisting of five parts, A, B, C, D and E is shown in Fig. 2. It can be seen that the nodes of the lattice represent combinations of parts taken ‘n’ at a time at each level ‘n’. It may be noted that a total of 2^m nodes are required to generate the n-hypercube lattice for ‘m’ parts.

3.2 Technical Requirements for Lattice-Based Embedding

In this section, technical requirements for the implementation of lattice-based embedding are discussed. These requirements cover the creation of lattice files for LatDraw and the embedding of individual BoMs within a complete lattice. Early requirements for using the complete lattice to create new BoMs are introduced, based on the outcomes of experiments with StrEmbed-2.

Requirements for creating lattice files. To avoid the need for CAD-system specific interfaces, a neutral file format in the form of a STEP (ISO10303) AP214 file is used as the input to the software. The NEXT_ASSEMBLY_USAGE_OCCURRENCE is the key entity because it represents part-whole relationships between parts (represented using the PRODUCT_DEFINITION entity). The next step is to generate a lattice file that conforms to the input requirements of the LatDraw software. This is a text

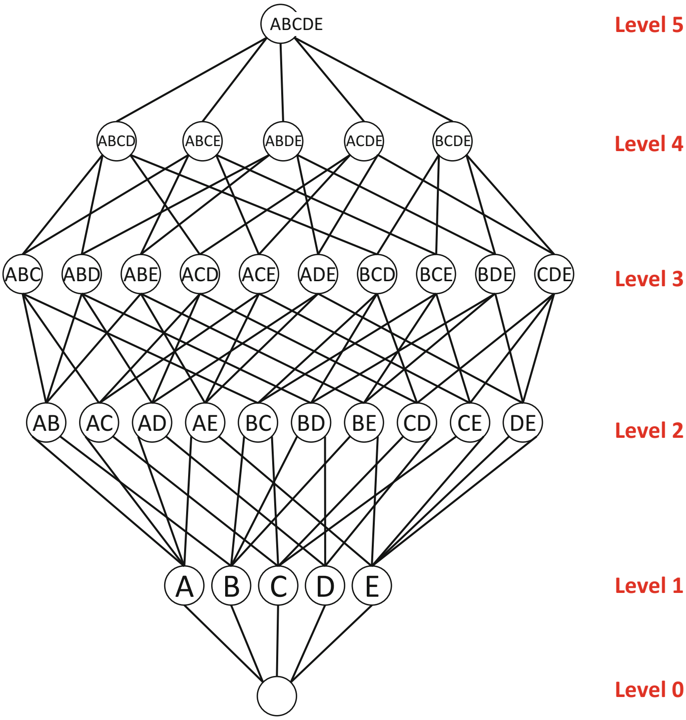
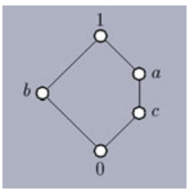


Fig. 2 Complete lattice for a product with 5 parts

file with the extension '.lat' and can be uploaded at [11]. The lattice is constructed from the bottom (infimum) up, a level at a time. For each node in the lattice, a new line is added to the.lat file in the format given to the right of Fig. 3. It can be seen that the file is written in a LISP-like syntax and the lattice is represented as a 'Hasse diagram' [14].

The StrEmbed-1 prototype creates a lattice file that corresponds to the BoM from a given STEP file and StrEmbed-2 creates a lattice file for an *n*-dimensional




```
(
 (0 (b c))
 (b (1))
 (c (a))
 (a (1))
 (1 ())
)
```

```
(name_of_lattice
        (0 (part1 part2 part3 …))
        (part1 (subassembly1 subassembly2 …))
        (part2 (subassembly3 subassembly4 …))
        …
        (top_level_subassembly_5 (product))
        (top_level_subassembly_6 (product))
        …
        (product ())
)
```

Fig. 3 Lattice (*left*) and lattice file structure and syntax (right) [11] hypercube where n the number of parts in the BoM. As in many applications that use BoMs and other design structures, the presence of multiple fasteners in a product description complicates the visualization of the lattice as the number of parts increases significantly. The current implementation treats each individual fastener as a separate part if they are included in the BoM; for the sake of visualization in this article, all fasteners that are in the neighborhood of each other and mating with the same parts in the product are treated as a single part.

Requirements for embedding. Embedding one BoM into another requires that the each node of the lattice corresponding to the BoM is mapped to a node in the complete lattice. In the current prototypes this is achieved using part identifications associated with instances of the PRODUCT_DEFINITION entity in the STEP file; these are referenced from instances of the NEXT_ASSEMBLY_USAGE_OCCURRENCE entity in the STEP file.

4 User Perspectives

StrEmbed-1 has been implemented as a web-based application and is available at [15]. A case study of a robotic arm assembly, adapted from [16], was used to demonstrate the feasibility of lattice structures in representing and embedding BoMs. The arm was 3D printed and formed a working robot. SolidWorks models and STL files corresponding to the arm were available from the manufacturer. The arm was manufactured using an Objet 1000 3D printer using the material ABS (acrylonitrile butadiene styrene). Two different BoMs, engineering and purchasing, were visualized and then embedded in the complete lattice. Figure 4 shows the

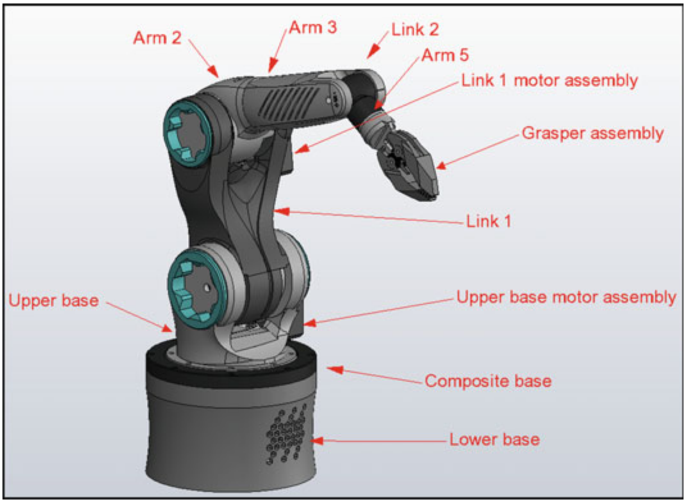


Fig. 4 Annotated robot arm assembly

annotated CAD model of the arm (annotated using open source viewer, eDrawings) while Fig. 5 shows the engineering and purchasing BoMs.

Lattices for the two BoMs were generated using StrEmbed-1 and visualized using LatDraw, yielding the results shown in Fig. 6. As the engineering BoM has more parts than the purchasing BoM, the Hasse diagrams for the engineering BoM lattice has more overlapping nodes (5) compared to the purchasing BoM (2). The

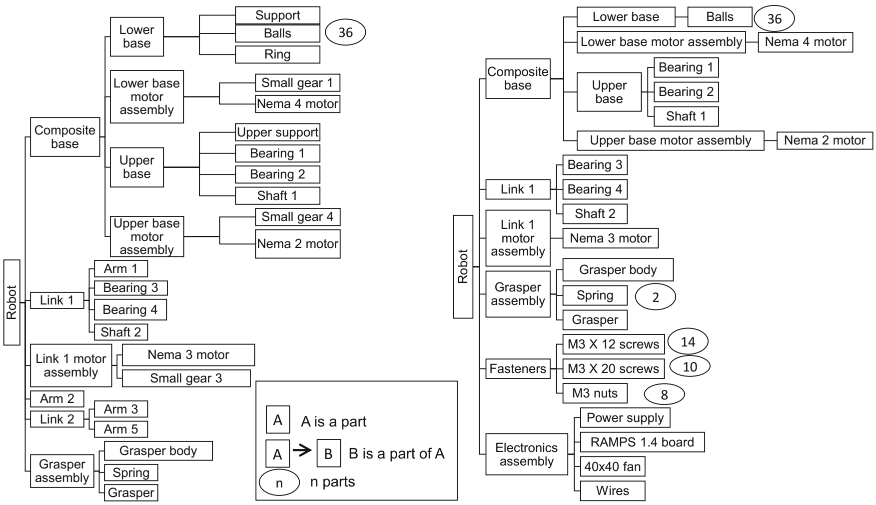


Fig. 5 Engineering BoM for the robot arm assembly (*left*), Purchasing BoM (*right*)

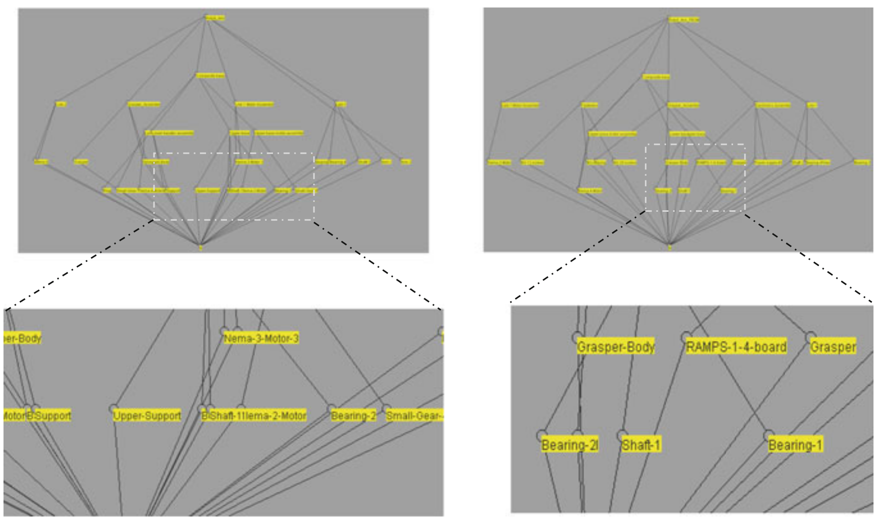


Fig. 6 Annotated lattices for engineering (*left*) and purchasing (*right*) BoMs

overlapping of labels in the engineering BoM is also higher than the purchasing BoM. It may also be noted that the purchasing BoM is not a subset of the engineering BoM, as it has two additional sub-assemblies in fasteners and electronics assembly, which were not present in the CAD model of the robot and hence, did not show up in the engineering BoM.

5 Results and Discussion

The results of implementing the software prototypes for lattice generation of individual BoMs and complete lattices with all possible combinations of parts show that, for a given assembly, it is theoretically feasible to embed new design structures into a complete lattice generated from the original assembly. Early experiments demonstrated that it is feasible to use lattice theory as an underlying formalism for the implementation of systems that allow design descriptions to be embedded into each other. Technical requirements for systems that support embedding were discussed in the context of specific case studies that highlight a range of user perspectives. The research reported in this paper is focussed on BoMs where relationships between parts are of the part-whole type. Current research is exploring the feasibility of embedding other kinds of design structure into design descriptions. For example, embedding of assembly mating structures or function structures typically requires references to shape elements and so the ability to reference aspects of shape models.

It may be noted that there is a limitation on the dimensionality of the hypercube lattices that can be optimized for visualization using the LatDraw software which can currently display up to 7-hypercube lattices. In addition, the compute time needed to generate large lattices grows exponentially with the number of parts in the assembly making it impractical to generate whole complete lattices. Two avenues for further research are to explore ways in which users might limit the number of parts of interest, for example by using methods such as holophraxis from human-computer interaction, or to be more parsimonious when generating the complete lattice so that only sub-lattices of potential interest are computed.

The use of the complete lattice generated by StrEmbed-2 to create new BoMs can be achieved by addressing user interaction challenges, such as those discussed by Pattison et al. [17]. Individual nodes can be selected by the user and based on the nodes selected by the user at an instant of creating a new BoM, only the feasible ones would be available for further selection. This type of dynamic generation of BoMs requires updating a linked list dynamically within the code while at the same type handling the visualization effects on the display interface of the user.

Lattice drawing (LatDraw) is based on a combination of mathematical rank function to determine the height of the elements in the lattice and a modification of the forces method of graph theory [18]. The use of the forces method involves applying a strong repulsive force to the nodes followed by a strong attractive force and finally balanced forces. In addition, each node in the diagram can be manually pulled horizontally to emphasize a certain structure that a user desires. Each node can also be pulled vertically to the extent that partial orders in the diagram are not changed. While this approach is useful in generating static lattices, dynamically generated lattices need better programming approaches.

The purchasing BoM may not have a complete CAD model associated with it, for example, electronic components or fasteners, which had not been designed in house by the manufacturer. The absence of these components meant that there were two solutions: (i) create a new CAD model for the purchasing BoM, or (ii) generate the lattice file manually. Furthermore, the absence of fasteners in the CAD model meant that the number and type of fasteners had to be manually interpreted. Typically, in many industrial designs, mechanical and electronic components may be designed in separate environments. Hence, a single STEP file may not be readily available for use within the developed prototypes. Furthermore, large products in firms may often create situations where different sub-assemblies may be modeled separately, even if all the components are of one type such as mechanical and it may not be readily feasible to bring them together to generate a singular description, which can then be exported into a readily interpretable file format such as STEP AP214. The purchasing BoM highlighted the need to accommodate such practicalities in developing a solution for embedding. Additionally, the present work does not yet consider assembly sequencing as demonstrated in recent work on product-process management techniques [3]. The feasibility of the same using lattice structures can be explored in the future.

6 Conclusions

The results from the early experiments on embedding design descriptions using lattice structures indicate the feasibility of using lattice theory as an underlying formalism for this purpose. Although there are established representations for BOMs available in the literature, they are not embeddable within design descriptions such as CAD models because of inconsistencies across the underlying meta-models. Hence, current representations do not provide the ability to minimize duplication across design descriptions within a firm or to enhance integration of CAD data between different divisions of a firm. By using lattices, multiple BOMs can be embedded to a given number of design descriptions thereby enabling a designer to implement and manage changes more robustly. In addition, alternate valid product structures can be easily generated from the lattice representation. We have demonstrated that it is possible to represent and visualize a BoM as a lattice, and embed a given lattice into a complete lattice generated from the same assembly model. We are currently exploring tools to enable the creation of new BoMs by selecting paths through the complete lattice. Challenges at this stage involve finding ways to generate dynamically new BoMs from a complete lattice, generating assembly sequences as another type of product structure and overcoming the issues related to visualization of large lattices. Issues remain in relating the impact of different BoMs on the shape of assemblies, especially when new BoMs can be topologically very different which affects the shape descriptions. Computational issues in dealing with large lattices also remain to be addressed.

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Part V
Design Management, Knowledge Management and Product Life Cycle Management, Design Analytics

Exploring Grassroots Innovation Practices and Relationships to Drivers of Start-Up Success in a Multicultural Context

Dipanka Boruah and Amarendra Kumar Das

Abstract This paper compares and contrasts how grassroots innovations are supported in a developing country such as India with how the support is offered in Wales, UK. In India, design support for grassroots innovations is provided through the National Innovation Foundation (NIF) with the help of local universities. In Wales, the Welsh Government provides funding for indigenous innovations through the Academic Expertise for Business (A4B) program. The paper presents two case studies, one from India where a grassroots innovation was developed into a commercial product with the design support of an Indian institution and one from Wales where design support was provided by PDR (the National Centre for Product Design and Development Research), Cardiff Metropolitan University and Welsh universities. Three key questions investigated in the case study research were: (1) what can be learned from comparing and contrasting the design support given to grassroots innovations in India and Wales? (2) How can people and local businesses benefit from collaboration with university research centres in India? (3) How could this design support be further improved?

Keywords Grassroots innovation · Techno-innovation · Techno-entrepreneurship · Start-up success

1 Introduction

The concept of the innovation system emphasizes that the flow of science, technology and information among people, enterprises and institutions are needed in order to turn an idea into a successful innovation in the market. The concept was extended to aspects of regional and cluster development in 1980 by two European

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economists, Christopher Freeman and Bengt-Åke Lundvall [1, 2], called the ‘National System of Innovation (NIS)’. In addition, a new model of innovation, the ‘Triple Helix’, was initiated by Professor Henry Etzkowitz in 1993 and Professor Loet Leydesdorff in 1995.

National Commission for Enterprises in the Unorganized Sector report [3] mentions that the informal employment in India is 58% in the agricultural sector, 75% in the industrial sector, and 72% in services, with most in underdeveloped enterprises and labour intensive employment—workers mainly having low-skill levels and low level of wages. To this point, the informal sector is a source of low-technology and is not considered an area for innovative activities [4]. However, India has an innovative ability to develop and support innovations in the informal sector.

2 Grassroots Innovation

Grassroots innovators are average people who tackle different issues they confront in troublesome circumstances in their everyday life or confronted by other individuals’ people in the society they live.

The term Grassroots Innovation emerged from the systematic and sustained work of the Honey Bee Network (HBN) in India on innovations emerging from knowledge and skills embedded in communities [5]. However, these innovations have the potential to contribute of an individual’s life, and contribute to a community by creating new entrepreneurship. In India the National Innovation Foundation (NIF) began working in March 2000 as India’s national activity to fortify the Grassroots Innovations and remarkable traditional knowledge (TK) together with the Grassroots Innovations Argumentation Network (GIAN). It’s a goal is to help India turn into an inventive and information based society by extending strategy and institutional space for grassroots technological innovators. In scholarly talks, Grassroots Innovators are described as base up social pioneers [6, 7].

In this way, Grassroots Innovators provide solutions that are different from mainstream innovations (i.e. Science and technological innovation) [8] focusing on the local situation and the interests and values of the communities involved [9] as well as technical change activities and practices involving trial and error [10]. Grassroots Innovations can be aimed at fostering inclusion as a process, e.g. fostering participation in the design of technology. Since Wales being a very design centric country considering each and every aspect of a concept to market for a product that triggered by individual users and communities seeking a solution to a personal or societal problems. In this view, Welsh Government initiated a numbers of top-down and grassroots-led design program happening across Wales and UK for demanding the design expertise in the private and public sectors. Therefore, a number of Welsh Higher Educational Intuitions (HEI) promote design in Wales through various activities such as Cardiff Design Festival and Venture Fest Wales. In addition, Welsh Government initiated a number of grassroots innovation and business program i.e. Eisteddfod, Dorkbot, Design Stuff Cardiff and Cardiff MADE. In this case, National Centre for Product Design and Development (PDR) at Cardiff Metropolitan University and UK has been providing design-led solution to small medium enterprises (SMEs) since 1994.

2.1 Beginning of a System of Institutional Support for Grassroots

The NIF, with the assistance of the Department of Science and Technology (DST), India, gives full support to innovators as far as access to information mapping and assembling; learning creation and value addition; and information application and dissemination. On the other hand, the Welsh Government's innovation team provides support for businesses in Wales to engage with universities and colleges. The Academic Expertise for Business (A4B) Program is program of support aimed at unlocking the commercial potential of grassroots innovations to provide an effective interface between academia and Welsh business startup. In addition, A4B provides mechanism of knowledge transfer, access to research, development, expertise, and facilities that are both small medium enterprises and wide range of technology business startup [11].

2.2 Techno Innovations to Techno Business Incubation

There are four main activities that are preformed in India within the NIF which collaborates the HBN, SRISTI and GIAN. These organizations have scouted and documented various activities relating to the commercialization of innovations such as (1) The value addition and research and development (R & D); (2) The business development and micro venture; (3) intellectual property rights (IPR), trademarks, and copyright; (4) dissemination mechanism [12].

The innovation process in Wales follows a broadly similar pattern. The Welsh government supports the creation and commercialization of new products and processes; increases efficiency in manufacturing through science and technology; and helps identify, protect and exploit the intellectual property rights (IPR) of local innovations.

2.3 Interventions for Grassroots Innovations—Case Studies

The case studies analyses inspected underneath were given to help provide gain an understanding of the motivations of two imaginative individuals who have invented, designed, developed and presented inventive products in India and Wales respectively. The people and products are:

- Deepak Bharali—his innovation, 'Chaneki', is an extra ornamentation device for Jacquard loom to facilitate extra weft insertion.
- Frank Edwards—his novel innovation, 'Synidor', is an intelligent mattress cover for bedsores.

Deepak's innovation Chaneki was supported through National Innovation Council (NIF) with the help of Indian Institute of Technology Guwahati, a local technical institution in Assam, India. On the other hand, Frank's indigenous innovation Synidor was supported from the Welsh Government Program—Academic Expertise for Business (A4B). Both case studies helped to explore commercial manufacturing facilities to the grassroots innovations between both countries like India and Wales as well. Both are grassroots innovators.

3 Methodology

This initial segment of the research involved included foundation inquire about on the products and inventor/designers concerned, utilizing published articles, patents, etc., trailed by preliminary interviews with the individuals. At that point material assembled at the interviews, including limited material, chronicle drawings, notes, and photographs, was analyzed and a further scan for published data was made. Afterwards, follow up interviews were conducted through telephone and email.

4 Indian Innovation

4.1 Chaneki

Chaneki means the printed design on graph paper followed by weavers to deliver it on cloth through the weaving process in Northeast India. Throughout the years, the weavers confronted basic issues while working with the Jacquard looms. Firstly, the treatment of weft strings at different interims and the tying of bunches brought about drudgery and required a great deal of time and effort. A normal texture, comprising of 30 columns of lines with 14 designs consecutively, would have no less than 3 knots per design. This would mean a sum of 1260 knots and that would require very nearly 10 h of work, accepting the weaver takes 30 s to make every knot. Besides, dealing with designs that need synchronous handling of at least five strings requires extraordinary aptitude that exclusive a couple of talented weavers have. Thirdly, while taking care of expansive designs or when the crevice between the weft strings is too little, the weavers think that it hard to slide their finger into handle the wefts. To build generation speeds, automate and chop down the dull procedure in routine errands, Deepak decided to make a devoted apparatus style attachment that can be fitted into the standard Jacquard linger.

4.2 Concept Generation

Expectedly the task of insertion of weft strings expected to make an assortment of design is done physically by tying knots, which is monotonous, lumbering and tedious. The string is additionally squandered in the association between one motif to another. The Chaneki facilitates texture efficiency help by more than 60% while wiping out the drudgery. This attachment to the Jacquard loom permits incompetent workers to enter the business and deliver extravagantly composed textures (Fig. 1).

4.3 Product Details

The new gadget was produced as an attachment that can be fitted into any Jacquard loom. The gadget has three parts, a base frame that goes about as a shaft holder; the magnet bearing shaft; and the uniquely designed bobbin. The uniqueness lies in utilizing the attractive magnetic clamping systems and uncommonly designed bobbin to accomplish its viability.

The attachment facilitates the Jacquard loom to do automatic choice and lifting of twist strings for design making. The magnet fitted shaft is fitted into the base casing. The quantity of magnets fluctuates relying on the quantity of designs that one has in every line. Not at all like typical design making looms where every weft string is associated with a bobbin, these bobbins are put on the lower surface of the base frame, just in light of top of the relating magnets altered on the shaft.

Once the magnet delicate bobbins are stuck to the surface, the frame is gone up against top of the twist strings. As the Jacquard machine chooses and lifts the twist strings, the gadget is put on top of the twist strings. The gadget is set in a manner

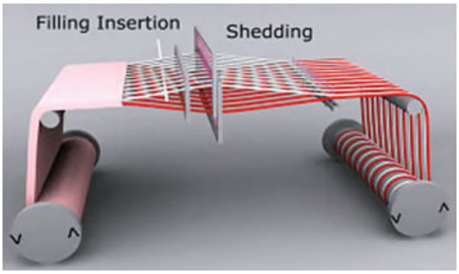

Fig. 1 Basic concept of designing in loom was finished by inserting the additional weft through the warp (*Source* http://slideplayer.com/slide/8744577/, accessed 20 April, 2016)

that the bobbins attached surface faces downwards and every bobbin falls in the middle of two arrangements of lifted twist strings.

As the magnet fitted shaft moves from one side to the next, it additionally drags along the bobbins appended to it from one side to other. All the while, the concurrent intersection of all weft strings for design making happens. Once the weft-string bobbins are intersected, the entire gadget is lifted to proceed with the typical loom weaving process. A similar procedure is proceeded for all the weft string arrangements until the plan making is finished.

4.4 Value Addition

The initial mock-up was made up of wood in 2006. The NIF then provided support for the project by gaining the help of an industrial design professor at the Indian Institute of Technology (IIT) Guwahati. Deepak and the professor made numbers of mock-up models and after dozens of trials and error, created a marketable version of the product (Figs. 2 and 3).

Fig. 2 Before value addition (*image-1*); after value addition (*image-2*) (*Source* http://nif.org.in/innovation/modification_jacquard/30, accessed 20 April, 2016)

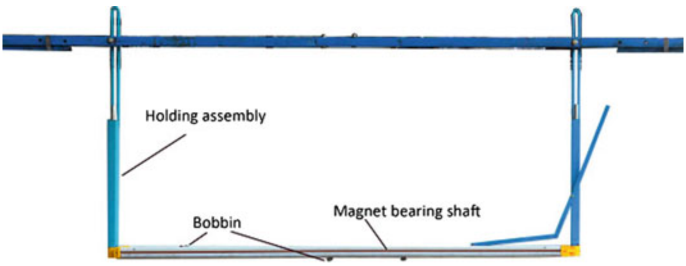

Fig. 3 Commercialist prototype (*Source* Site picture of Deepak's innovation)

4.5 Value Addition in Bobbin

In the entire process of development of the device, the development of the bobbin took most of the time. The result was the design of a new, special bobbin using a micro ball bearing (Fig. 4).

Another problem with the bobbin was that the art silk got uncoiled due to the elasticity and this created a problem in working, so to avoid this the innovator added a cup shaped cover surrounding the bobbin keeping a hole for the art silk to pass through Therefore Deepak modified the shape of the bobbin with the help of design professor to solve the problem.

4.6 Value Addition in Magnet

Earlier Deepak used the magnet of a small speaker that is round in shape. Then he thought of replacing it with a magnet having a thread at the bottom so that it can be screwed.

But from the discussion with the design professor it was decided to use a pyramid shaped magnet (Fig. 5) that will get itself clamped with the magnet bearing shaft (Fig. 6).

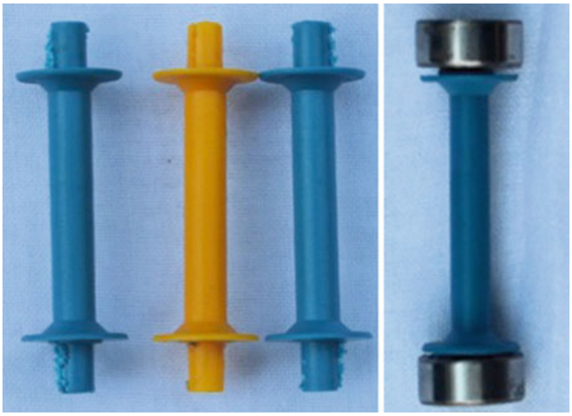

Fig. 4 Bobbin without bearing (*image-1*); Bobbin with bearing (*image-2*) (*Source* Site picture of Deepak's innovation)

Fig. 5 Pyramid shaped magnet (*Source* Site picture of Deepak's innovation)

Fig. 6 Bottom view of magnet bearing shaft (*image-2*); Side sectional view (*image-3*) (*Source* Site picture of Deepak's innovation)

4.7 Value Addition in Magnet Bearing Shaft and Holding Assembly

In the first model a weaver needs to keep the shaft over the weaving material, while in the new model the shaft dangles from the loom and is set close to the beater. Whenever required, a weaver can pull it down and after the work is over a spring will pull the shaft to its original position. The design professor instructed to utilize a pipe rather with respect to a metal sheet for the holding assembly (Fig. 9), in light of the fact that the spring mechanism can be kept inside the pipe reducing the possibility of duplicating yet if there should arise an occurrence of the metal sheet it must be kept open (Figs. 7 and 8).

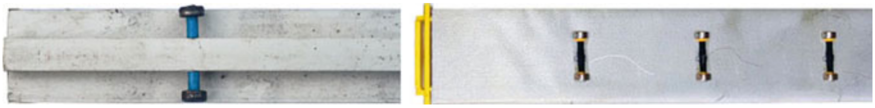

Fig. 7 Top view (*image-1*); bottom view of whole magnet bearing shaft (*image-2*) (*Source* Site pictures of Deepak's innovation)

Fig. 8 View of holding assembly (*Source* Site picture of Deepak's innovation)

Fig. 9 Iron suspension inside the holding pipe (*image-1*); Magnet bearing shaft with holding assembly pipe (*image-2*); Sliding lever of magnet bearing shaft (*image-3*) (*Source* Site pictures of Deepak's innovation)

4.8 Diffusion

To date Deepak has sold around 1500 pieces all through India. The gadget has been generally acknowledged by the weavers of various states of India. Globally the gadget additionally has wide potential in the South Asian nations.

4.9 Role of Technology Business Incubation

In the initial stage Deepak invested INR 3.7 million from his own source for developing the concept and to make test models from wooden mock ups. He went to NIF for discussions and then met a Professor of Department of Design, Indian Institute of Technology (IIT), Guwahati, India. The professor and Deepak made different models with the help of the Department of Design, IIT Guwahati, India. After numerous iterations, the final design iteration was fabricated and successfully tested in IIT Guwahati. Then a Delhi based plastic fabrication factory made the casings for the magnetic bobbins.

At that point NIF provided budgetary support of about INR 1.2 million, a 8% soft loan with a 10 year contract and later an INR 3 lacs premium free grant for market development. Deepak was given the venture finance from the Micro venture innovative fund (MVIF).

At present many government organizations are taking interest to introduce the product all over the country as a practically convenient product. Currently the Central silk board in India provides a 75–80% subsidy of cost of the device to the beneficiaries.

4.10 Financial Support

The business improvement bureau of the NIF bolsters the working of a value chain grassroots developments to encourage their move into self-supporting economical endeavours. In 2008–09 the NIF offered financial assistance as a Micro Venture Innovation Fund (MVIF) of INR 0.235 million for institutionalization and test advertising, with the sum authorized from the Small Industry Development Bank in India (SIDBI). MVIF is a novel association, which was set up in October 2003 and gives financial assistance to pioneers and entrepreneurs who are associated by NIF for innovation commercialisation [13].

4.11 Problem, Challenge and Future

The NIF helped Deepak in many ways including documentation, publicity, patenting, and partial financial support for commercialisation. However, the significant issues confronted by Deepak for his development, Chaneki, as saw by him, are as per the following:

- Procedural delay: Deepak saw that there was some postponement in commercialisation of his advancements with the assistance of NIF. Notwithstanding, it is essential to note that Grassroots innovators get their advancements a crude shape that require significant work to get them to a level appropriate as attractive product with the assistance of design establishments.
- Limited funds: Deepak perceived that the NIF had not fully supported him for his innovation in the initial stage.

5 Wales Innovation

5.1 Wales Innovator's Background

Frank Edwards was born in 1952 in Llandeilo, a Carmarthenshire town in Wales, UK. When he reached the 8th standard he dropped out of school. After dropping out his studies he started working in a Fiberglass shop in Cardiff. He made various boat models and later started to work on a human anthropometric device including wheel chairs. These experiences inspired him to become an inventor and to date has 29 innovations.

5.2 Concept Generation

The Synidor system, was to help the anticipation of pressure ulcers by checking and cautioning of fixed status of at-hazard patients. Bedsores happen on regions of the skin that are under pressure when a man difficulty moving, is incapacitated, oblivious, not able to detect torment or fixed. The get together appends to a fitted covered bedding sheet. Edwards built up the essential specialized plausibility of his thought by testing a basic stethoscope with a sphygmomanometer gadget and saw how these two gadgets functioned. This is an unmistakable instance of the transfer for a thought and innovation starting with one application then onto the next. The device could work for those patients who have pressure ulcer by between 20% and as much as 60%. The device incorporates a sensor that lies under the bottom of a patient's spine. If a patient has not moved for a certain period of time it alerts healthcare staff. The alarm can be set to go off at intervals of 30 min.

5.3 Product Detailing

The Synidor system consists of two basic configurations:

- Sensor assembly: attached to the full-length waterproof fitted mattress cover sheet.
- Patient Immobility Monitor (PIM) alarm unit: a battery driven remote caution unit that can be customized for the picked turning administration. At the point when inadequate movement is distinguished, unmistakable and capable of being heard alerts will trigger (Fig. 10).

An astute bedding cushion cover is made by the provision of a strap across the bed or seat, which joins a proprietary sensor. Patient movements, however little, are observed through the sensor appended to an electronic processor. On the off chance that no patient movement is identified in a predetermined time, prescribed by the nurse or caretaker, the patient may be at danger of creating pressure ulcers and will require nursing mediation (Fig. 11).

The Synidor PIM caution unit should have been set as per the timing of the turning regime recommended for the patient by the medical attendant. Once the setting had been chosen, the Dataline cable (Fig. 121–4) is inserted into the base of the PIM alarm unit (Fig. 10).

5.4 Role of Technology Business Incubation

The Welsh Wound Network (WWN) exhorted Frank Edwards to make an alarm system for wheelchairs and sleeping bedding covers. The latest research has demonstrated that pressure ulcers in the UK cost £1.4–2.1 billion (INR 124.27 billion approx.) every year. Straight to the point Frank Edwards got bolster from the Assembly Government from the early feasibility stages by means of the Wales Innovators Network (WIN) through to manufacturing. Edwards got to the expertise at PDR (the National Centre for Product Design and Development Research),

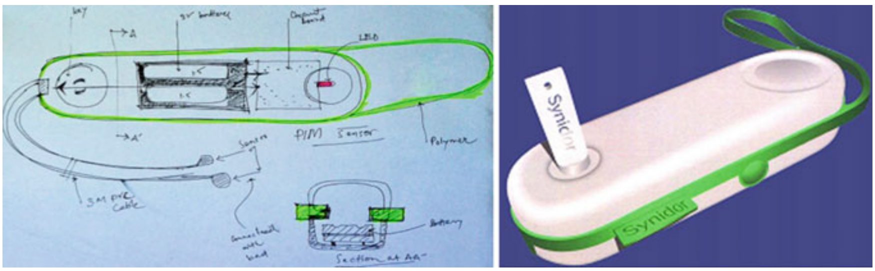

Fig. 10 Internal sketches of the Synidor (*image-1*); Synidor Final product (*image-2*) (*Source* Frank Edwards)

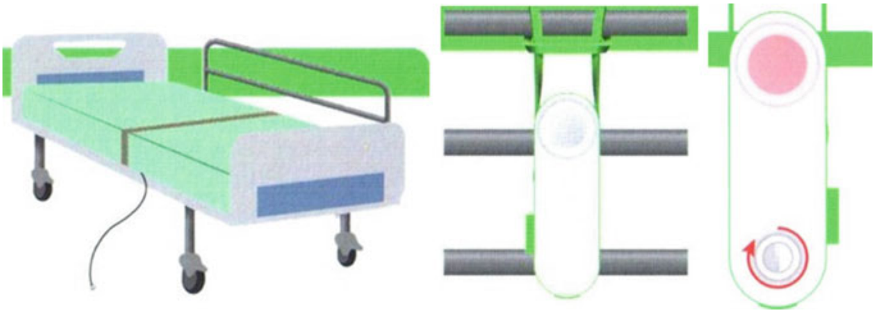

Fig. 11 Hospital bed where 3 m length wire connects with the Synidor alarm unit (*image-1*); Hang in position using the *green* strapping (*image-2*); Clockwise key settings (*Source* Frank Edwards)

Fig. 12 Different views of the Synidor (*image-1, 2, 3, 4*) (*Source* Dipanka Boruah); Edwards demonstrating the Synidor (*image-5*) (*Source* Swansea bay Business Life, Newspaper, 2010)

Cardiff Metropolitan University to build up the casing for the alarm unit. PDR charged INR 1.2 million approx., and after many triales, the (Acrylonitrile Butadiene Styrene) casing alarm unit had been successfully tried within 6 weeks.

PDR collaborated with Glamorgan University for assistance in designing the electronics for the system. During those days Edwards worked at the Cardiff Medi-center for 3 years (2007–2010). His daughter designed the electronic circuit board at the University of Glamorgan. The system was initially trailed by the Sunderland NHS Trust on his 80 years old mother. A China based plastic injection moulding factory made 1000 pieces of casing unit for Synidor and 1000 pieces of circuit board were developed by a Newport based electric company, costing INR 69 million approx. Edwards received INR 18 million approx. from 49 investors in the UK. In total the cost of innovation was £4 million.

5.5 Financial Support

In 2009, the Welsh Assembly Government funded INR 14.8 million approx. to Edwards's innovation through its Academics for Business (A4B) program, and the Welsh Assembly Government helped Edwards develop his business model.

5.6 Problems, Challenge and Future

In early November, 2010 the Synidor was shortlisted in two award categories, as part of WWN's Nursing Times Product Awards, (1) dignity, daily living and wound care and (2) pressure ulcer prevention category. Unfortunately, Synidor was not successful in either category but introduced in the event as a brand new product for NHS [14]. Straight to the point Edwards highlighted that he confronted issues amid advancement of his development Synidor, and that he felt an absence of appropriate instruction had fetched him a considerable measure.

5.7 Diffusion

In the first stage after commercialization, two devices had been sold to Birmingham hospital; two units to Hammersmith hospital; one unit to the Home Watch Network in Cardiff; and one unit at Llanstrisant hospital. Synidor aims to gain 20% market share in the UK, North America and European territories in 5 years. Due to its highly unique nature the inventor has kept the intellectual property guarded, even refusing to patent it as this would entail having to disclose the formula. This IP has been independently valued at £6.5 million, based on its application in the UK market and it is therefore expected that the product can be successfully distributed globally.

6 Comparisons

From the case studies of the Grassroots Innovation procedure of both nations it is conceivable to recognize numerous similarities in: concept development; the individual characteristics of the people who created the indigenous innovations; and the path in which the products were effectively acquainted with the market, however there were contrasts in the points of interest on the context of innovations of the people concerned.

What can be learned from comparing and contrasting the design support given to grassroots innovations in India and Wales?

Case study 1—Deepak's innovation: In India, the most vital factor is the creation of a speculation subsidize made to support endeavors and innovators that provide solutions to enhance India's lowest-income group. At the underlying phase of startup, it is truly hard to contract to retain skilled and competent individuals in the administrative group because of low compensations.

Case study 2—Frank's innovation: The Welsh Government provides support for local innovations, from initial ideas to the implementation of the final product or innovation including business innovation to help drive business success.

How can people and local business benefit from collaboration with university research centers in India?

The main functions are performed within NIF promoted innovators and their business startup with the collaboration of university research centers which integrated the activities. NIF arrange the transformation of invention into a product by involving university research centers to develop an innovative product design (scouting, confirmation, approval, testing, prototyping, intellectual property rights protection, commercialization, design, innovation and technology transfer, social disseminations) and abatements exchange cost at all stages.

7 Conclusion

In India, the institutionalization procedure of Grassroots Innovation and Business startup through design advancement is built on 'bottom up pyramid' standards. The research work unfolds a need to develop indigenous design with an Indian need and context.

How could this design support be further improved?

Despite the fact that the grassroots innovators have advancing credits however their creation is by one means or another imaginary. Their inventive product is not industrially feasible and technically inaccessible. For this situation, Government of India ought to provide standard financing to building up the idea in introductory stage. So that, the indigenous development can be tended to.

The design and development of grassroots innovator's innovation procedure would upgrade the participatory approach.

- Innovation studies ought to concentrate on the arrangement of innovation based around the organizations, market and scholastic innovation foundations like National Institute of Technology (NIT)s, Indian Institute of Technology (IIT)s, Indian Institute of Management (IIM)s and other neighborhood establishment also.
- Promote local innovation in environmentally situated farming and characteristics asset management. It perceives indigenous knowledge and casual experimentation among agriculturists, timberland occupants, pastoralists, and fisher folk.

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Methods to Capture and Model Craftsmen's Tacit Knowledge in Traditional Designs

Sai Prasad Ojha and Pradeep Yammiyavar

Abstract Local crafts and traditional designs are symbolic representations of culture of their origin. Conservation of this art has always been accorded priority. Several instances have been reported of a craft's lineage having died out because there being very few craftsmen willing to continue practicing or train new interns. Continuing the family traditions is becoming difficult besides resulting in documentation gaps and tacit knowledge loss. Designers need efficient methods to capture and document a craftsman or a fine artists or a designers' mental model not only during creation but also during reflection and conservation. This paper outlines a method and process to identify components of tacit knowledge within Implicit and Explicit knowledge categories of a crafts object. Craftsman engaged during the creation of the objects are observed and documented. Using ethnography and personal interviews, their activity is analyzed to derive and categorize components of knowledge. It is posited that such methods have potential use in conservation, geographical identification and documentation. Ultimate aim is to be able to translate such traditional knowledge into the digital format for use with machines so as to be able to reproduce—to the best of mapping possible—such designs that have been abandoned due to their inability to be passed on to newer generations.

Keywords Crafts · Tacit knowledge · Conservation of art and crafts · Human learning

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1 Introduction

India is one of the largest countries with cultural variations and traditions. There are varied communities in India who practices traditional crafts which symbolizes their culture of origin. Though there are attempts by the government towards conservation of these crafts, a holistic approach is needed in this area of conservation. To carry on traditional crafts craftsman need to train the next generation of the apprenticeship under them that is available within their close knit communities. This practice of son carrying on with the father's profession seems to have now been discontinued as very few craftsmen's sons/daughters are willing to continue the family tradition. With decrease in artisan numbers and onslaught of mechanization and mass production accompanying skills and more importantly tacit knowledge are likely to lose out. Designers need efficient methods to capture and document a craftsman or a fine artists or a designers' mental model not only during creation but also during reflection and conservation. As a consequence, there exists growing gaps in documentation of arts and crafts. North-Eastern India is abundant in natural resources and is home to different tribes who practice various crafts. There has been a decrease in production of crafts items from these areas of the North East. There is a need for design intervention to conserve crafts of this area.

The work presented here is based on the posit that the if tacit knowledge behind these crafts be captured and documented there is a fair possibility of capturing the unique knowledge base and thereby assist preserving the crafts and arts for future generations.

The term 'tacit knowledge' used here is defined as the knowledge which is learnt by repeated practice from a master craftsman for a certain span of the time and which is internalized as knowledge skills in terms of touch and feel. Tacit knowledge is often described as extremely difficult to capture and transmit as compared to implicit knowledge. Tacit knowledge has been passed on from one generation to another under apprentice mode amongst craftsman.

2 Literature Review

The crafts domain has been an exciting area of work for the designers and researchers in India since independence. The Indian Craft museum in New Delhi is an excellent example of conservation of art from various parts of India [1]. Sethi et al. [2] has studied the Dilli craft village in India and has mapped the craft there to the contemporary India. A major role was played by Pupul Jayakar in the traditional crafts tourism Post-Independence [3, 4].

Some industries are attempting to capture the experience of retiring employees by assigning them new trainees for apprenticeship learning. Knowledge and practice time gaps and disconnect between traditional practices (say in different pockets of bamboo basket weaving communities) starts reflecting in such training too. The present generation of youth in the North eastern part of India is migrating to the cities in search of the other more lucrative occupations. To continue preserving skills and to retain new generations into the crafts-trade new design ideas but within the traditional boundary becomes necessary [3].

Elsewhere in the world too researchers have been making attempts to preserve and transmit traditional knowledge. In the review of the book, 'Nigeria's traditional Crafts' the author [5] has mentioned about the varied description of Crafts ranging from wood carvings, decorated gourds, mat work and basketry, woven textiles, died textiles, leather working, pottery, beads and bead works, Bida glass, wall decoration, and finally cicatrisation, body decoration, and hairdressing in Nigeria. The author has also mentioned about the lack of the importance to the crafts sector in Nigeria. For example, some of the primitive's methods of pot making in Nigeria like Gwari pot making and techniques used by the Yoruba potters are neglected and may be lost if not conserved in due course of time (Fig. 1).

The modern craft industry is a combination of the both the implicit and explicit knowledge of the craftsmen. Implicit knowledge is the knowledge which is gained by reading the books, literatures and whereas, the explicit knowledge is obtained by experiencing, and practicing the craft repeatedly [7]. The distinction between explicit and tacit knowledge was introduced by Polanyi [8] in 1962 and elaborated by Nonaka [7] in 1991. Both these are presented in different ways while the craftsmen work on a product such as for example a bamboo basket.

Wittgenstein [9] in his studies also pointed out different ways in which tacit knowledge is expressed by people for example recognition of faces in the crowd.

Smith [10] studied the Dhokra artisans of West Bengal, India. The tribe worked on the decorated brassware products created by the cire perdue or lost wax process which is now getting obsolete. He has suggested that the theory of artificial as proposed by Negrotti [11] can be a path way to archiving the lost knowledge of the

Fig. 1 Gwari pot (*Source* [6])

craftsman. Their project was involved in creating a multimedia archive of the tacit knowledge of the artisan (Fig. 2).

Marshall McLuhan, in 1966 [13] had pointed out that the importance of the craftsman in the future in 'global village' concept. In his concept he has mentioned that with the increase in the technology and cultural globalization the world will become a mixed market place and thus the craftsman will be playing a major role in promoting their culture and also the business. Figure 3 shows the combination of crafts with the modern day objects [14].

Kersey et al. [15] have given a brief review about the state of Indian crafts during the World war I scenario. Due to high demand of traditional crafts goods resulted in their imitation and some cheap goods from the foreign market. Collins [16] have spoken about the formal form of education which was started in the industrialized nations and the importance of apprenticeship training which had existed before industrialization. The value of thinking and problem solving practically in the presence of masters brings large an of confidence to the students/learners. There is a need to recognize the cognitive and meta-cognitive strategies while imparting practical training to the learners especially where large amounts of tacit knowledge are involved.

The term 'cognitive apprenticeship' which involves learning through guided experience describes a type of apprentice wherein large amounts of tacit knowledge are transferred from master to learner. The framework being proposed in this paper consists of four dimensions-content, methods, sequence and sociology.

Chartrand [17] have categorized the crafts intro industrial and handicrafts. The basic difference between the two simply can be in terms of production one by machines and the other by individuals by hand. The authors observed the gradual

Fig. 2 Dhokra art (*Source* [12])

Fig. 3 Combination of modern day materials with traditional crafts item (*Source* [14])

decline of the handicrafts because of the cheaply available industrial crafts. There was a loss of skills which was involved in production of common household crafts.

Aguilar et al. [18] describes knowledge of a person into two kinds: declarative and procedural. The declarative knowledge is the general heuristics, or a fact explaining the system where as the procedural knowledge is the skill of an individual in performing certain task.

Reber [19] defined implicit knowledge as an independent conscious effort to learn in the absence of explicit knowledge of how it was acquired. The authors have referred to the inequality from Erdelyi [27] for the importance of the implicit and unconscious knowledge as:

$$\alpha > \beta \tag{1}$$

where α is the information available to the unconscious system and β is the information available to the conscious system. The authors have discussed two popular methods of transfer of implicit knowledge, i.e., artificial grammar and probability learning method. In the artificial grammar method, the subjects are made to first acquire the knowledge and then are tested with that knowledge. This is similar to the modern day learning in which a student reads a subject and then answers the questions in the exams related to that. The only difference in artificial grammar is that some of the strings which are shown are not occurring regularly in literature. This kind of input of artificial words to the learner before telling him to face real identical of the strings test is called as stimulus. This was first devised by Miller [20] in his *Project Grammarama*. Table 1 shows a simple stimuli used in the artificial grammar.

In Probability Learning users can accurately anticipate the changing probabilities of events even when the anticipatory response requires an integration of information across 50 preceding events. In an experiment conducted by authors the probability of each event was subsequently increased or decreased as the trial went from n to 50 trials. The subjects were then given 1000 instant asymptote with the above event sequence and then told to predict the event prior to their occurrence.

Table 1 A simple artificial grammar stimuli (*Source* [20])

Learning stimuli	Testing stimuli	
1. PVPXVPS	[a]1. PTTTVPVS	[a]26. SVPXTVV
2. TSSXXVPS	[a]2. PVTVV	27. PVPXTTVV
3. TSXS	[a]3. TSSXXVSS	28. PTTVPXVV
4. PVV	[a]4. TTVV	29. TSXXTVPS
5. TSSSXXVV	5. PTTTTVPS	30. TXXTVV
6. PTVPXVV	6. PVV	31. TSSSSXS
7. TXXVPXVV	[a]7. PTTPS	[a]32. TSXXPV
8. PTTVV	8. TXXTTVPS	33. TPVV
9. TSXXTVPS	9. TSXXTTVV	[a]34. TXPV
10. TXXTVPS	[a]10. PVXPVXPX	[a]35. TPTXS
11. PTVPS	[a]11. XXSVT	36. PVPXTVPS
12. TXS	12. TSSXXTVV	[a]37. PTVPXVSP
13. TSXXTVV	13. TXS	38. PVPXVV
14. PVPXTVPS	[a]14. TXXVX	39. PTVPXVPS
15. TXXTTTVV	[a]15. PTTTVT	[a]40. SXXVPS
16. PTTTVPS	16. TSXXVPS	41. TXXVV
17. TSSSXS	17. PTTTVV	[a]42. PVTTTVV
18. TSSXXVV	[a]18. TXV	43. TSSXXVPS
19. PVPXVV	19. PTTVPS	[a]44. PTVVVV
20. TXTVPS	20. TXXTTVV	[a]45. VSTXVVS
	[a]21. PSXS	46. TSXXVV
	[a]22. PTVPPPS	[a]47. TXXTVPT
	23. PTTTTTVV	48. PVPS
	[a]24. TXVPS	[a]49. PXPVXVTT
	25. TSSXS	[a]50. VPXTVV

[a]Indicates a non-grammatical string

The accuracy of predicting the events increased with the increasing trials. The authors have also pointed out that automatic processes are one of the best examples of the transfer of tacit knowledge as they are outside of our conscious control and thinking [8, 21–23]. The author has given an example in which the subjects were shown different objects which were masked to hide their identity. The subjects choose the objects based up on their experience. All of the above literature have given methods and describe how tacit knowledge is captured and used in literature but very few have studied its impact and usage in the crafts domain. Though the cognitive thinking analysis was captured [24–26] between designers and artisans, it was just to compare the thoughts of both during the idea generation phase. The next section will brief about a proposed methodology adopted for a craft domain in capturing the tacit knowledge.

3 Methodology

There were several methods reported in literature as mentioned in Sect. 2 to evaluate tacit knowledge. But very few literatures were found which were able to identify and capture it specifically in the crafts domain. The method proposed here in this paper is limited to the crafts domain but can also be extended to other similar domains. Figure 4 gives different steps involved during the capturing of data in the craft domain. During these steps the craftsman is asked various questions related to the crafts products he is involved with.

The background of the craftsman is also noted during the study. This gives a brief idea where the crafts originated from. This ethnographic study also helps to learn the conditions of the craftsman and how much time apprenticeship training has been taken to learn the crafts. The next step was to categorize the data collected into implicit and the explicit parts. Then the crafts items from a craftsman are compared to get a brief idea of the differences of the uniqueness of that craftsman. This is under the hope that these unique characteristics can become the metaphorical fingerprint of that particular craftsperson and that every crafts object produced by that craftsman carries a tacit component within the design as a fingerprint.

Figure 5 shows the proposed methodology to capture the tacit knowledge of the craftsman. The proposed methodology is made to suit the crafts domain but can be extended to any domain of similar interest.

The first step in the methodology is to categorize the collected data into different groups for a product of similar craft domain. This data is then analyzed to by dividing each of the products views into grids. The different products were then compared through visual analysis to get it into the same scale or a normalized state. This is compared with the other products of the same group of the craft domain1. The tacit knowledge captured is then defined for the craftsman for the certain group of the product. The next section will have the brief discussion on results obtained by applying this methodology to a group of products.

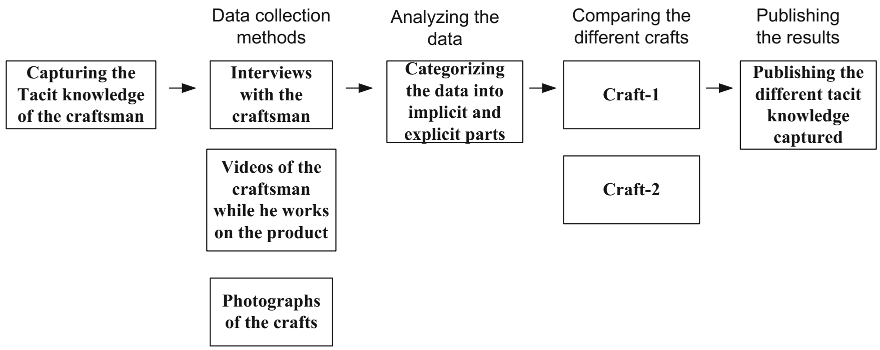

Fig. 4 Different steps involved during capturing of domain knowledge data from the craftsman

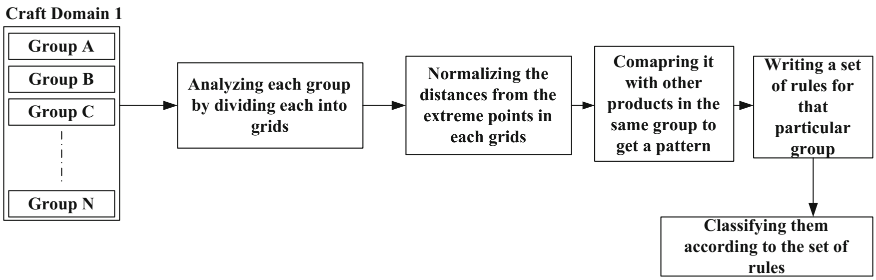

Fig. 5 Proposed methodology for measuring the tacit knowledge of craftsman

4 Results and Discussions

A group of potters (Manik Das, Chandan Bora, Manoj) settled in the North East (mainly Amingaon, North Guwahati) were recruited for this study. 500 numbers of diyas (oil lamp in earthenware) were examined. The Fig. 6 shows the potter working and the set of the products produced by the potter.

The data which was collected from the potter was analysed and then was divided to different categories. For example, the conversation with the craftsman of pottery

Fig. 6 Collection of data from a potter

is reproduced here: "The experience in making pottery triggers my decision when to thrust my fingers at a particular time while the pottery wheel is rotating, to give a particular shape to the pottery." This data clearly has a decision in design and has a 'feel' component, a 'time' component, a 'speed' component, an 'experience' (kinaesthetic knowledge) component that are unique to this potter. Likewise, the conversation during the making of a single diya from scratch till the finish was analysed to get the full picture of its making. All these components can be can be analysed at a first categorisation level as shown in Table 2.

The group of products here 'diyas' from one potter was termed as group A. Likewise different groups belonging to different potters were formed. The different views of the diyas were then compared to extract 'patterns' from the same group. The reason for finding the' pattern' was to find, identify and isolate certain characteristics of a particular craftsman in the assumption that these patterns embed the unique fingerprint of tacit knowledge of that craftsmen. The Fig. 7 shows the categories formed for the different groups.

Table 2 Analyses of the data collected from the craftsman

Statement/image/audio	Explicit knowledge	Implicit knowledge
The experience in making pottery triggered my decision to put my fingers at a particular time while the pottery wheel is rotating, to give a particular shape to the pottery	"Triggered my decision to put my fingers" "Pottery wheel is rotating"	"The experience in making pottery" "At a particular time" "Shape to the pottery"

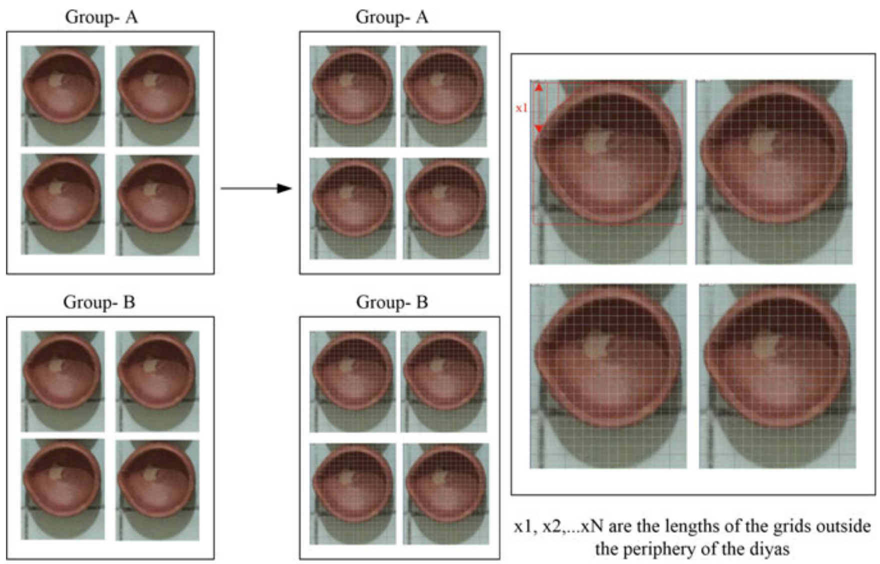

Fig. 7 Categorization of the different groups and the grid comparison of the diyas

The difference in the length of the spout for example can predict the difference in the groups of diyas. Techniques of pattern recognition by digital recognition algorithms are intended to be eventually developed for purposes of recognising, extracting and comparing patterns. This in turn will help the diyas to be placed into different groups. The difference is due to the unique characteristics of the craftsman's transference of his–her tacit knowledge during the production of diyas. This uniqueness intensifies with the repeated practice of the crafts. We call this as 'tacit design signature' of the particular craftsman.

5 Inferences and Conclusions

The above survey was done on a set of the craftsman who practices pottery. A total number of 500 diyas from three different craftsmen from Amingaon, North Guwahati was collected and compared. Only the circular/elliptical form of the product as captured from top view was considered. The anatomy of the crafts (only shape) was only debated in this work. The other characteristics like the material, three dimensional characteristics like depth, height, etc. curve of the form was not considered in this study but are planned to be included in further investigations. Attempts to identify, set apart and define a tacit design signature was carried away. The procedure has application potential to different craftsman of similar craft domains. The methodology proposed in this paper is intended to not only capture tacit knowledge, but also to reverse use it to categorize and identify a craftsman of a certain geographical area - given a craft product. Further research work is carried to reproduce the above methodology to produce the crafts by machines.

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Adaptable Mechatronic Engineering Design Processes: Process Reference Model and Methodology

Christoph Hollauer, Lucia Becerril, Niklas Kattner, Dominik Weidmann, Nepomuk Chucholowski and Udo Lindemann

Abstract Mechatronic product development is a complex endeavor. Process and project management are approaches expected to handle the arising complexity in engineering design. Formal yet adaptable design processes have been identified as best practice in empirical studies, but an effective management requires appropriate process models. While general design methodologies in literature do exist, they are often very abstract and need to be adapted to an organization's context as well as the context of its individual projects. In this paper, we present a reference model for mechatronic system design along with an initial methodology for systematic organization-specific process concretization. The reference model has been developed from a literature basis as well as in cooperation with five SMEs with a background in mechatronic system development, performing an analysis of the company-specific processes regarding commonality and differences.

Keywords Process management · Interdisciplinary product development · Process adaptation

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1 Introduction

Modern interdisciplinary product development is characterized by a high pressure to succeed in terms of profit, quality and time-to-market, as well as by issues of dealing with high complexity due to a rising number of constituent elements and relationships in products [1, 2].

Examples for such complex product development endeavors are the development of mechatronic products. Mechatronics combines mechanics, electronics and information technology, using synergies to develop innovative products [3].

In order to handle the arising complexity in product development, organizations have turned to approaches such as process and project management as well as model-based systems engineering. Empirical studies support the hypothesis that formal and structured, yet adaptable processes aid in successfully carrying out engineering design projects (e.g. [4]). However, since engineering design processes (EDPs) are inherently intangible, approaches to describe and model such processes and to turn them into tangible artifacts have become a necessity. According to [5], the following purposes of process models can be distinguished:

- Visualization of PD projects (actions, interactions, commitments, customized "views")
- Planning of PD projects (choosing activities, structuring the process, estimating, optimizing and improving key variables)
- Execution and control of PD projects (monitoring, assessing progress, re-planning)
- Development of PD projects (continuous improvement, organizational learning, training, metrics, compliance).

However, while formal process definition and process modeling present a viable solution approach for the aforementioned challenges, available methodological support for process modeling is currently limited [6]. The available support for creating engineering design process (EDP) models is mostly focused on the use and application of specific modeling notations and formalisms [7]. Hence, we derive an existing need for methodological support in order to capture, to conceptually design and to adapt EDP models and the corresponding processes themselves. In order to best support engineers and managers in their daily activities, the processes must fit closely to an organizations context.

In order to address this identified need, we first present a generic reference model for mechatronic system design in small and medium sized enterprises (SMEs). This reference model is intended as a basis for further concretization in specific organizational contexts. Based on this generic reference model we propose a methodology with the intention to help guide the gradual adaption and concretization of the process model for different organizational and project contexts.

The structure for the rest of this paper is as follows: First, background information on EDP definition and process modeling is given. Second, the research setting and approach is described in Sect. 3, followed by the results, namely the derived reference model and the proposed methodology for concretization in Sect. 4. The results are discussed in Sect. 5, followed by a summary and outlook in Sect. 6.

2 Theoretical Background

EDPs are classified as knowledge-intensive processes and thus differ from regular business process: They are very dynamic, with iterations and jumps, resulting in little predictability. Their description lacks in precision and constituent elements such as designs, concepts and ideas do not always manifest. Since this results in a high possibility of disruptions, dynamic reaction capabilities are needed consequently [8].

Four relevant process layers are distinguished in the context of this paper (cf. [9] and Fig. 1). General design methodologies, such as the V-Model or VDI 2221 [10] reside on a high level of abstraction, describing how design is done in general. As evidenced by earlier publications, a large number of design methodologies exist, catering to different purposes and design problems (e.g. product design, service design, cf. e.g. [11]).

To be useful in organizations, these need to be adapted to a specific organization's context (i.e. its needs and conditions) [11, 12]. Company-specific standard processes represent the next lower level, defining how engineering design should be

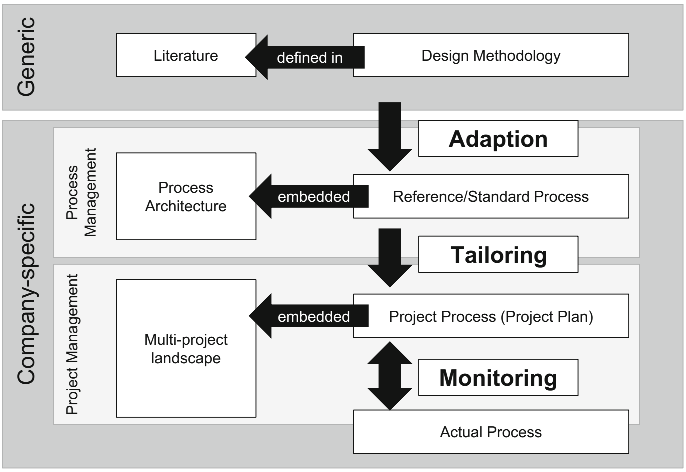

Fig. 1 Levels of engineering design processes (based on [9])

done within a specific company [13]. These are embedded within a company's overall process architecture [14]. The next step of concretization are tailored processes of specific projects, "with an actual and real task to address" [2]. Hence, a project instantiates a standard process by defining its starting conditions, such as schedule, budget, resources and initial requirements. The most concrete level is the actual process of a project, which needs to be monitored and compared to the project plans continuously, taking corrective actions as necessary. The individual concretization steps are each heavily influenced by the emerging organizational and project contexts.

3 Research Setting and Approach

This research is embedded in a research project involving several small and medium-sized companies (SMEs) with a background in mechatronic product development (cf. [15] for an overview over the involved companies). The objective of the research project is to conduct a descriptive study of the EDPs and the identification and development of means to design more appropriate, company-specific EDPs. The results will be documented in a SME-specific guideline for process design in mechatronic design contexts.

The involved companies cater to different markets, different industrial branches and differ in their focus on mechatronic disciplines. They also show a strongly differing degree in process orientation and process modeling expertise. In order to develop the results presented in this paper, the research methodology follows a two-pronged approach: On the one hand, a literature survey has been conducted, gathering relevant design methodologies. On the other hand, the companies EDPs have been analyzed for commonalities and differences. Along with document analyses, interviews have been conducted with representatives from the individual companies in order to derive challenges in EDP design and management. One of the challenges mentioned was a lack of transparency, communication, and coordination between discipline-specific activities, resulting from a lack of common ground in terms of product and process documentation. Another recurring theme was the insufficient flexibility of the companies' EDPs, especially when faced with different process contexts and new arising challenges. This corresponds with the identified needs and challenges in scientific literature (cf. Sect. 1). Further contributing is the fact, that while EDPs are often represented as a single process, each of the disciplines is often following its own process, covered by different paradigms (e.g. agile development approaches in software engineering) (cf. [15]).

4 Reference Model and Methodology

4.1 High-level Reference Model

The presented solution approach consists of two complementary parts: a high-level reference model to structure the design process and a methodology to further concretize the reference model in organization-specific contexts.

As has been observed in literature as well as in practice, EDP models tend to be very generic and thus theoretically always correct, but at the same only of limited use in practice in correlation to the four uses of process models described in Sect. 1, without further concretization and specification. We have collected and generalized the phases and disciplines most commonly involved in mechatronic product development. Due to the focus of the research project, the reference model is intended to target SMEs specifically, where we observed that they often lack the resources for dedicated process management departments, thus primarily requiring simplicity and ease of use. The model (see Fig. 2) is intended to be more specific than existing design methodologies in literature, but still generic enough to enable company-specific adaption, as well as lower the barrier for process definition, specifically addressing the needs of the industry partners.

The model has been developed on the following grounds:

- Literature regarding design methodologies has been reviewed, collecting 144 references for design methodologies in total. Existing reviews and comparisons have also been taken into account (e.g. [9, 11, 16]). From these references, the most relevant models addressing mechatronic product development have been chosen.
- Five company-specific mechatronic development processes have been analyzed for communality and differences between each other and the literature-based models as part of a descriptive study (cf. [15] for company descriptions).

Within the model technical domains and organizational disciplines are differentiated. This is done in order to take into account the fact that both are not always directly identical in reality. For example, what might be defined as a “mechanical” component (levers, gears, scaffolding and frames etc.) can be designed by different organizational functions or faculties hierarchically subordinate to the overarching mechatronic discipline (e.g. gear specialists, hydraulics experts etc.).

The model covers the EDP from the start of concept development to launch preparation. Phases regarding life cycle management are currently not included.

The model is divided into two overarching groups: Concept development and project execution, in order to pay respect to the different required management styles for Front and Back End, the former of which being characterized by a higher degree of uncertainty (cf. [17]). After an idea (e.g. new product, variant, or adaption) is launched into concept phase, requirements are collected and managed, functions defined and concepts developed. In order to set up boundaries for the concept phase in terms of budget and resources, the size and scope of the product

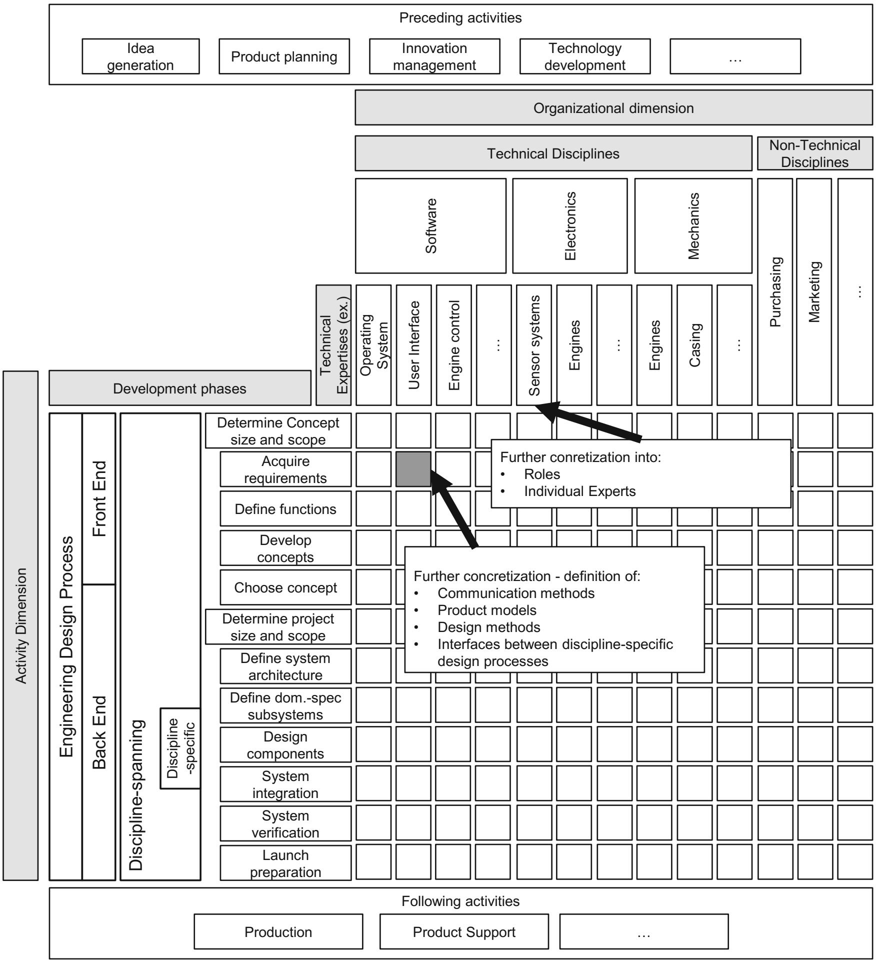

Fig. 2 Proposed reference model

concept to be developed needs to be defined upfront. Finally, based on criteria derived from the requirements, concepts are chosen. The Front End is depending on the tight collaboration between the different technical and non-technical disciplines and characterized by a high number of iterations.

After a concept decision has been made, a top-down development approach is followed, by defining the overall system architecture. During subsystem definition, the subsystems are defined in more detail in a process called “partitioning” [18], where the individual subsystems are gradually mapped to the organizational disciplines and faculties. The design of components (mechanical parts, circuit boards and software) is then a mostly mono-disciplinary task. Since changes are becoming increasingly costly during these latter stages of the EDP (cf. “Rule of Ten”, [19]), iterations need to be minimized, kept locally (e.g. within disciplines), or carefully planned. This requires effective and efficient discipline-spanning communication and collaboration based on the artifacts (i.e. product models and documents) developed during discipline-spanning activities.

Since disciplines differ between the investigated organizations, e.g. due to different product structures, the selection of disciplines and expertise in Fig. 2 can only be exemplary and a starting point for company-specific concretization.

In the following, we present a number of further use cases for the reference model, supporting the integration of the reference model in companies and consequently, increase the process orientation:

- Coordination of discipline-specific processes:
  - Serve as a basis for workshops and interviews in which synchronization points and coordination measures between the individual disciplines are identified and defined.
- Plan and assess methods, models, documents, tools, and communication measures:
  - Place models, methods and documents on the intersection of discipline and phase, in order to support the inter-disciplinary communication and improve model-orientation in product development.
  - Use as an analytical tool, in order to map existing support in the EDP regarding models, methods, documents and communication means.

4.2 Methodology for Process Adaption and Concretization

In the industrial processes investigated, we found several differences, e.g. between original equipment manufacturers and suppliers (cf. [15]): The first phase of the supplier's process started with creating an offer, while the processes for OEMs started directly with the collection and management of requirements, e.g. through marketing departments. Likewise, system integration and verification is approached differently in a plant engineering company than in a company designing household appliances, creating different challenges (e.g. testing on-site versus testing in a lab-environment). Hence, the second part of the solution approach presented in this paper consists of a methodology for further, context-specific concretization of the morphology (i.e. its content in the form of process elements such as phases, activities and documents) of the prior presented reference model (cf. Fig. 2).

Its purpose is to develop EDP measures (e.g. recommendations for activities to be carried out and models/methods to be used) and corresponding implementation strategies based on the acquisition and analysis of organizational and project contexts. The derived measures are to be described based on the elements commonly found in EDP meta models, such as the definition of activities, documents, methods, milestones, and tools and systems (cf. [20]). An initial methodology for the company-specific adaption of EDPs has been presented in [15]. Such a methodology enables SMEs to concretize and adapt the reference model according to their specific organizational contexts. A graphical representation of the basic methodology is shown in Fig. 3.

The proposed methodology is based on an initial assessment of the current situation of an organization's process orientation and project management practices: Within this step, e.g. the existence of EDP models in the company needs to be investigated and existing processes can be analyzed and mapped to the reference model in order to identify existing process support and missing steps. It is equally important to investigate whether the current process is indeed used to plan products or whether it is unused within the company. Another step within this phase is the scoping of data availability for the subsequent information acquisition.

Subsequently in phase 2, organizational context factors are elicitated using a workshop- and interview-based approach and characterized according to criteria such as relevance and impact on the design process. General categories of context factors are e.g. the organization, the team, or the product in question. As support, context models or existing listings of influencing factors can be used (cf. [21, 22]). For example, in this step the reference model can be concretized along the organizational axis, by identifying and mapping the disciplines, faculties and experts onto the reference model. Further influencing factors are e.g. a pending certification of the EDP according to norm or standard (e.g. ISO 9001).

Necessary data availability provided, further project contexts are elicitated using historical project data, supporting the project-specific definition of process measures.

Based on the acquired context data, context classes and structure (dependencies between contexts, e.g. certain project contexts might only occur in specific organizational contexts such as certain subdivisions) are defined in the following analysis step. A context class can describe either an organizational context, e.g. a subsidiary or product group, or a project context, e.g. "low-risk variant development" or "high-risk new product development". Each class is described by characteristics, enabling the classification of future projects (budget, scope, requirements stability, etc.). Based on the analysis, requirements are then formulated, documenting the need for action to be taken in the subsequent synthesis steps.

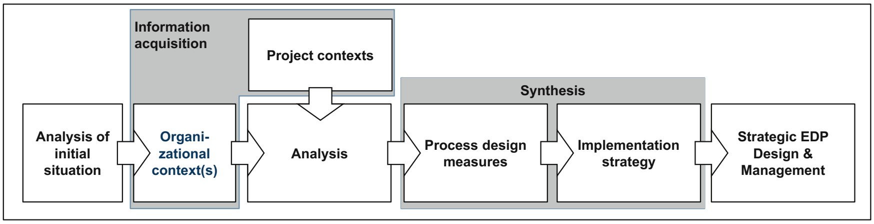

Fig. 3 Methodology for adaption

In these synthesis steps, measures for process design and concretization are defined, e.g. based on risk or success factors for the defined process contexts.

Based on the process design measures and the identified contexts, appropriate implementation strategies are formulated according to the range of the design measure, targeting for example either the reference process, a specific process variant (e.g. for a subsidiary or specific class of projects), or being formulated as a tailoring guideline for specific project instances.

Lastly, the identification of context factors supports continued monitoring and forecasting and thus enables a strategic perspective on EDP design, thus supporting not only current EDP design, but also planning ahead for necessary changes due to changing needs and trends in the future.

5 Discussion

The presented reference model is based on state of the art reference models and still quite generic, since it only addresses phases, not prescribing documents or methods to be used. However, it is only intended to provide a starting point for organizations to map and design their own EDP. As such, its scope of application is primarily intended for SMEs that are just starting to define and formalize their own processes. Companies with existing process definitions could use the reference model in order to map their own EDP onto it and define further need for formalization and e.g. further model support. The reference model is targeted at mechatronic system development and currently does not cover disciplines such as service development. The reference model has since its inception been discussed with the involved industry partners in the form of a guided expert workshop. Initial responses were promising, addressing the increase in transparency a more systematic representation would create.

The presented methodology for process adaption is currently a work in progress. While the general methodology has been defined, the individual steps of the methodology need to be further detailed. For example, the possible and available methodical support for each step is currently investigated. In order to make the approach useable, the development of tools such as forms and software support is intended. In the aforementioned workshop, the methodology for adaption was also discussed. The fact that a company's current and future context (e.g. technological trends such as digitalization) has a noticeable influence on the design activities, and consequently the formalized process, gained universal acceptance with the experts involved. The need to systematically identify such context factors was affirmed, although with the limitation that the cost/benefit ration needs to be taken into account. The methodology thus addresses the need for a structured approach to model adaption, as e.g. stated by [11].

6 Summary and Outlook

In this article, we presented a reference model for mechatronic system design in SMEs and a methodology for further concretization of this reference model in organizational and project contexts. The model has been synthesized from scientific literature regarding design methodologies as well as industrial processes developed and applied by five different companies with a mechatronic background.

Further workshops with the involved companies on management and engineering level are planned in order to enhance the reference model proposed in this paper. A number of academic and industrial case studies are underway and planned in order to further evaluate individual aspects of the proposed methodology and derive need for further improvement. Hence further work will focus on the methodology for process adaption.

Another aspect to be addressed is the methodical identification for lack of model support and the subsequent integration of new model support in EDPs. An approach will be developed based on the identification of already applied models as well as generally known models within the individual disciplines (e.g. functional modeling or SysML). The gained knowledge regarding use and familiarity of product models will serve as decision support regarding which models are appropriate to integrate in the EDP next.

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Design Process Tailoring: A Review and Perspective on the Literature

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Abstract The definition and formalization of engineering design processes has been identified as a best practice in empirical studies, and process reference models in literature are plentiful. However, since no two engineering design projects or even organizations are the same, flexible processes and their adaption and tailoring are a necessity. This results in corresponding activities to be carried out by process and project managers. Hence the question arises what approaches do exist in order to support individuals in carrying out these tasks? In this chapter, a literature review has been carried out in order to identify existing approaches, which have consequently been categorized. Since the investigated approaches stem mainly from the domain of software development, we propose the need and opportunity to transfer these approaches to interdisciplinary product development.

Keywords Engineering design process · Process tailoring · Process management

1 Introduction and Motivation

While formalized engineering design processes (EDP) are still used by best-in-class companies, especially in early development phases, a need for flexible adaptation to different contexts can be observed [1]. This in turn requires activities such as the adaption and tailoring of EDPs and corresponding method and tool support. The focus of this chapter is an examination of the activity of tailoring the EDP to

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different project contexts. Since this is a repetitive activity to be carried out by project leaders for each project, a literature review has been conducted in order to identify existing forms of support.

The contribution of this chapter is a structured overview over the state of the art of approaches for supporting process tailoring in product development. The review is intended to summarize and categorize existing approaches in literature, focusing not just on established EDP research, but also software engineering and business process design. The intention is to identify gaps in existing tailoring support and to prepare the existing literature for the identification of approaches that are applicable in interdisciplinary product development (mechatronic or product-service system development).

This chapter is structured as follows: First, the necessary background concerning engineering design processes as well as tailoring is presented. In Sect. 3, the general research methodology applied in this work is described, followed by an overview of identified approaches in Sect. 4. The identified approaches are discussed in Sect. 5 and a concluding outlook is given in Sect. 6.

2 Background and Fundamentals

2.1 Engineering Design Process

EDPs are generally regarded as being knowledge-intensive and different from regular business processes: They are dynamic, creative and often chaotic with iterations and jumps, lacking overall predictability. Their description is not always precise and their constituents such as designs, concepts and ideas do not always manifest. Capabilities for dynamic reaction are needed due to a high possibility of disruptions [2].

Within the scope of this chapter, four categories of processes (or models thereof) are distinguished (represented as layers in Fig. 1) General design methodologies, such as the V-Model or VDI 2221 [3] reside on a high level of abstraction and need to be adapted to a specific company's needs and conditions [4]. The next level represents company-specific standard processes, defining how engineering design should be done within a specific company [5]. These are embedded within a company's process architecture [6]. Even more concrete than standard processes are tailored (cf. Sect. 1) processes of specific projects, "with an actual and real task to address" [2]. Hence, a project instantiates a standard process by defining its starting conditions, such as schedule, budget, resources and initial requirements. The most concrete level is the actual process of a project, which needs to be monitored and compared to the project plans continuously, taking corrective actions as necessary.

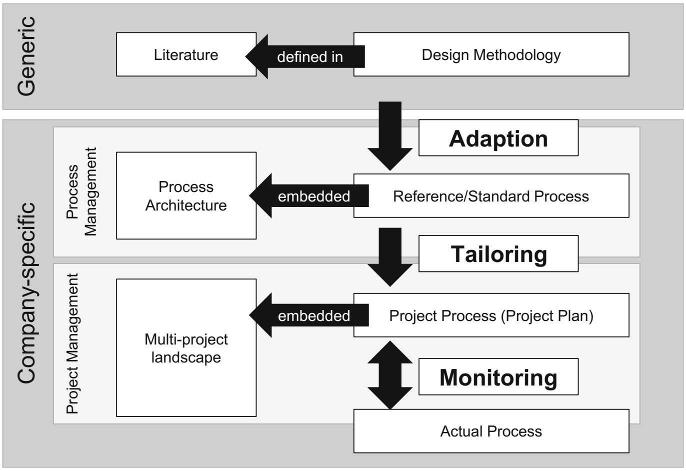

Fig. 1 Levels of engineering design processes

2.2 Process Tailoring

Tailoring is formally defined as "the act of adjusting the definition and/or particularizing the terms of a general description to an alternate environment" [7]. Specifically for EDP, this is interpreted as the adaption of a company's standard set of processes to specific project contexts, which are defined by certain context variables, such as team size, development objective, technologies, disciplines involved, etc. [8, 9]. Another interpretation of the term addresses the adaption of reference models of the design processes found in scientific literature and documents such as standards and norms to a company's boundary conditions.

While within the conducted literature review approaches concerning both interpretations have been found, the focus of this chapter lies on the adaption of standard processes to project-specific boundary conditions.

3 Research Methodology

The intention of this chapter is to present an overview over approaches supporting process tailoring. The research methodology is based on a structured literature review which was guided by the following research questions: (1) Which approaches to support process tailoring do currently exist in scientific literature? (2) According to which categories can these approaches be classified?

In order to identify the relevant approaches, the methodology contains the following steps: First, a preliminary exploratory literature research has been performed using Google Scholar. Based on this initial literature review, search strings have been compiled and relevance criteria set in order to conduct the systematic review. The search strings have been compiled using a combination of the following basic terms: “Engineering”, “Design”, “Process”, “Project”, “Tailoring”. After gaining an initial overview, the search within the individual databases has been further focused based on the selection of appropriate research fields and publications. Thus, only literature related to the development of processes in the field of engineering design, software development and business management has been regarded as relevant in the further course of this work. Literature available in German or English has been considered in the search and the search was limited to references not older than the year 1999.

Databases and search engines used to conduct the literature review were: IEEE Xplore, Web of Science, SCOPUS, and the German National Library (GNL, specifically for doctoral and professorial dissertations). Since the number of publications found in the catalog of the GNL was low (4), the search parameters have been extended to general process management, adding 64 hits and identifying further relevant approaches. Duplicate entries have been omitted at the time of consolidating the search results from each of the databases and hence are not included in the table. Based on the initial results, the references of relevant publications were analyzed in order to conduct a backwards-search to gather further relevant approaches as well as background information. References have been chosen for further consideration in case they propose a substantial theoretical approach. Application in practice was not a primary driver for the selection of relevant references at this stage. Implementation of a software prototype has been initially taken into account, although omitted within the scope of this paper. Finally after further consideration of the approaches identified in literature 63 publications were analyzed for the approach contained within them. The identified references have been coded according to the type of approach covered in each paper. In another iteration, the developed codes were then clustered bottom-up in order to arrive at the categories presented in Table 1.

Table 1 Overview over identified tailoring approaches

Category	Description	Approach	Reference
	High-level requirements addressing tailoring support in general	General tailoring requirements	[11]
Reference model	Reference model with integrated but limited tailoring capabilities	V-Model XT reference model	[12]
General approaches	Integrated approaches, focusing on the entire EDP	Framework/methodology	[7, 13–18]
		CASPER	[19, 20]
		Meta-model	[21–24]
		Process lines	[25, 26]

(continued)

Table 1 (continued)

Category	Description	Approach	Reference
		Unified lifecycle template	[27]
		Optimization-based approach	[28]
		Megamodel	[29]
		MDE-based approach	[30–32]
Process modelling approaches	Process modeling languages with integrated tailoring support	BPMNt	[33]
		Business process design environment	[34]
Analysis approaches	Approaches that support data acquisition necessary for downstream tailoring activities	Project scoping	[35–37]
		Project context modelling	[8, 9, 30, 38–40]
		Challenge assessment questionnaire	[13]
Process fragments	Focusing on a cross-cutting subset of the EDP	Process slicing	[41]
		Process modules	[42]
		Process patterns	[43–45]
		Process configuration	[46]
Specific process elements	Focusing on a limited subset or single element of the EDP (Activities, Methods, Tools, Roles, etc.)	Situational method engineering	[47–49]
		Activity based tailoring	[50]
		Tool chain tailoring	[51]
		Feature-based tailoring	[23]
		Role mapping	[52]
Knowledge-based support	Systems for storing and reusing tailoring knowledge	Knowledge base/knowledge support	[16, 53]
		Fuzzy expert system	[54]
		Case-based reasoning	[41, 55]
		Rule-based process planning	[56]
Supporting approaches	Other approaches, that aim at supporting tailoring but cannot be sorted into any of the other clusters	Fuzzy logic based evaluation and selection of tailoring operations	[14]
		Neural networks	[57]
		Variability modelling and management	[22, 58–60]
		Rationale modelling	[61–63]

[1]Due to space constraints, Table 1 represents an abridged view. For a ist with added descriptions, please see http://bit.ly/tailoringPaper or contact the authors

4 Results

The conducted literature review revealed a spectrum of existing approaches, listed and clustered into categories in Table 1.

5 Discussion

The presented classification can be a first step for choosing suitable methods to support tailoring activities. As can be seen, approaches support different activities over the process lifecycle, such as preparing tailoring (i.e. by acquiring data and formulating/modeling tailoring rules), performing it, or evaluating tailoring decisions. Moreover, approaches vary in regard to the scope of the process changes, focusing on the process in its entirety, on individual elements, on classes of elements or on cross-cutting process fragments.

As can be seen from the overview, relevant approaches to support process tailoring have mainly been identified in the field of software engineering. An alternative to tailoring is the use of process variants (cf. [10]). In the software domain, reference models with built-in tailoring capabilities such as the V-Model XT (cf. Table 1) are already available. What seems to be missing is a transfer of the available approaches to other engineering domains, such as interdisciplinary engineering design. This transfer seems not only feasible but highly desirable. However, one restriction is the dependency of the tailoring approaches on the existence of a formal EDP model in a given organization, a prerequisite not always given in practice. Further, the presented approaches require information concerning the available degrees of freedom and constraints for process adaption within a given organization. This information is often difficult to access in organizations (e.g. due to the involvement of a multitude of stakeholders, differing influencing factors, and complex dependencies), resulting in a lack of transparency and high uncertainty regarding tailoring decisions. Systematic approaches with which tailoring-relevant process contexts can be elicitated and modelled are few (cf. “analysis approaches” in Table 1).

Hence for transfer into interdisciplinary product development, a form of support to capture, document/model, and analyze the relevant information such as influencing factors and their effect on the EDP seems a logical starting point. Such information would inform not only project-specific tailoring activities, but also strategic decisions concerning the design of a company’s reference EDP itself. Based on influencing factors and existing information such as the planned product roadmap and documentation of previous projects, the need for future process design and required tailoring (e.g. the strategic selection of design methods for certain project types, depending on duration or complexity of the project) could be forecast and planned ahead. Since these factors are at least partly dynamic, monitoring on a regular basis is necessary. So far, we only found limited support for such a strategic perspective on the adaption of EDPs, e.g. in the form of "project scoping" (cf. Table 1).

On the one hand, available methods and approaches for process tailoring are plentiful in the field of software engineering, as shown in the literature review. On the other hand, in a qualitative interview study involving six companies with a mechatronic background, we only found evidence for a limited tailoring support in one of the companies. Within this specific company, checklists for tailoring activities prescribed within the EDP are available to project leaders and the possibilities for tailoring are very limited. Conducting tailoring operations and judging their feasibility and necessity (cf. 12), such as omitting certain process steps is up to the project leaders and their knowledge and experience, e.g. in regard to different project contexts (see also Chap. 64). There was no discernible evidence for reuse of past tailoring checklists.

6 Outlook

Using the presented literature review as a starting point, we intend to extend the literature review through further categorization of the identified tailoring approaches. This work is intended to contribute to the definition of a methodology (currently a work in progress) with the objective to support a more strategic perspective on process definition and adaption. This requires increased transparency and traceability in regard to decisions concerning the adaption of reference processes and the formulation of tailoring guidelines. From the identified approaches, a flexibility framework will be derived, consolidating the different forms of process flexibility and variability discussed in literature, in order to foster understanding of the degrees of freedom for EDP adaptation. Further work addresses the modeling of projects contexts and mapping influencing factors onto process models. These integrated process-context models would then serve as a basis for further process design activities, such as deriving response mechanisms to influencing factors, forecasting the change of individual influencing factors and thus the changing effect on the EDP.

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UX in 'Practice' for Starters—A Guided and Simplified Approach to Live Projects in the Industry

Shaon Sengupta

Abstract This paper outlines, in a very comprehensive way, a guidance based articulation to help fresh designers transition into a professional user experience (UX) designer, in a project driven organization. It aims to bridge the gap by providing three-fold directions honed after substantial trials and abstraction: (a) Projects—To understand the bigger picture of a project lifecycle and see how the design process aligns across the overall project timeline. (b) Design Process—Every designer follows a process, but how can that be streamlined into a coherent way of working. This direction provides an easy guided compilation of steps by translating the process into tangible action points (c) Quality—How can we measure and quantify design output? What ensures quality? This direction provides a set of metrics across process, communication and product by asking meaningful questions in order to evaluate design outcome.

Keywords UX design · UX design process · UX metrics · UX projects · UX in industry

1 Introduction

There is a growing demand for user-experience designers in India. Design schools help to support this surge by rearing students to be as industry ready as possible. Other graduates also find their calling in this field, as the money is lucrative and the career prospects, promising. However, the demand-supply equilibrium is quite a distant dream because here the demand is not always about '**quantity**' of candidates available, but also about '**quality**' contribution they make. Also, 'quality' is not always about design brilliance, but also about being 'realistic' and 'meaningful' in terms of the goal and vision of the company.

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[“We have, from a teaching and research experience, found that HCI/ID/UX are hard to teach, in as much as it seems that theoretical reflection and abstract models of human-computer interaction, are alien even to advanced students. They struggle, after having been exposed to it, to translate such knowledge to practical task and project solution strategies”] mentions Steinar Kristoffersen in his paper ‘Consequences for UX Didactics’. On the contrary, there is a plethora of rich design resource, in the form of books, articles, tools and methods that constitutes a solid reference for design practitioners, but there is a lack of guided coaching for starters —guidance that are not just about hands-on approaches to designing products, but also about how does the design process blend into a living, breathing project. **How outcomes of phases of design, fit into a project milestone, how can they become consumable inputs for other teams and most importantly, at the same time, how can a designer drive quality**. Companies don’t detail that out either, and provide just a list of responsibilities as ‘key performance areas’, which is primarily result oriented. It has been observed that it takes about half a year for a fresh designer to contribute to the best of ability.

Hence, from a design organization perspective, it becomes essential to hire, train and retain talent in a way where time to delivering quality output is optimal. It becomes imperative to (a) build a team that drives design quality as best as possible while working with constraints (b) use tools, guidelines and methodologies to their benefit, while bringing in value to a project (c) speak the same language as a team, while still focusing on their own style and individuality. It is a challenge to balance the seemingly opposite traits.

2 Background

Working in the industry for about 10 years, in 4 multinational companies, that have dedicated design teams globally, I have also helped in the hiring process of interaction designers. It is never easy to judge a candidate purely by the resume and portfolio they submit during the hiring process. The design exercises that we use to estimate candidature have also been quite deceptive as it is often difficult to simulate the constraints, challenges, project dynamics w.r.t the capability of the candidate to overcome them. Every time a new candidate has joined, we had to spend considerable time in on-boarding the candidate into the organization. The dialogue was repeated for each candidate however, the information was not always retained by the candidates.

Triggered by this need in the organization, it was imperative to develop something that **captures both the explicit and tacit knowledge that goes about on-boarding new candidates and test if this was useful for the candidates.**

Further to that, it was also noticed that even trained and experienced candidates did not particularly follow or use a robust design process and many crucial steps in the process were either skipped or not given the deserved importance. This not only affected the quality of design output but also put the designers in an awkward situation when they were questioned about the ‘rationale’ of a particular design decision. Often, a design decision did not have a strong foundation and hence diluted the proposal in question. Particularly in the context of designing user experiences, it becomes very important to translate and interpret user needs and requirements and reflect solutions around them, along in the offering.

Also while designing interfaces and experiences, it gets tricky to measure how good or bad a solution is. Unlike designing a fine product or a high end automobile, which immediately catches our fancy; it is indeed difficult to draw the same parallel for software or digital offerings. Everyone has an opinion about the color used, fonts considered or how it should look and behave and perhaps one can never end this discussion. So how do we term a software product to be of ‘good quality’? In ‘Bringing clarity to the concept of UX design,” results from the Dagstuhl Seminar on Demarcating User Experience, states that:

> [UX practitioners also need explicit areas of responsibility and to develop effective working relationships with the complementary functions and competences, thereby getting UX work accepted as a valued part of the overall design and development effort of an organization. In the longer term the emphasis should be on positioning UX in order to secure strategic influence over: • the business directions in terms of new value propositions to be developed, • the choice of designs to be developed and their contribution to the business objectives of an organization, • the development of the processes used to guide the way the organization operates.]

UX as a discipline is thoroughly interactive, both with your clients, your users and team members. Hence, as a designer, it is important to root the solution to the context of use, translate a team’s vision and to analyze the possible pointers that help us to deliver meaningful output We will in this paper go through the identified gaps and possible easy-to-understand solutions to address this.

3 Methodology

At the onset, it was also important to understand how design was managed and deployed in other companies. In the report by Design Council ‘Eleven lessons: managing design in eleven global brands” conducted a study that

> [“looked at the way design is used in these firms, how designers work with staff from other disciplines and how the design process is managed to deliver consistently successful results. How is design managed across complex, global, product and brand portfolios, we wanted to know. So we asked leading design teams how they select and organize their designers, and when they bring designers into the product or service development process. We also wanted to find out what skills today’s designers need in order to succeed.”]

The study outlined several ways in which the design process is similar, but also different e.g. “Design teams in companies like Virgin Atlantic Airways and BSkyB conduct user research at a stage where a prototype is well developed, rather than involving users at the concept development stage”, it states. It also highlights insights like “At Xerox, the aim is to present one concept that has been thoroughly reviewed and tested". With this variety of ways in which design process can be flexed, it is also interesting to see the commonalities and how it can be used by beginners who have only practiced design in theory.

In "A Project Guide to UX Design" by Unger and Chandler, talks about this generic approach to designing for projects and states,

> ["Sometimes there seem to be as many project approaches as there are projects. How to choose the right approach for a project is a large topic in itself. The methodology you choose can depend on many things, including the structure and location of the project team, the technologies being used on the project, and the degree to which collaboration is a part of the company's culture."]

This paper is not about a project approach, but a design approach to projects of several variety. This paper does not claim to be the only way or the best way to do things, but is a guideline to enable a standard of practice or an equipoise for those who need it.

It uses the backdrop of the **knowledge from the comparison** made above, coupled with the **design process as followed in companies** I have worked on and **the knowledge of the process as available as literature** and maps it to the dynamics of a live project environment, as witnessed by fresh designers. It also reflects on the experience of learning and delivering as a part of coursework, for current students.

To arrive at this understanding, a brief study was conducted on 16 interaction (UX) designers hired since 2013 and 22 new design students of the Masters course in a reputed design college based in Mumbai, who were evaluated during a coursework. The findings and directions in the paper have been consolidated after researching common questions, general difficulties faced and rate of adoption of the guided approach provided in this paper. It is solely focused on interaction/UX design process (Fig. 1).

4 The Guided Approach: UX and the Industry Context

It was noticed that fresh designers often tend to look at projects as 'design projects' secured in their own imaginary word. This section will outline the practicalities of a project environment and how a designer essentially needs to play their part amidst

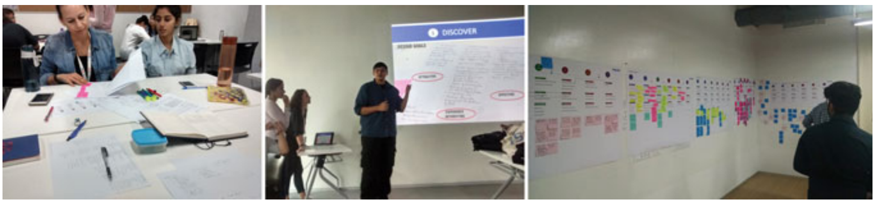

Fig. 1 Designers and students referring to the guide-sheet and presenting their work and learnings

the constraints and resources. It will take us through essential information a designer needs to have in order to see the bigger picture.

[A UX designer is responsible for maximizing the return on investment; this includes managing resources (time, material, technology and skills) and identifying the right level of fidelity and scope for each phase.], says Maggie Hendrie et al. in Prototyping adaptive automotive UX.

4.1 Knowing Your Project, Team and Your Role—The Project Ecosystem

Only if the designer is aware of dynamics, company vision, budget, roadmaps etc., can he/she maneuver the way into finding the right balance between creativity and reality. This section will elaborate on the different aspects of a project.

4.1.1 Key Stakeholders

It is important to first understand where the designer fits in the team and who else would she partner with. Everyone has a role to play and has a goal to fulfill. Every facet of a product launch is important and only by working as a team, can they present a commendable product in the market. The following diagram lists the key stakeholders in an organization who are directly responsible for a product (Fig. 2).

4.1.2 Stakeholders Network and Relationships

Besides the stakeholders, it is important to see the network and relationships in order to understand the level of influence and question the basics of what truly matters (Fig. 3).

4.1.3 User and Customers

Companies usually sell to customers and hence customer experience is key to them. However, as designers, it is important to know who will finally use our product.

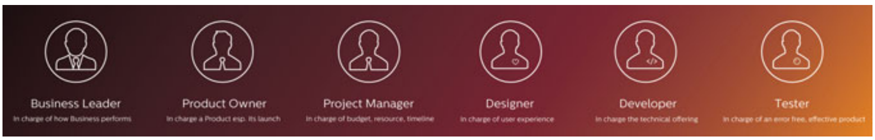

Fig. 2 Key stakeholders in a typical project

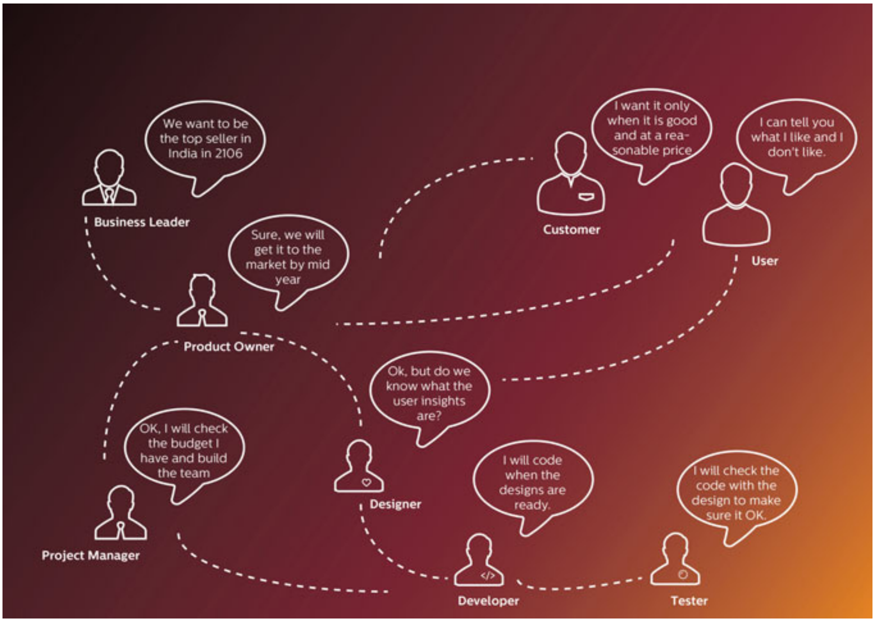

Fig. 3 Network and communication channel of stakeholders

Hence, it is useful to understand the difference between the two. In some cases, users can also be customers, and can have dual expectations from the product (Fig. 4).

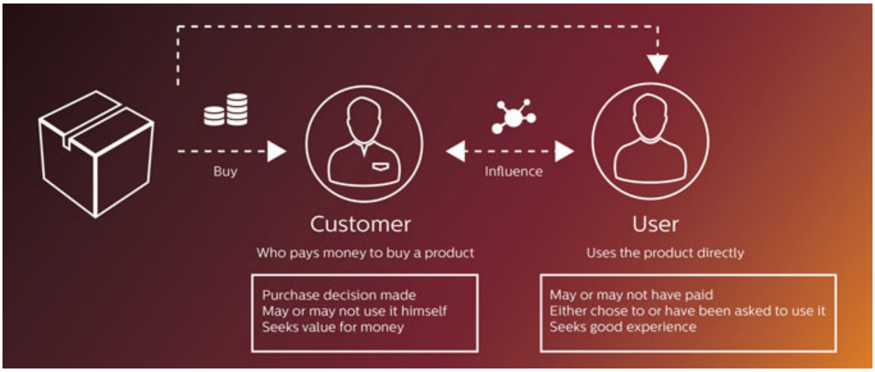

Fig. 4 Users, customers and their relationship

4.1.4 Project Plan

[When you start a new project, you probably have project objectives from the project's sponsor (the business stakeholder who has direct responsibility for the success of the project), as well as a set of project-related requests coming from business stakeholders and from customers], states Russ Unger in 'A project Guide to UX design.

Similarly, every project will have a plan and key contributors. The product is owned by a product manager who is responsible for its execution. It is important to understand the project lifecycle and the stakeholders that contribute to it. Broadly the phases are categorized as—Preparation, Realization and Lifecycle Management (Fig. 5).

The phases of UX design process have been broadly categorized as Discover, Define, Design, Develop, Deploy and Drive. However, **it is important know which phases of design process aligns with which phases of the project plan**, as they need to work together, as design deliverables will be used as inputs by other team. However, the designers must keep the iterative approach to design while doing so (Fig. 6).

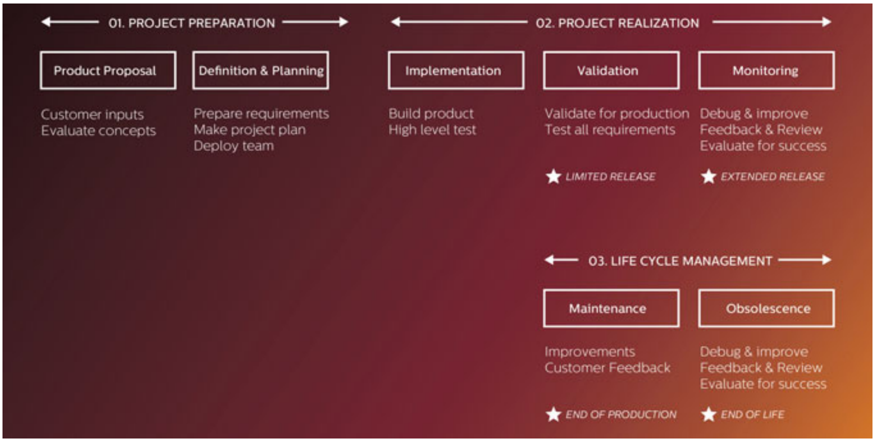

Fig. 5 A typical project process and its milestones

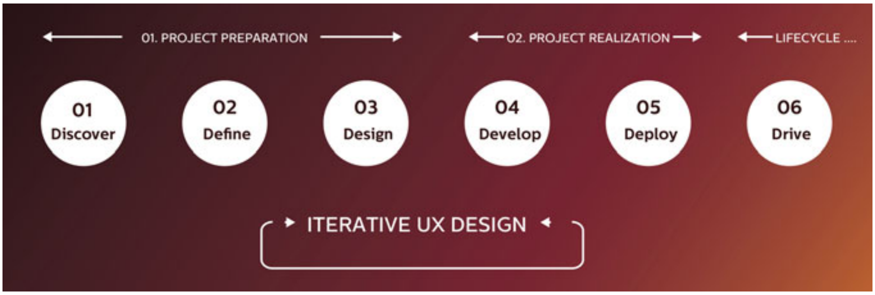

Fig. 6 Project plan and design process mapped

It's vital to remember we are working together with other teams, across the same project timeline. Every designs decision has an implication and it's important to be responsible for what we introduce. Dominik Pacholczyk in "UX Process and Documentation states,

> [Do your ideas line up with the direction of the company? Have you considered "second-best" options which might achieve 90% of the impact but with less time and money? Working in a team helps understand these questions. This process of elimination can help you from being blindsided later due to over-ambition or poor judgment early on, especially as you start gauging how the market and customers might react to your product idea.]

4.1.5 Role of UX Designers

Though design as a field has come a long way, it is still a challenge to establish the true role of design and make others comprehend the exactness of the job we do. Many times, the bigger team in the organization has very different opinions about designers. Some examples of what they might think vis-s-vis what designers really are. It is important to understand this difference so we can engage in a meaningful dialogue (Table 1).

4.1.6 Types of Projects

Unlike our design school exercises, not every project in the industry requires the same approach. As designers, one should flex the process in order to achieve maximum results and leverage what exists already. Designers should not use each project as a tool to change the world, but instead create the maximum difference in UX for the end users (Fig. 7).

Table 1 Design engagement—role of interaction designers

Perceived (by others)	Reality (your defense)
"They make the product look good"	"Yes. But we also make users feel good"
"They make products brand compliant"	"We synthesize brand experience"
"They can be used to execute my idea"	"We translate user insights"
"Involving them guarantees a cool factor"	"Yes. And also saves you money"
"Having them guarantees a great UX"	"Only if we involve users at each stage"
"They make it user-friendly"	"Not just that, we create users' delight!"

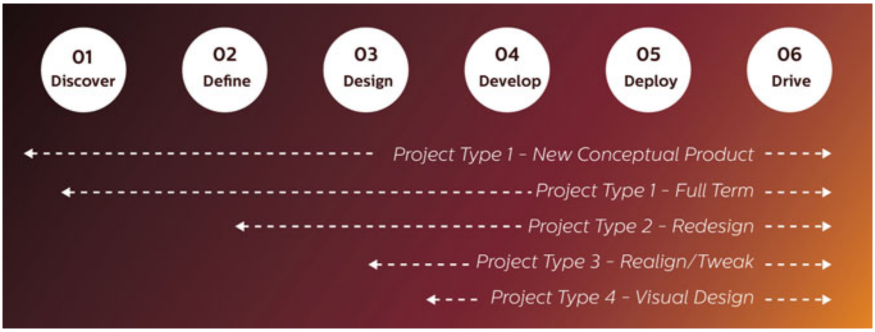

Fig. 7 Different types of industry projects

5 Step-by-Step Direction: UX Design Delivery

The design process is not an abstract, magical phenomenon. It is not a cryptic and complicated phenomenon but rather a methodological approach to design. It is the amalgamation of data, activities, attitude and deliverables. This section prepares the designer to ask basic questions to understand the details of each phase. Fresh designers often take information for granted and are in a hurry to get started without understand the context of why, how and what. Simon Sinek's Golden circle is a valuable direction for UX design. We are often lost in 'what' are we designing by talking about features, functions and capabilities rather than creating meaningful solutions. He says ["Do you know your Why? The purpose, cause, or belief that inspires you to do what you do."]

5.1 Process Kit and Checklists—UX Design Attitude

After careful observation and analyses over multiple projects, the following pointers help to have the right attitude and outlook in order to be a 'professional' designer. It elaborates on the purposeful details of each phase rather than steps/content of design.

5.1.1 Discover Phase

Your role	• As in details what is expected out of you • Understand who you need to collaborate with • Understand way-of-working model of your team
Your clients	• Meet/talk to your primary contact (client) on regular basis • Meet/talk to other members you are collaborating with • Keep your primary contact in loop in every communication

(continued)

(continued)

Your project	• Ask your client for the project brief/POC • Collect all requirement document that are available • Maintain a library location for your documents • Ask to be informed when any document has an update
Timeline	• Enquire how your project will be run (e.g. Agile) • Understand the basics of a project lifecycle • Negotiate and agree on deliverables date well in advance
Background	• Know your target users. Identify or define personas together with the team • Identify top level challenges to be solved • Identify other requirements

5.1.2 Define Phase

Scope	• Influence/modify user stories through discussions • Agree on user stories to be detailed per sprint (in Agile) • Group requirements that are meaningful together as an experience and not just a functionality
Principles	• Determine the core values of the product • Translate them as principles in a short and memorable way • Share them with your project team. Inspire them • User design principles to support your proposals henceforth
Deliverables	• Use SW tools that are accepted in your organization • For presentations, use templates of your organization • Give meaningful trackable names to files (not Myfile.ppt)

5.1.3 Design Phase

Task flows	• Share workflows with the team. Have elaborate discussions • Identify corner cases along with project team • Seek as much agreement as this stage on workflows
Wireframes	• Wireframe in any tool you are comfortable with • Translate flows into wireframes. Have options • Use relevant UI components while wire-framing • Avoid using too many colors yet
Visual design	• Use design templates or toolkit. Reuse as much as you can • Make sure it is latest in terms of guidelines

5.1.4 Develop Phase

Assets	• Understand development framework and code style • Understand what defines an asset and what can be coded • Think module wise and not screen wise. See what patterns can be repeated
Specifications	• Provide in formats that are understandable by coders • Include specifications on color, layout, font and behavior • Use a template structure that is common in the team

5.1.5 Deploy Phase

Development support	• Make sure developers are interpreting your design correctly • Sit together with developer whenever possible • Keep checking progress and seeking updates
Review	• Review to check implementation vis-à-vis design proposal • Note and track issues. Never compromise on quality • Schedule review meeting where you discuss deviations
User tests	• Validate your design with users • Ask help of your clients to get in touch with your users

5.1.6 Drive Phase

Change requests	• Always ask for original text of the change request • Ask by when they need to be solved. This is probably not negotiable as the next release is waiting
Improvements	• Keep checking your products after release • Note usability of implementation flaws • Note improvements that you want to propose at this stage

5.2 Inputs, Activities and Deliverables—UX Process Breakups

UX/interaction designers can look into the design process more like phases involving sets of inputs, required activities and desired outputs. Each output is essential to stitch the story of requirements and establish how a well-designed proposal meets those needs (Fig. 8).

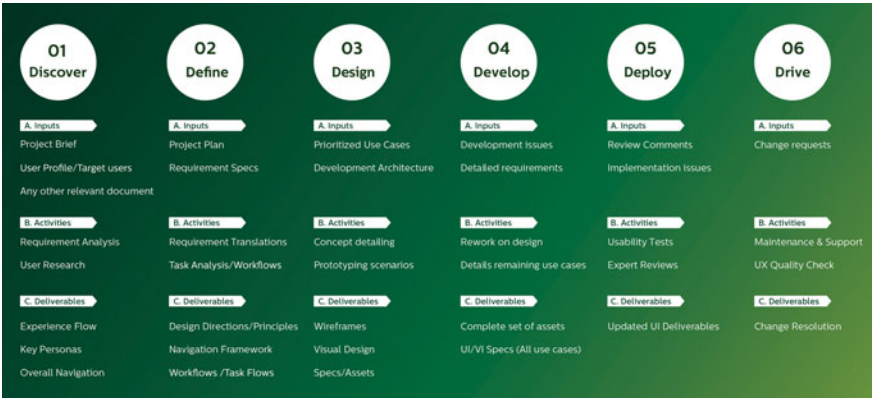

Fig. 8 Process—inputs, activities and outputs

5.3 *Goals of Key Deliverables*

Each key deliverable has a goal and are aimed to produce solid outcomes (Fig. 9).

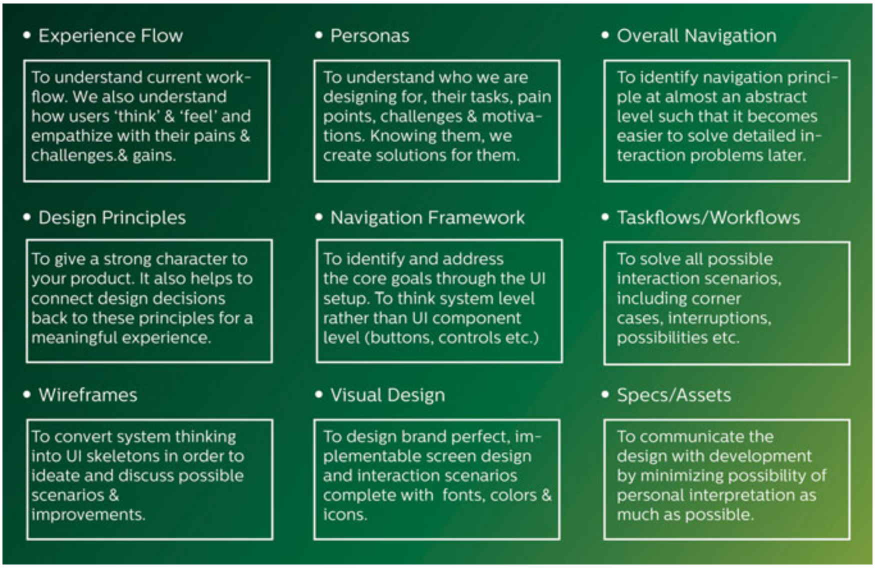

Fig. 9 Goals of key deliverables

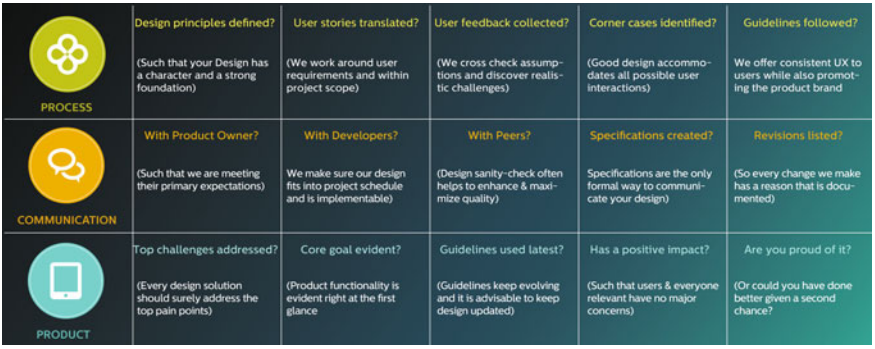

Fig. 10 UX deliverables - Quality checklist

6 Self-check Quality Indicators: Measuring Design Quality

Design quality is not just representative of how good the design looks and feels but about a lot more. It is a journey of how the designer has empathized with the user, how the designer has liaised with the stakeholders and how strong is the designer in translating latent user needs to the design journey. A product is appreciated for its quality if the designer has worked on 3 dimensions—**followed a solid design process, been effective in communication and expectation management of key stakeholders and been successful in establishing the depth of the solution.** This section briefly outlines these parameters into a general checklist that a designer can use (Fig. 10).

7 Conclusion

This paper makes an attempt to capture the tacit knowledge in industry practice and giving it meaning, structure and form. The basis of the paper is grounded in project experiences in India, specifically in the field of user experience design. It makes some generalizations in order to cater to most of the software, digital and product companies, and also for the student curriculum. The method proved both positive and useful, but the true success of such a framework would lie in its usage beyond India and in different industries like media and automobile, which have not been considered yet. The goal of this paper is to provide the basic tools and context that will help beginners start designing and contributing to their effective best. It is expected that the step by step approach will direct their attention into what matters the most and what is important to execute a project. However, there needs to be sufficient quantitative measurements to measure the efficacy of the toolkits. Perhaps it's also useful to capture result based findings like—how much guidance do they still need, which areas are difficult to comprehend or apply and lastly, does this prove useful in making one a better designer?

[Informed consent: Informed consent was obtained from all individual participants included in the study.]

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Formation of Inter-subjectivity as a Basis of Sustainable Collaborative Innovation

Akane Matsumae and Yukari Nagai

Abstract The aim of this study is to discover how inter-subjectivity is formed among various organizations in horizontal relationships as a basis of sustainable collaborative innovation. Since each organization in a horizontal relationship is independent, generating a sustainable project among multiple organizations is different from one within an established organization or one among organizations in vertical relationships. Forming inter-subjectivity among organizations is required as the founding phase of collaborative projects. The authors have empirically approached this problem and introduced the research methodology of dynamics, referring to knowledge creation theory. The results of our study demonstrate that it is essential to form inter-subjectivity among collaborators, which could be the base for dynamic innovation shared by stakeholders. Further, the outcome of this study will likely contribute to the development of the design methodology for innovation ecosystems among organizations in horizontal relationships, as well as to the substantial expansion of the scope of knowledge management theory.

Keyword Inter-subjectivity · Formation process · Boundary object · Innovation design · Horizontal local innovation ecosystem · Knowledge creation

1 Introduction

1.1 Research Background

The background for this research is the lack of a local innovation ecosystem in Japan. Although the revitalization of local society has become a significant national

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issue in Japan, local small and medium sized enterprises (SMEs) still remain dependent on vertical relationships with larger companies and excluded from innovative opportunities, channels, and human resources. The more feeble and out-dated the existing centralized innovation ecosystem becomes, the more necessary it becomes to form an alternative one designed for local SMEs, which account for more than 99% of the enterprises in Japan [1].

Due to this limitation of resources and networks in each local SME, it is essential to establish a methodology to design an innovation ecosystem to generate a sustainable collaborative project among them. Moreover, gathering various organizations in one place is not enough to form the basis of sustainable collaborative innovation. The authors have approached this problem by designing and implementing horizontal and distributed local innovation ecosystems, utilizing local national universities in several fields since 2002, based on knowledge creation theory [2, 3].

1.2 Research Subject

Since knowledge creation theory has mainly been developed empirically within established larger companies [4], it should be carefully examined with experimental evidence to expand its theoretical scope to the formation process of new business entities, the so-called 0–1 phase, where the authors focus in this study. On the other hand, there is research that aims to understand the concept generation process of designers, approached by modelling and simulation based on real-life experiments [5, 6]. In contrast with the abovementioned research, the authors of this paper try to capture the generation process of inter-subjectivity in this study as a basis of sustainable collaborations in horizontal relationships.

1.3 Paper Structure

First, the authors propose criteria to judge whether inter-subjectivity has been formed in Chapter 2 as a part of our research methodology. These criteria are led both by knowledge management theory and by observations from accumulated experimental and practical case studies. Second, the authors propose a basic structure of the innovation ecosystem designed for local SMEs and indicate case studies of its implementation in Chapter 3. Key factors of the design are not only the structure of stakeholders, but also the boundary object dynamically chosen and shared among them. Moreover, case studies support the hypothesis of our methodology. Third, in Chapter 4, the authors abstract the patterns of the dynamic knowledge creation process from the cases introduced in Chapter 3, and then discuss the relationships between the formation of inter-subjectivities and pattern of the observed dynamic process.

2 Methodology

2.1 Outline

In this study, the authors took an empirical approach, referring to fundamental knowledge creation theory [4, 7] to understand the formation process of horizontal collaboration among organizations. This research methodology is characterized by the analogy of the research methodology of dynamics, which also deals with interactive and complicated systems and is usually understood by four experimental approaches: (1) simplification of research objects into dynamic models, (2) practical experiments, (3) analysis of observed phenomena from case studies, and (4) extraction of generalizable knowledge based on theory (Fig. 1).

In this study, we referred to basic knowledge theory, especially knowledge-enabling conditions, and the SECI model [4], when designing experiments. Knowledge-enabling conditions and the SECI model have been developed in and applied to established organizations. Little practical evidence has been demonstrated of the formation of quadruple knowledge clusters among organizations, although Nonaka and Konno [8] have mentioned the theoretical possibility. In our research, we empirically explore the limitation of these theories—whether they can be applied not only to established organizations, but also to the formation phase of organizations, and whether not only within, but also among organizations.

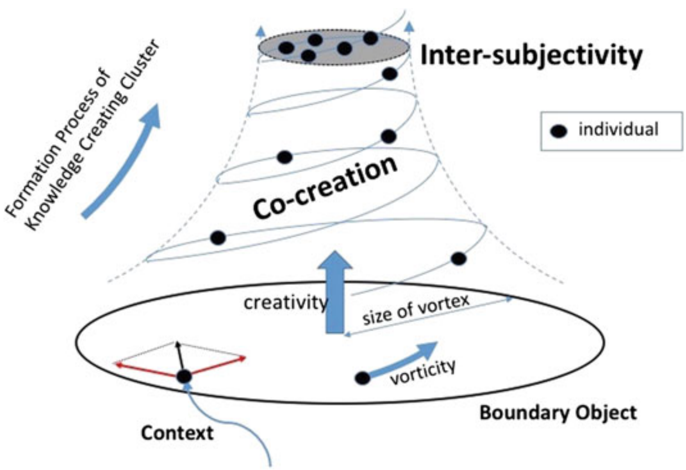

Fig. 1 Key design elements in dynamic models for formation of inter-subjectivity

2.2 Definition of Co-creation

The term co-creation is widely used as an important keyword in knowledge creation. However, it has not been clearly defined, and the difference between it and collaboration is ambiguous. In this paper, referring to the SECI spiral [4], we define co-creation as creating something together, sharing the phase of socialization among individuals. Inter-subjectivity among stakeholders is formed as the basis of co-creation by sharing socialization, which is the process of converting tacit knowledge to new tacit knowledge through shared experiences and social interaction [4]. Sharing a common goal among individuals is not required at the beginning of the co-creation process, but appears throughout the process of dynamically developed co-creation.

On the other hand, we define collaboration, distinctive from co-creation, as working together for a common goal. Sharing the phase of socialization is not required among individuals, but a common goal must be central among individuals from the beginning (Fig. 2).

2.3 Formation of Inter-subjectivity Among Individuals

In the formation phase of a new business entity in a horizontal relationship, it is essential to form inter-subjectivity among members to start co-creation, since they have originally been working in different contexts as independent entities. Individuals that are expected to commit to co-creation are required to share a phase of *socialization*, according to the definition of co-creation in this study. The authors

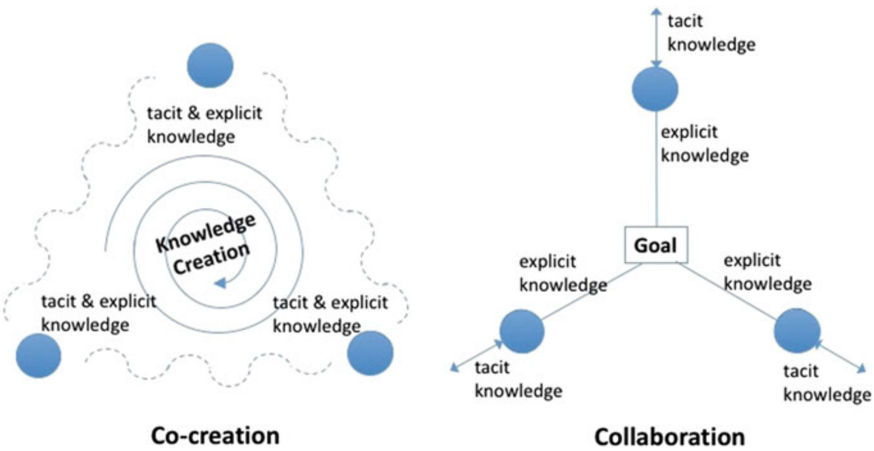

Fig. 2 The definition of co-creation and collaboration in this study

regard this as inter-subjectivity through which tacit knowledge is transferred directly among individuals.

Utilization of Customer Journey Map to Capture Formation of Inter-subjectivity. From the observation of accumulated case studies [2, 3, 9, 10], the authors concluded that sharing a common goal is not required in co-creative relationships, but the formation of inter-subjectivity is essential. Moreover, knowledge obtained from comparison between the formation of inter-subjectivity and team outcomes, or one between the formation of inter-subjectivity and its formation process, will contribute to developing the design methodology for forming new co-creative organizations. One of the major problems at this point was how to capture whether inter-subjectivity was formed among individuals. As such, the authors propose the utilization of a *customer journey map* to solve this problem.

Essential Factors of Customer Journey Map. The customer journey map is a comparatively new framework to support user experience design, and is mainly used by practitioners in the service-design-thinking domain. There are various descriptions from the practitioner's point of view—what a customer journey map is, how it is used, or how effective it is in application. Yet, it is difficult to find an established definition of a customer journey map.

However, the authors found a minimum consensus that the essential role of a customer journey map is to visualize the user's dynamic subjective experience. Therefore, the authors adopted the simplest customer journey map in this study, which consists of an individual's emotional fluctuation along a timeline (Fig. 3).

To capture the formation of inter-subjectivity, the qualitative coincidence of fluctuations, in other words, emotional wave patterns, should be analysed by comparing the customer journey maps of all participating individuals. In contrast, it is not important to meet quantitative coincidence, since each individual has a different degree of intensity in his/her expression (Fig. 3).

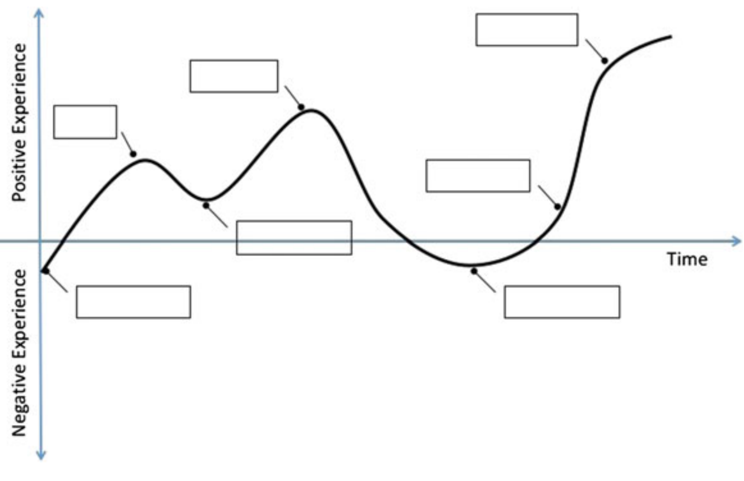

Fig. 3 Essential elements of customer journey map

Preliminary Experiment Among Individuals. The authors performed the following preliminary experiments before deciding to utilize customer journey maps in this study. The authors believed the customer journey maps would delineate each participant's dynamic internal status. As such, each newly formed team of six or seven members was assigned a design-thinking project. The projects were carried out by each team following the standard five steps [11], as well as an additional step: empathize, define, ideate, prototype, test, and redesign. This was done with minimum guidance from the instructor. As part of the sixth step—redesign—each team was required to return to the previous steps as needed.

After completing the six steps, each participant was asked to draw a customer journey map reflecting his/her own experience during the design-thinking project. To better understand each emotional fluctuation, the participants were asked to add what had caused the fluctuation in their customer journey map. The authors observed the process of this preliminary experiment and compared the customer journey maps submitted by each team with the authors' observations of each team's performance.

The results of this preliminary experiment confirmed that a customer journey map is useful for judging the formation of inter-subjectivity among individuals: the qualitative coincidence of fluctuations in customer journey maps can be seen as the inter-subjectivity is formed among participating individuals in observations.

2.4 Boundary Object

A boundary object is an object that is adaptable to multiple viewpoints and robust enough to maintain identity across them [12]. By setting an appropriate boundary object in the project, different contexts of each individual can be bundled and sharpened. Focusing its function to involve different contexts in this particular co-creation, the authors introduce two concepts to characterize a boundary object from the analogy of Rankine's combined vortex: (1) the size of a boundary object to describe its reach and (2) vorticity of the boundary object to describe how it works in each individual.

2.5 Context

Creation exists in various contexts. Some contexts can be described in same dimension, but others can be described in different dimensions. Each individual or organization also has its own original context as a creator. A context can be modified through interaction with other contexts, and contexts can generate a new context. Authors introduce the concept of context force vector to describe the direction and the magnitude of each creators' context. A sum of context force vector components to the specific direction and vorticity of a boundary object is one of the parameters to determine a dynamic process of co-creation.

3 Application to Innovation Ecosystem Design

3.1 Design Methodology for Innovation Ecosystem

As innovation ecosystems are designed, one of the essential factors to be considered is the *relationship* between each entity, whether co-creative or collaborative (Fig. 4).

In terms of the way in which to assemble the abovementioned design factors, there are two logical approaches to deal with the relationship factor: (1) that the types of relationships between each entity are determined following a business model design and (2) that business models are designed based on the possible relationships between specific entities. In practice, these two approaches are used dynamically, based on the results of implementation.

From an ontological point of view, innovation ecosystems include different levels such as individual, group, organization, and inter-organization. However, in the context of knowledge creation, essential design elements are still based on individuals and the relationships among them, since co-creation requires sharing tacit knowledge among individuals. Therefore, the basic model and design methodology, as described in Chapter 2, is applicable to designing innovation ecosystems.

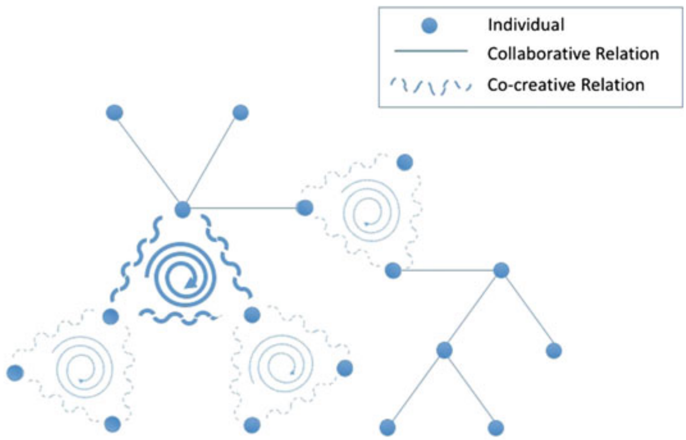

Fig. 4 Design elements of innovation ecosystem focusing on the type of relations

3.2 Practical Experiments

In practical experiments, the authors designed and implemented horizontal and distributed local innovation ecosystems utilizing local national universities in several fields. In this context, the role of universities in university-industry collaborative projects was fundamentally changed, from an involved party to facilitative platform among organizations.

Structural Engineering Experiments with SMEs. A nationwide, autonomous knowledge-creating cluster was formed among diverse parties, centring on a series of structural experiments to prove the engineering rationale and effectiveness of traditional Japanese architectural structure, as its boundary object. It was almost 2-years project and four hundred and twenty organizations joined its incorporation. The details on why and how this co-creative cluster was formed and developed are described in [2].

Design-Thinking Programs with SMEs. The authors have been accumulating case studies that apply design-thinking methodology to co-create innovation among various individuals from profit/non-profit organizations. More than fifty teams which mainly consist of individuals from SMEs have challenged designing and implementing innovation. Outline of these programs are introduced in [3, 9, 10].

Proposition of Innovation Ecosystem Model for SMEs. Utilizing the knowledge obtained from these case studies, the authors propose the basic local innovation eco-system model, which is designed focusing on the formation of inter-subjectivity: secondary effect of design-thinking methodology derived from its human-centred and highly co-creative process (Fig. 5). Utilizing this basic innovation ecosystem model, the authors expect to find: (1) the sharing design thinking methodology as a common language among participants, (2) designing of actual innovation in teams, (3) forming of inter-subjectivity in teams to implement design innovation, and (4) bridging between teams and various types of innovation collaborators.

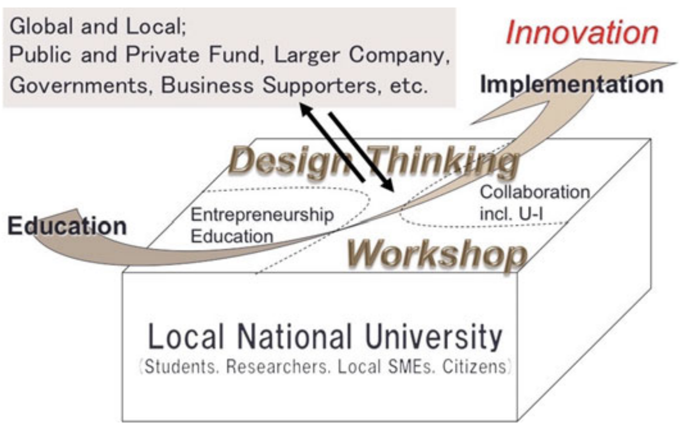

Fig. 5 The basic framework of local innovation ecosystem in this study

3.3 Results and Discussion

Based on observations, the authors categorized team projects of dynamic knowledge creation into three patterns: (1) *co-creative*, in which every individual joins co-creation; (2) *collaborative*, in which few individuals co-create and others collaborate with them; and (3) *non-creative*, in which individuals collaborate, but co-creation is not/seldom observed.

In the co-creative pattern, contemporaneous internal fluctuation was observed among individuals after the earliest stage of the project, and the project track was comparatively more dynamic and flexible. In the collaborative pattern, a clearly separated pattern of internal fluctuation was seen between co-creators and collaborators, and the track of the project was comparatively stable and linear. Lastly, in the non-creative pattern, both the internal fluctuation and track of the project remained low. Further, projects were continued autonomously in the co-creative and in collaborative patterns, even after the compulsory period; in contrast, projects ceased in the non-creative pattern at the end of the compulsory period.

In this study, knowledge on the relationships between the formation of inter-subjectivity and pattern of dynamic knowledge creation process was obtained as follows: (1) inter-subjectivity is formed in the process of co-creation, (2) inter-subjectivity encourages a dynamic and flexible co-creative project among individuals, and (3) inter-subjectivity contributes to the sustainability of collaborative projects as the base of co-creation.

4 Conclusion

In this paper, the authors:

(1) visualized the role of inter-subjectivity in the context of the forming phase of new knowledge-creation entities in horizontal relationships;
(2) placed inter-subjectivity as one of the key design elements in the dynamic model of the formation process of a knowledge-creating cluster;
(3) proposed the utilization of customer journey maps to evaluate the formation of inter-subjectivity among individuals, and empirically confirmed the appropriateness of this approach;
(4) expanded the dynamic model of the formation process of a knowledge-creation cluster among individuals into one among entities in different ontological levels, to apply it to the formation process of innovation ecosystems;
(5) proposed a basic model of a local innovation ecosystem, focusing on the secondary effect of the design-thinking methodology, derived from its human-centred and highly co-creative process; and
(6) elucidated the empirically obtained knowledge on relationships between the formation of inter-subjectivity and pattern of the dynamic knowledge co-creation process.

The formation of inter-subjectivity among different ontological entities in horizontal relationships and its effect on knowledge co-creation are the key elements for designing and managing horizontal innovation ecosystems for SMEs and startups. Thus, the knowledge obtained from this study will serve the revitalization of SMEs and formation of startups.

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Engineering Change Management Within Agile Product Development—A Case Study

Lucia Becerril, Veronika Heinrich, Annette Böhmer, Sebastian Schweigert and Udo Lindemann

Abstract Currently, numerous approaches on how to cope with engineering changes exist in form of complex Engineering Change Management (ECM) systems. However, startups and small companies have difficulties implementing these systems due to the lack of flexibility and agility—in addition to financial aspects. A trend mostly used within Software Development to cope with fast changing environments is agile development. However, while transferring agile frameworks into the development of mechatronic systems new challenges on managing Engineering Changes arise. The approach proposed in this paper aims to manage Engineering Changes within an agile framework providing decision support for three different situations in which changes can occur.

Keywords Engineering change management · Engineering change · Agile · Scrum

1 Introduction and Motivation

An Engineering Change (EC) is an alteration made to parts, drawings or software and it comprises any modification to the form, fit and/or function of the product as a whole or in part [1]. Currently, there are numerous approaches on how to cope with these engineering changes in form of complex processes. In many large companies, these processes are embedded into Engineering Change Management (ECM) systems. However, startups, such as the one studied in this case, are inhibited to implement these large and expensive systems due to the little flexibility and the large infrastructure these systems entail—in addition to financial aspects. Furthermore, most of the work in engineering change management focuses on mature firms although designing in a start-up context can pose different requirements than the ones fulfilled by current approaches [2].

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Thus, in the case of startups agile project frameworks have been successfully in order to cope with an ever changing environment. One of this frameworks, namely Scrum, is the focus of this paper. Although Scrum is mostly used within Software Development, it is applied as well for developing mechatronic products.

In Scrum, the development process is divided into time boxes called “sprints”. At the beginning of each sprint, the development team deduces concrete tasks for the sprint duration that together lead to a product increment (e.g. a new function) [3].

One of the core principles of Scrum is that no ECs are made within a sprint, but incorporated into the Product Backlog, which contains the requirements to be fulfilled in the consequent sprints [4]. In the case of customer triggered changes, the process is relatively straight forward since change requests are mostly received after finishing the sprint, during the sprint review. However, when ECs arise during an ongoing sprint (for example due to non-satisfactory partial results), few practical support exists. Thus, the development team often has to cope with the engineering changes with only intuition and common sense, especially if the team members lack experience, as is the case of a large number of start-ups.

Within this paper, an engineering change management workflow that can be easily integrated in the agile framework Scrum is presented. Hereby, the Scrum methodology is integrated into mechatronic product development. The situation of a change request occurring during a sprint is investigated and solved by adhering the proposed workflow to the Scrum framework.

2 Methodology

The approach presented in this paper was formulated based on the experiences of Scrum practitioners, Scrum process’ regularities, and Engineering Change Management methods. A literature survey revealed a research gap in the area of Engineering Change Management within agile frameworks, especially for mechatronic product development. Thus, blogs and practitioners’ articles were explored and the results were discussed with project teams at a startup.

Furthermore, the early stage of a development process within this company was observed. The Scrum Team comprised of four persons, including Scrum Master, Product Owner, and developers. Selected engineering change requests that were generated during ongoing sprints were then further investigated.

3 State of the Art

In this section the core concepts of Engineering Change Management and Agile Development of mechatronic systems with Scrum are presented. Moreover, the research gap is further clarified.

3.1 Engineering Change Management

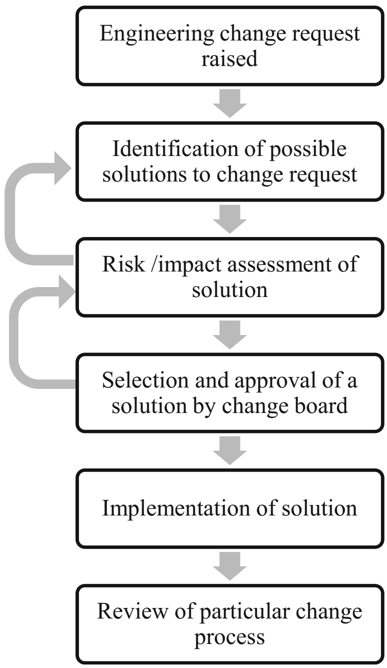
Engineering Changes are one of the main cost drivers in product development, Fricke et al. [5] estimate that roughly 30% of work efforts are due to changes. The later the engineering changes occur the more expensive it is to realize them since the risk of change propagation increases with the development progress [1]. In order to cope with these Engineering Changes, a number of processes and methods have been developed. For example, Jarratt et al. [6] suggest a six step process for managing ECs, which is illustrated in Fig. 1.

Furthermore, Wickel et al. [7] compared seven industry-specific Engineering Change Management processes and identified six common steps: Identification, Preparation, Decision, Operation, and Review. Although the companies studied were mostly OEMs and larger suppliers, these general steps are transferable in different scopes to the management of changes in a startup and provide a frame for the process presented below.

3.2 Agile Project Management

Agile project management was derived from agile software development. Its purpose is to help a project team "adapt quickly to the unpredictable and rapidly changing requirements" [8]. Several approaches for developing products with agile

Fig. 1 Generic ECM process, adapted from Jarratt et al. [1]



methods exist today, for example Scrum. However, they share some basic concepts that distinguish them from traditional project management approaches [8]. The "Manifesto for Agile Software Development" [9] states four core principles:

- Individuals and interactions over processes and tools.
- Working software over comprehensive documentation.
- Customer collaboration over contract negotiation.
- Responding to change over following a plan.

Moreover, agile project management emphasizes two important concepts [8]: The first one is focusing on short iterations of clearly defined deliverables and thus minimizing risk, especially in fast-changing environments. The second is emphasizing direct communication over project documentation.

One popular agile framework is Scrum. It comprises roles (Product Owner, Scrum Master, and Development Team) and artifacts (Product Backlog, Sprint Backlog, and Product Increment). The Product Owner decides what work will be done, while the Scrum Master ensures the best use of Scrum. Moreover, the Development Team develops the product incrementally, in a series of short periods of time named Sprints. A sprint is a fixed timed period, usually between one and four weeks, in which the team develops and delivers a Product Increment. [3]

Furthermore, the product backlog is a list of ideas for the product while the Sprint Backlog comprised the detailed plan for the next Sprint. The Product Increment is a "recognizable, visibly improved, operating subset of the product" and the required result of a sprint [3].

4 Workflow for Managing Engineering Changes Within an Agile Framework

This section gives an overview of the workflow proposed for managing Engineering Changes within an agile framework. Assuming a manageable number of changes, this workflow does not substitute the decision making by the project responsible persons but provides a set of questions and rules to guide them through this decision making process. It contains three decision points that cover most cases of changes that can occur within a sprint. These are:

- The engineering change is implemented in a future sprint (as foreseen in the Scrum methodology).
- The engineering change is implemented within the current sprint.
- The cause of the engineering change compromises the Product Increment so that the current sprint is cancelled.

The flowchart in Fig. 2 illustrates the proposed approach. In the first step of the proposed workflow, an Engineering Change Request (ECR) is created. Once the

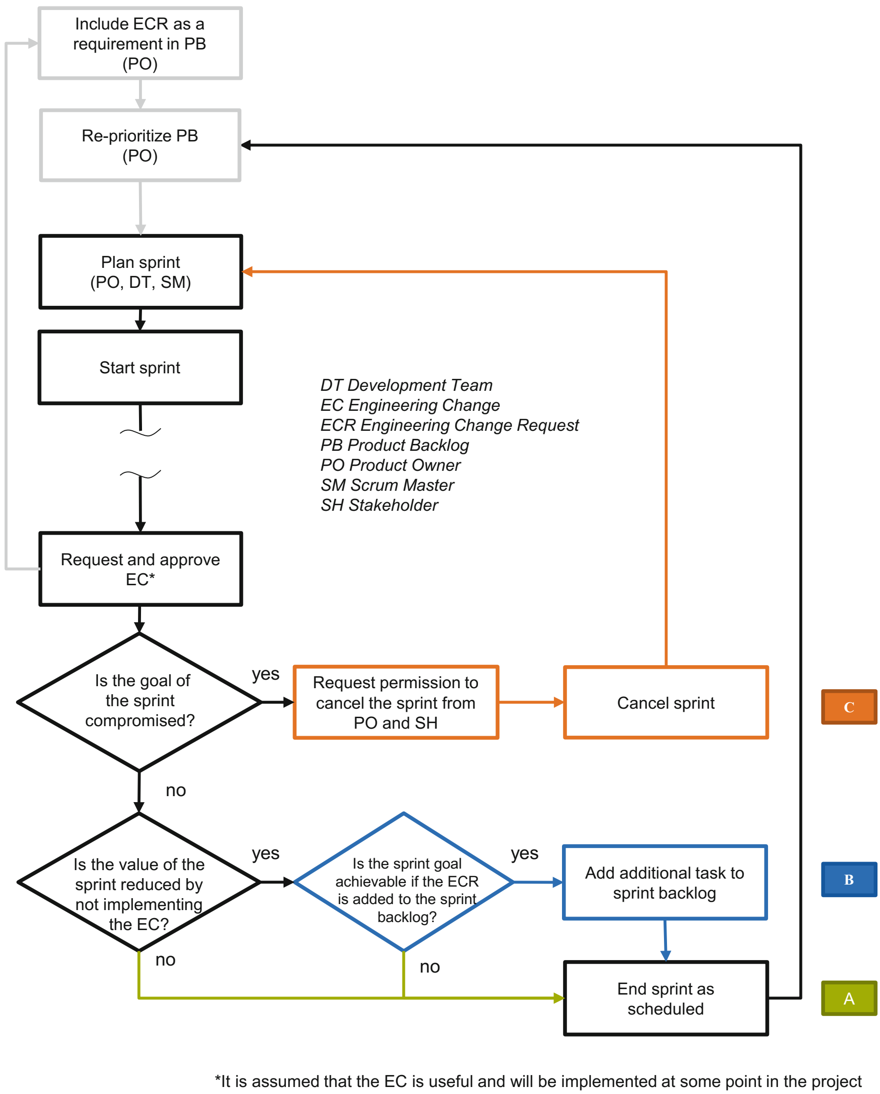


Fig. 2 Managing engineering changes within *Scrum*. *A* Engineering change is implemented in future sprint (Standard procedure). *B* Engineering change is implemented within current sprint. *C* Engineering change requires immediate reaction. Current sprint is cancelled

ECR is evaluated and approved, it is transformed into one or more requirements of the product backlog, which is then prioritized as indicated in [4].

Although the steps of "Identification", "Preparation" and "Review" of the engineering change mentioned above are as important (c.f. [7]), these are outside of the scope of this paper. It is assumed that the change requested is useful and should be implemented. A number of existing support approaches for this decision can be found in the literature (c.f. [1]).

Moreover, besides adding the ECR to the product backlog, this workflow proposes to evaluate the implication of the request for the ongoing sprint. If the EC is a mayor change that causes the sprint goal (i.e. the Product Increment) to be invalid, the current sprint should be terminated in agreement with the product owner and the stakeholder—and a new sprint must be planned (Path C).

If the planned sprint goal is valid despite the change causes, but the value of the results would be (significantly or somewhat) reduced by not implementing this change, then, the ECR could be added to the ongoing sprint backlog. However, it should be assessed if the sprint goal is still achievable within the planned timeframe after adding these additional tasks (Path B). If not, the requirements derived from the ECR are executed in a future sprint, which is the regular procedure in Scrum (Path A).

If the value of the sprint results is not (or slightly) affected by the EC, the sprint will also continue as specified in the sprint planning and the standard procedure for managing changes will be followed (Path A).

5 Case Study

The startup in which this case study was conducted, founded in 2012, is currently implementing agile product development. This company focuses on the realization of innovative engineering ideas from different external customers and the development of a fundamental prototype that can be carried over to the production stage by the customer. Several development projects in small teams of two to five developers are running at the same time. Each development team is individually composed of graduate students and young professionals from the fields of computer science, mechanical, and electrical engineering.

The startup's customers vary from large experienced industrial partners to private citizens having no technical background but an innovative idea. Moreover, the company emphasizes the close collaboration between development team and customer. Thus, it ensures that most change requests made by the customer are implemented.

One of the pilot projects for implementing agile frameworks was the development a food processing system. Within this project, the development team faced both the challenges arising from the integration of agile project management and the product-related technical problems of early development phases. Furthermore, the analyzed project was funded by a governmental organization with few technical background. Hence, the development project had abundant iterations while working under time pressure. Engineering changes were required frequently. Due to these conditions, this and similar projects had triggered the need for a framework on how to deal with engineering change requests.

Nevertheless, comprehensive ECM Systems are very expensive and their implementation is time consuming [1]. Furthermore, due to the lack of flexibility of these systems and their scope, these established ECM processes and tools were not suitable for the startup presented in this case study. Thus, an alternative solution which can be easily embedded into the agile framework was required for these situations. Moreover a mayor requirement was to remain loyal core principles of the agile framework—for example, usually not making alterations during a sprint.

As stated in Sect. 3, when the necessity of an Engineering Change arises during an ongoing sprint, the standard process within Scrum is adding the ECR to the product backlog. Subsequently, the product backlog has to be reprioritized and the highest prioritized items of the backlog are carried out throughout the following sprint [10]. In this case, the sprint can be completed as scheduled without extending the sprint backlog. However, this procedure only works if the results of the current sprint are not significantly affected by the cause of the ECR.

In this case study, the project examined presented two situations in which the value of the sprint goals would be significantly reduced or could not be reached following the standard approach. These two situations required immediate action of the development team and the stakeholders.

The first EC derived from a complex situation at the early stages of the project. The rough concept of the food processing machine was required by the external stakeholders at the beginning of the project. Due to time pressure the concept could not be evaluated thoroughly beforehand. Several weeks after the project had started, the developers conducted a series of experiments, with the outcome that the properties of the selected material are inadequate for the proposed concept. After further experiments with different materials, the initial concept had to be discarded.

Since the necessary change involved redesigning the whole concept, to continue the current sprint was useless since the sprint goals were matched to the original design. Thus, it was necessary to request a cancellation of the ongoing sprint (Fig. 3). Once the permission was given by product owner and the stakeholders, the sprint was cancelled and the product backlog could be modified to the new proposed concept.

During the later stages of the project, a second EC was triggered by an incomplete CAD-Model. This error caused an incorrect drawing, which was then sent to an external workshop for manufacturing a part. The error was discovered when the prototype showed a malfunction that was traced to this part.

Although this was a minor change, its implications could not be neglected. If this ECR was not attended immediately the Product Increment (e.g. the prototype) will not meet its requirements at the end of the sprint (hence it value would be reduced). The effort estimation indicated that the part can be modified rapidly without delaying the sprint. Thus, the sprint backlog was extended by the corresponding task “complete CAD-Model” to ensure a satisfactory product increment by the end of the sprint (Fig. 4).

In summary, although both engineering changes appeared during an ongoing sprint, they had very different scope and implications for the project. Thus, it was

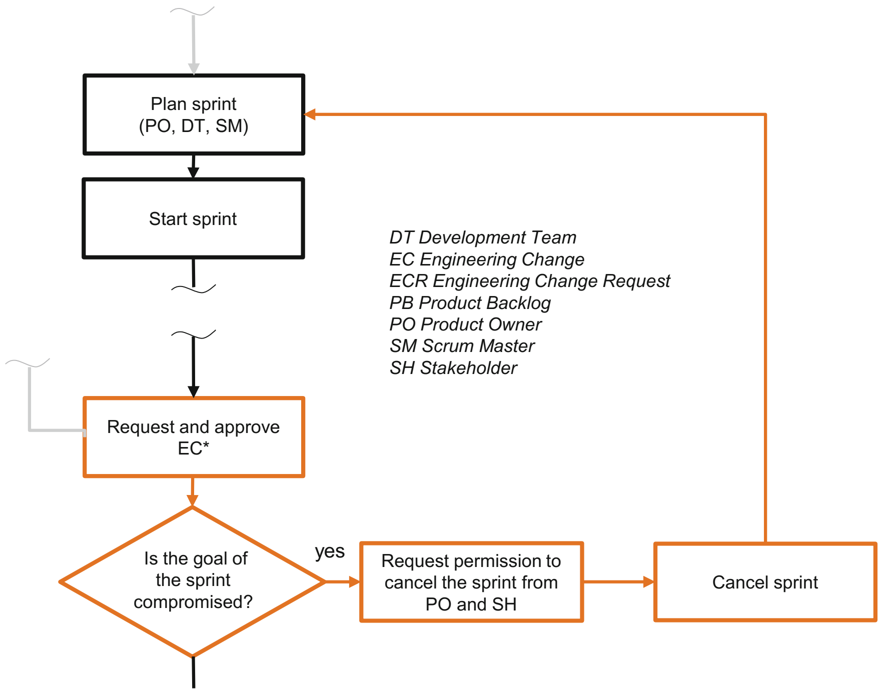


Fig. 3 The sprint is cancelled after approval of PO and SH

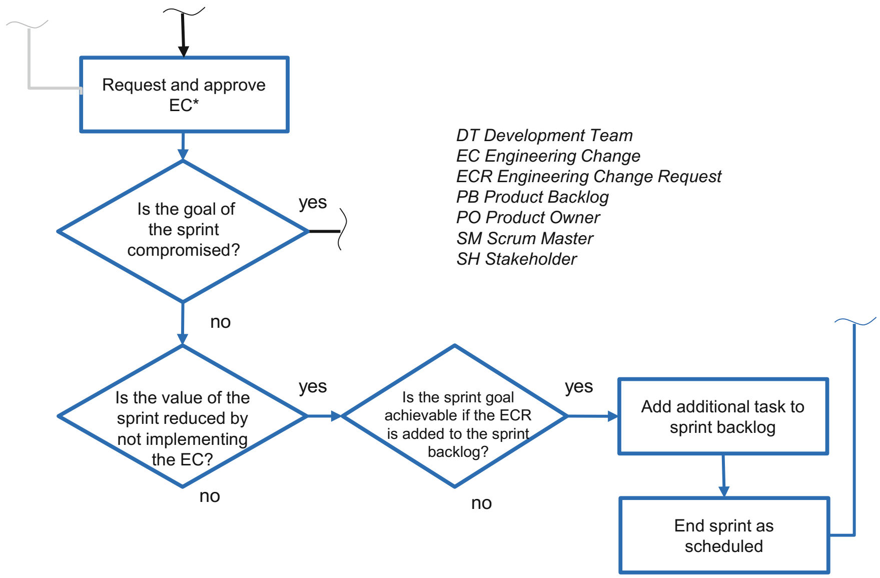


Fig. 4 The EC is added to the product backlog to be implemented in a future sprint

not possible to handle them similarly. Acknowledging these issues and guiding the team through the decision points of the proposed workflow was proven to be helpful for this case study.

6 Conclusion and Outlook

The Workflow for Managing Engineering Changes within an Agile Framework presented in this paper provides decision support for evaluating the change request's implications on the ongoing sprint—as illustrated in the case study. Moreover, in contrast to the standard Scrum procedure for managing changes, the proposed approach regards the impact of the EC and the sprint situation at the time of an ECR. One of the main advantages is the simplicity and intuitive understanding of the workflow proposed, compared it to existing ECM approaches. This enables the project team to easily integrate it into an agile framework, thus maintaining the desired flexibility.

Nevertheless, it is suggested to proactively manage changes by scheduling short sprint durations at the beginning of the development process and deriving highly specific tasks from the product backlog [4]. Consequently, significant errors will be detected earlier and the change effort remains low.

Future research will examine, whether this approach is a sufficient documentation of engineering changes, when adding and removing requirements to and from the product backlog. This is especially relevant for companies, such as automotive suppliers, that are required to compile with norms for documenting their engineering changes (e.g. VDA 4965 [11]). Moreover, the workflow should be further evaluated in a broader selection of startups and projects that use agile project management methodologies.

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A Time Based Approach to Reduce Product Development Time in New Product Development in Machinery Industry

R. Logesh, A. Gomathinayagam, S. Rammohan and G.S. Narayana

Abstract In this current scenario of highly competitive market, the product development time plays a key role in determination of existence and excellence of an organization in a business. Organizations involved in new product development try to reduce product development time by employing different methods such as concurrent engineering, value stream mapping, efficient-scheduling, accelerated testing, etc.… Despite various techniques available, the reduction of bottlenecks in product development remains a challenge in many organizations. In Machinery Industry, the product consists of combination of make and buys. In most cases, the major source of lead time is from bought out components where the scope of control is limited. Proper scheduling and modifications in design processes and review methodologies to adapt these kinds of situations can accelerate the product development process significantly. This paper elucidates various challenges in product development, factors affecting lead time and a time based approach for design that reduces product development lead time at design stage itself. The approach uses concurrent engineering that enables and guides through the process to create an optimized design by itself in such situations involving make and buy components. This method has been implemented in development of a product which has helped to reduce the design time by more than 40%.

Keywords Product development · Lead time · Concurrent engineering · Machinery · Design time

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1 Introduction

Every organization strives to reduce their product development lead time. Time to market is a major parameter for success and excellence in new product development. One of the major contributors for product development lead time is design lead time. The benefits of NPD cycle time reduction include not only increased profitability but also the advantages associated with pioneering [1]. Concurrent engineering is one of the effective ways to reduce product development lead time. Scalable and complex systems must be highly parallelizable if short development times are required; otherwise valuable development time and resources are wasted [2]. Hence Effective scheduling and increasing the number of parallel activities are major contributors for reducing the new product development lead time.

Despite the optimistic claims of its proponents, there are a number of problems with the concept of Concurrent Engineering. While there is a general agreement on what Concurrent Engineering seeks to achieve, there is considerable disagreement on how the approach should be implemented [3]. Yadati Narahari et al. discussed product lead time reduction through Process Control, Input Control, Load Balancing, Cross-Functional Work and Effective Scheduling [4]. The current work is an approach to implement Concurrent Engineering for designs involving bought-out components using a case study of design and development of two variants of All Electric Injection Moulding Machines (AEIMM). AEIMM is a machine involving large number of original Equipment components, along with in-house designed components. As many as 4000 number of components are present in the machine. It is an integration of OE components made to suit the application, standard bought-outs and in-house developed components. While developing the second variant, leanings from design and development of first variant of AEIMM were taken and major challenges during the process were listed and a process was developed to address these issues. Prior to the work the earlier models followed the design process as depicted by Ulrich and Eppinger [5].

2 Major Challenges in Design of Machinery

In most machinery industry, the majority of components sources from outside suppliers are high value components with large lead times. These high value components affect the design process to a great extent as the size, shape and technology vary from supplier to supplier. These factors results designers to face some of major challenges in product development that affect Product development lead time in machinery industry involving bought-out components. Similar Challenges were faced during development of first variant of AEIMM. These challenges are discussed below.

2.1 Lead Time of Bought-Out Components

In machinery industry, the Lead time of brought out components is a major factor affecting the new product development time. The effective management of the lead time, Initiating supplier interaction at a right time plays a vital role in product development. In early phases, the information available might be less and delay in initiating the discussion may increase the product development lead time.

2.2 Interdependent Activities

The interdependent activities especially when it involves components from two different suppliers attract more iteration of activities increasing product development time.

2.3 Iterations

The information and knowledge on the product would continuously improve throughout the product development. This may affect our initial assumptions and may result to repeat the whole processes enabling more iteration for same processes.

2.4 Uncertainty over Constraints

In initial stages of design, there is little knowledge on the product and effect of some major decisions on development time. Understanding the need of the customer and setting right constraints for design is one of the major challenges in design. The design constraints can be derived from the customer need, time and cost targets.

2.5 Control over Costs, Dimensions and Weight of the Machine

Establishing a mechanism to control costs and dimensions of the machine is major challenge. As the design evolves, due to complications involved in the systems, it becomes difficult to control costs and geometrical dimensions of the product.

3 The Process

Ulrich and Eppinger identified five major phases: concept development, system-level design, detailed design, testing-refinement and production ramp up [5]. The proposed method shall be applied in phases of concept development, system level design and detailed design for brought out long lead items. Procurement is identified as a one of the significant processes in case of presence of bought-out components. The conventional process of product development is depicted in Fig. 1.

The proposed process is about parallelizing the procurement of long lead bought out components with detailed design process that can reduce the development time significantly. The required process modification is depicted in Fig. 2.

Figure 3 defines how the procurement of long lead items can be parallelized by incorporating a process at design stage where the selection of long lead bought out items are given priority.

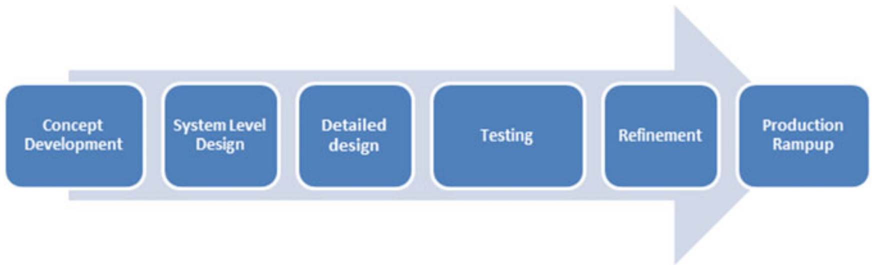

Fig. 1 Conventional product development process

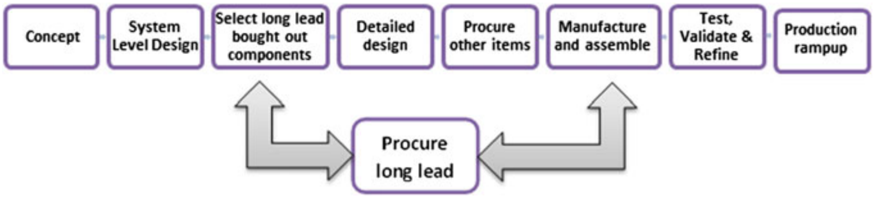

Fig. 2 Proposed product development process

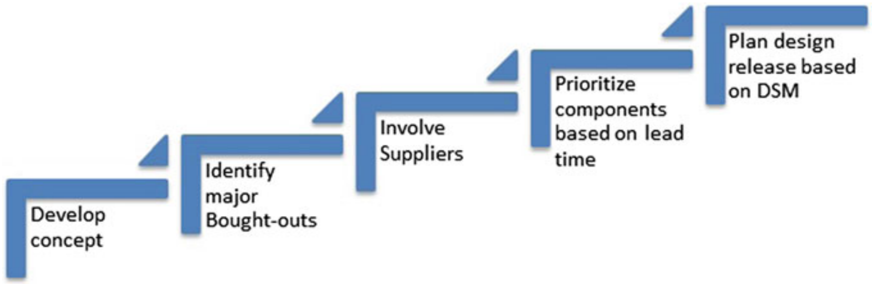

Fig. 3 Proposed design plan for bought-out components

3.1 Concept Development

As all conventional product development process, after obtaining customer needs in the form of specifications, design process starts from concept development. Concepts are developed, evaluated and finalized in this stage.

3.2 Identify Major Bought-Out Components

Concept development enables us to identify major bought out components. Identification stage involves identification of suppliers and specifications associated with the aggregates. The components used in various systems are grouped based on component type.

3.3 Involve Suppliers at Early Stage

Benefits include reduced project length and, of course, an improved product [6]. The number of innovations can also be improved when suppliers collaborate with manufacturers. Involving suppliers at early stage enables us to identify the major long lead items. Few of long lead items in one of machinery developed and their lead time are listed in Table 1.

Table 1 Major bought out components and their procurement lead time

S. no	Part description	Lead time in weeks
1	Servo motor	20
2	Servo drive	20
3	Choke and DBR	4
4	Controller and HMI	12
5	Geared induction motor	16
6	VFD	4
7	Ball-screws	16
8	Cyl. thrust roller bearing	12
9	Track roller bearing	8
10	Ball-screw support bearings	24
11	Deep groove ball bearings	4
12	Angular contact bearings	4
13	Belts and pulleys	12
14	Locking elements	18
15	LM guides	20
16	Disc springs	8
17	Load cells	12

3.4 Prioritize Based on Lead Time

Early drawing release of long lead items enables better parallelizing of activities; hence prioritizing the component drawing release based on lead time helps in parallelizing the activities.

3.5 Apply Design Structure Matrix (DSM)

A DSM is a compact, matrix representation of a project network. The matrix contains a list of all constituent activities and the corresponding information exchange patterns. Once the DSM is partitioned, tasks in series are identified and executed sequentially. Parallel tasks are also exposed and can be executed concurrently [7]. A component wise DSM is made. The DSM is used to restructure the priorities.

The presence of marking on upper triangle of DSM shows the need to reprioritize the components (Fig. 4). The components are reprioritized such a way that all the marking are in lower triangle; this ensures the dependent components are addressed after finalizing the independent (Fig. 5). DSM not only provide a clustering and reordering method but also show any information hidden in the design activities such as dynamic information flow and the direction of information flow [8]. We can observe few interdependent components which are to be placed nearby. It is also easy to identify number of parallel activities that can be done. It is evident that most of the activities can be done in parallel after finalizing the servo motors. Only three components are interdependent i.e., ball-screw support bearings, ball-screws and belt and pulley. The design and release of components are prioritized based on the restructured DSM that improves the effectiveness and the early release of long lead items can be exploited to plan procurement activities in advance thus making the process parallel to design activities reducing product development lead time.

3.6 Design Process

The design process as described requires releasing of bought out components well in advance. This drives the need for reducing the dependency of design finalization of other parts. In order to reduce the dependency, the Specifications of the machine drive the selection of bought out items. Further dimensions of the components can be derived from the need or specifications. A typical example for arriving at dimension of a bought out component i.e. ball-screw is depicted in Table 2. As the dimensions of the components are finalized this drives the design of the other

S. No	PART DESCRIPTION	Lead time in Weeks	Ball-screw support bearings	Servo motor	Servo drive	LM guides	Locking elements	Geared induction motor	Ball-screws	Controller & HMI	Cyl. thrust roller bearing	Belts and pulleys	Load cells injection	Track roller bearing	Disc springs	Choke & DBR	VFD	Deep groove ball bearings	Angular contact bearings
1	Ball-screw support bearings	24		x					x										
2	Servo motor	20																	
3	Servo drive	20		x															
4	LM guides	20							x										
5	Locking elements	18							x			x							
6	Geared induction motor	16																	
7	Ball-screws	16	x	x				x				x							
8	Controller & HMI	12		x	x														
9	Cyl. thrust roller bearing	12		x															
10	Belts and pulleys	12		x					x										
11	Load cells	12		x															
12	Track roller bearing-stud type	8							x										
13	Disc springs	8						x	x										
14	Choke & DBR	4		x	x														
15	VFD	4						x											
16	Deep groove ball bearings	4		x					x										
17	Angular contact ball bearings	4		x															

Fig. 4 DSM of long lead components

manufactures items and forms as constraints for the design of other components associated and drives to make an optimum design. This reduces the iterations in design as few components are finalized and hence design to be driven to accommodate these components. Since bought out components' dimensions are based on

S. No	PART DESCRIPTION	Lead time in Weeks	Servo motor	Servo drive	Geared induction motor	Ball-screw support bearings	Ball-screws	Belts and pulleys	LM guides	Locking elements	Controller & HMI	Cyl. thrust roller bearing	Load cells injection	Track roller bearing	Disc springs	Choke & DBR	VFD	Deep groove ball bearings	Angular contact bearings
1	Servo motor	20																	
2	Servo drive	20	x																
3	Geared induction motor	16																	
4	Ball-screw support bearings	24	x				x												
5	Ball-screws	16	x		x	x		x											
6	Belts and pulleys	12	x				x												
7	LM guides	20					x												
8	Locking elements	18					x	x											
9	Controller & HMI	12	x	x															
10	Cyl. thrust roller bearing	12	x																
11	Load cells	12	x																
12	Track roller bearing	8					x												
13	Disc springs	8			x		x												
14	Choke & DBR	4	x	x															
15	VFD	4			x														
16	Deep groove ball bearings	4	x				x												
17	Angular contact ball bearings	4	x																

Fig. 5 Restructured DSM for long lead bought out components

need and dimensions are to the level that are just enough to satisfy the needs, optimum design in terms of dimensions and in turn results in optimum weight and cost also.

4 Benefits of Implementation

Finalizing the bought out components at initial phases based on machine specifications and less dependency over layout of machine

- Enables to put in right constraints in early stages of design to achieve optimum dimensions and cost as major aggregates are designed for optimum dimensions and other components were made to accommodate these high value components.
- Reduces iterations as the major high value components are finalized at early stage and other items are designed to accommodate the major brought outs.

Table 2 Determination of dimensions of ball-screw

Description of dimension on ball-screw	Dimension break up	Dimension value	Dimension on ball-screw	Input source
Threaded length	Front clearance (threaded)	20	527	1 × pitch of ball-screw
	Stroke length	208		From specification
	Ball nut length	279		Supplier input (based on load)
	Rear clearance (threaded)	20		1 × pitch
	Rear clearance (non threaded)	20	20	1 × pitch
	Aperment dimension	25	25	1.25 × pitch
Bearing seating area	Bearing width	27	258	From bearing selection
	No of bearings	6		From bearing selection
	Spacer width	18		From load
	Threaded lock nut area length	68		Locknut calculation
Pulley seating area	Pulley width	68	90	Pulley design
	Locking flange projection length	21		Pulley design
	Overall length	920		

- Helps to eliminate iterations caused by interdependent activities as they are done simultaneously.
- Parallelize procurement of long lead items with design of other components.
- Enables better utilization of resources. As in conventional method, the human resources involved in purchase of items are involved in early stage of product development and resources involved in design also is engaged throughout the product development cycle as there is no waiting period for long lead items to be available for assembly.
- Hence reducing product development lead time and control costs.

5 Conclusions

Companies face unique sets of individual development risks and integration abilities that should be the basis for Product Development Process design [9]. This paper proposes a product development process where the product involves major bought out components whose lead time invariably affects Product development time. This method helped to reduce product development time by parallelizing procurement activities of bought out components with detail design of other components. In the case study presented, the parallelizing the procurement lead time of major bought outs could save 24 weeks as the maximum lead time of a component is 24 weeks which otherwise would have been initiated after detailed design that would have added the procurement lead time to total development time. This “24 weeks” is 40% of total product development time which is significantly a large proportion of the time.

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Consumer Preferences and Value Proposition Disconnect—Assam Rattan and Bamboo Furniture Industry

Prarthana Majumdar, Shiva Ji and Sharmistha Banerjee

Abstract Rattan and bamboo are important forest resources for the North Eastern Region (NER) of India. Naturally growing in abundance, they find use in a number of industries such as housing, construction, handicrafts, furniture and food industry. Of late, this industry has seen considerable growth outside the NER. But it has not been able to realize its full potential in NER due to significant lack in market orientation of the craftsmen who work from remote areas in NER and try to sell in urban markets. This paper looks into the urban markets, which holds the highest scope for revenue growth for this industry and investigates the gap in the customer preferences and current industry value proposition. The main gaps found are: lack of awareness, limited training focused only on techniques, lack of design awareness and sensitivity (ergonomics, attention to detail, finishing, presentation), lack of branding and marketing knowledge and limited outreach of self help groups (SHG) and clusters.

Keywords Bamboo and rattan · Crafts and furniture design · Branding · Market induced design · Rural craftsmen

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1 Introduction

The last decade saw a growth in eco-consumerism. A number of ethnic groups in South East Asia depend on Bamboo and Rattan (B&R) for varied purposes such as making houses, furniture, containers, high-grade paper, food items and decorative handicrafts. B&R, by being economically valuable to such native communities, can also lead to preservation of forests. Ben-Zhi et al. [1] report that though forest areas have shrunk worldwide, in China, the total area under bamboo plantations is steadily increasing.

Furniture and craft making out of these two materials has continued for centuries in the North-Eastern state of Assam, India (Fig. 1). According to the Indira Gandhi National Center for the Arts [2], both these resources are found in surplus in the forests of Mizo Hills, Mikir Hills, North Cachar Hills, Nowgong and Lakhimpur districts. In view of its importance in the rural economy, the Government has started several programs under the Department of Industries and Commerce (DIC) [3], Government of Assam and has established Industrial Clusters in several districts in Assam. These clusters are each run by an NGO at the management level and employ around 15–20 craftsmen on a part-time or full time basis. The Government provides these clusters with loans and subsidized machinery. Individual craftsmen in the area can rent this machinery by paying the expense of the electricity used.

B&R furniture (B&Rf) are usually considerably cheaper than wooden furniture. It might hence be expected that the B&R industry will have good market share in the developing South-East Asian countries. But unfortunately, B&Rf have only been able to sell well in local markets with mostly low-income consumers. It has not been able to successfully tap into the high-income urban markets. Reubens et al. [4] state that this is because the product suffers from negative connotations attached to it by people as being ‘low-cost’ and ‘rustic’. It has not been able to capture the interest of industrial designers who prefer to work with regular flat boards and render designs that are tailored for assembly-line manufacturing. The technology push for the B&R industry is to have both these materials in an industrially processed form, either as flat boards or as composites. But industrializing this handicraft is likely to push the furniture makers further down the value chain ending up as raw material suppliers.

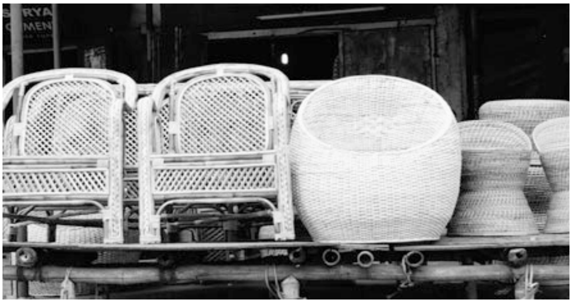


Fig. 1 B&R furniture in a shop in Guwahati, Assam

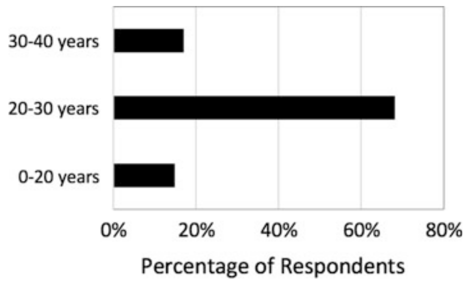


Fig. 2 Age distribution of respondents

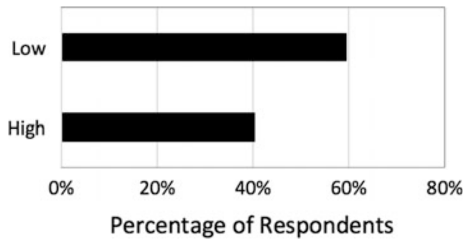


Fig. 3 Income distribution of respondents (*High*—Income >15,000 USD p.a. *Low*—Income <15,000 USD p.a.)

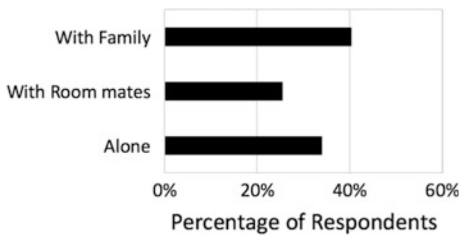


Fig. 4 Living situation of respondents

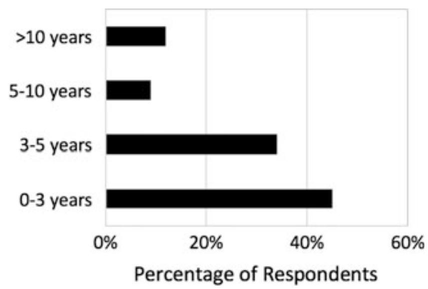


Fig. 5 The frequency with which respondents move homes

In Assam, Das et al. [5] state that the Industrial Cluster model has distinct advantages over modest home-based production. It helps in the pooling of resources and attracts higher public investment by providing superior quality products. It also stimulates innovation by promoting knowledge sharing. However, the biggest benefit that clusters have is that they enjoy collective bargaining power with suppliers and can brand their products with their identity.

Despite efforts by the government for higher commercialization of this industry, majority of the furniture makers remain part-time home based business owners. Fabeil et al. [6] investigate the factors that are responsible for the resistance in moving towards full-time workshop based production for the handicraft makers in rural Sabah, Malaysia. The craftsmen usually engage in such production for their passion for handicrafts but have limitations of time due to trade-off with other income generating activities.

The need to have a good business model is as crucial to this industry as having a competitive product. Chesbrough [7] discusses how an appropriate business model can set the technical specifications of a product. He cites the example of Xerox, which realigned its strategy to making faster printers since the sale of printer supplies was higher than the sale of printers. Kumar et al. [8] demonstrate how companies like Ikea with no significant competitive edge from product innovation, have been able to be market driving through their disruptive business models.

B&R are usually associated with nature and South East Asia. While these connotations make it hard to market B&Rf in urban markets where the demand is usually for industry-processed, fine-finished goods, it also opens up two effective avenues to market these products, namely—ethnic branding and green marketing. Currently B&Rf mostly sell as garden or outdoor furniture. But there is scope to brand these products as 'eco-friendly' and 'ethnic' and increase their market share. Scrase [9] examines how two online retailers (Craftsbridge and Oxfam) selling Indian crafts, use ethnic branding in the form of stories of the producing communities to appeal to online visitors. Mahoney [10] describes how Kenyan crafts have become part of western households by highlighting the "tribal" imagery of the products selectively to suit to western tastes. Emphasis is also laid on aspects such as 'Fair trade' and 'Hand made' that western consumers care about. Ittersum [11] states that some of the most important factors in the buying decision of consumers for products with ethnic labels are quality of the product relative to its alternatives and the consumer's cognitive association with the region of origin. The post purchase behavior is determined by how much the product exceeds expectations or 'positive disconfirmation'. Most urban consumers exhibit environmental consciousness in their buying decisions. Arribas et al. [12] follow the success story of the international Spanish brand, Hoss Intropia that relies on sustainability as its brand strategy. In order to reduce waste, Hoss Intropia distributes overstock among homeless people. It also regulates its production center in India to reduce environmental wastes generated from manufacturing of textiles. Dove [13] demonstrates that successful marketing of non-timber forest products indirectly leads to preservation of forests when such resources become valuable to the local population. Handicrafts are also extensively marketed through social media. There are three reasons for social media such as Facebook, Twitter, Pinterest, etc. being good as promotional media for the small scale handicraft producers, namely—low cost, global reach and easy recognition. Rahadi et al. [14] discuss about ways in which handicraft makers in Palembang city in Indonesia are able to brand their products and fetch competitive prices in international market using social media.

Despite the strengths and opportunities, the B&R industry of NER is unable to scale up. This paper seeks to understand the gap in the value proposition of the B&Rf makers and the customer segment profile of the young, urban consumers in Indian cities. The young, urban consumers are of particular interest as they frequently change housing and have a preference for light, economical furniture. B&Rf being both light weight and low cost, this industry has the potential to tap into this market.

2 Research Methodology

Questions. The research was designed to answer the following questions: (1) What are the preferences and buying trends in furniture among urban consumers? What is their perception about B&Rf (2) Do the B&R manufacturers understand the pains, gains and jobs of the urban consumer? (3) Is their a disconnect between the current market demand and the current products and distribution channels? If yes, then what is it? (4) What are the cradle to market steps involved in B&R? (5) What are the infrastructural support systems available to B&Rf makers? (6) What is the understanding and perception of the B&Rf manufacturer regarding the market?

Participants. The participants in this study fell into two groups: consumers and manufacturers. The consumer group consisted of 47 users living in Indian cities who were either in college, just started working or were in the early phase of settling down with families. They were students and professionals from different industries. The manufacturer group included craftsmen, business owners and employees in a bamboo industrial cluster from three districts in Assam—Nagaon, Kamrup and Barpeta. All the craftsmen, except the ones working full time in the cluster, are part time farmers. Only the industrial cluster has direct access to the urban markets and transports its own furniture via railways (Tables 1 and 2).

Methodology. We created an online questionnaire for the consumer research with closed and open ended questions. For the manufacturers, one-to-one interviews were conducted in person using a semi-structured questionnaire. Their responses were compiled in the form of a value proposition and this was compared to the customer segment profile to locate mismatches.

Table 1 Demography of consumer respondents

Consumers respondents (47 in number)	
Figure 2	Figure 3
Figure 4	Figure 5

Table 2 Business organization, location and selling outlets of B&Rf manufacturers

B&Rf manufacturers				
Type of business	Number	Employees/members	Location	Selling outlets
Industrial cluster	1	20 employees	Barpeta	Furniture showrooms, expos
Self-help group	2	5–10 members	Barpeta	Expos, wholesalers
Family business	3	3–4 members	Barpeta, Nagaon	Wholesalers
Single owner business	3	4–5 employees	Guwahati	Wholesaler, furniture showrooms

3 Key Findings and Discussions

Perception of B&R. When the users were asked about what comes to their mind when they think of B&Rf, most of the users came up with favorable adjectives like "Beautiful/Aesthetic", "Eco-Friendly", "Light-weight", "Homely" and "Strong". Unfavorable adjectives included "Obsolete", "Not durable", "Not strong" and "Prone to Termite Infestation". The bubble chart in Fig. 6. represents all the user expressed adjectives. The size of the bubble represents the frequency of usage. From the negative sentiments expressed, the most notable perception is that it lacks "modernity" in design and is not structurally strong.

Preference of Consumers. Users were asked to rate eight different themes, namely Rustic, Modern minimalist, Classic, Cottage, Industrial, Contemporary, Eclectic and Elegant Country. The users showed a preference for the modern looking, Contemporary and Minimalist themes (Fig. 7). However, the furniture made by the rural craftsmen mostly fell under the Rustic and Classic themes. While the users liked the clean look of modern designs, the B&Rf have a raw, natural finish and intricate weaves of rattan strips on surfaces. These features heighten the sense of ethnic origins of the furniture and the crude appeal makes it ideal to use

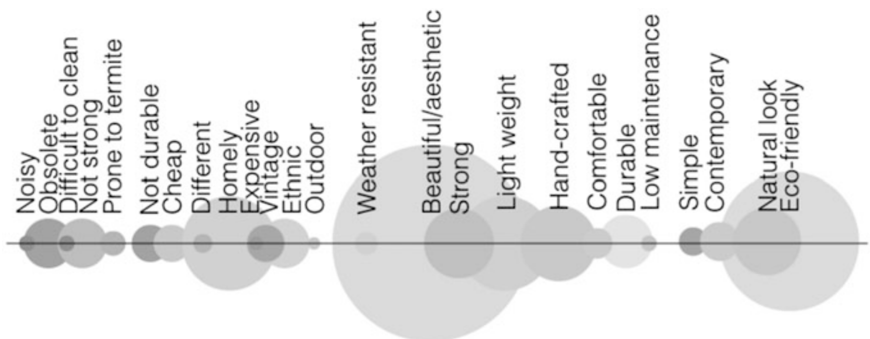


Fig. 6 Bubble Chart representing adjectives expressed by respondents for B&Rf

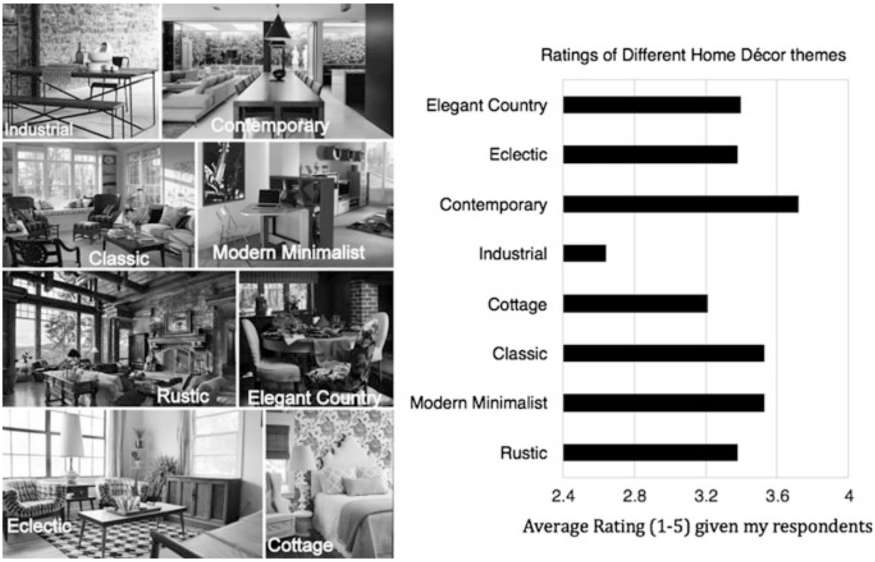
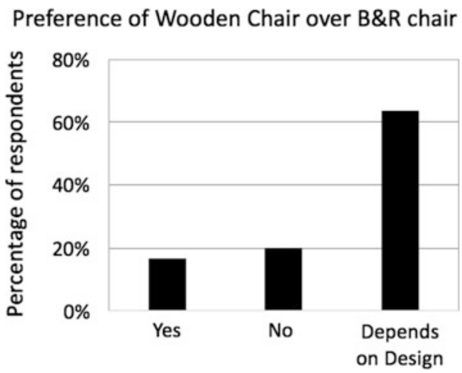


Fig. 7 Different Home Décor themes and average ratings (1–5) given by respondents (*picture source*: Pinterest)

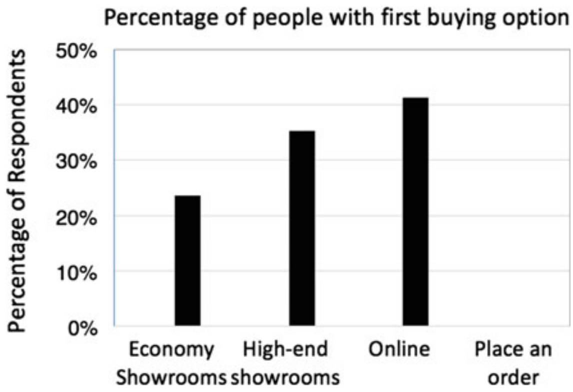
Fig. 8 Respondents preferring wood over B&R



them as garden furniture. For indoor purposes, users preferred less intricate designs and vivid colors.

The Design. "Design of furniture" emerged as a major factor for consumers. When the users were asked whether they would choose a wooden chair or a B&R chair, a significant majority said, "It depends on design" (Fig. 8). On the other hand, the craftsmen suggested that their designs needed new ideas and inputs of market trends from their observations in exhibitions that they attended in cities. However, only the industrial cluster and one independent manufacture reported using the internet to draw inspiration for new ideas. The other manufacturers were

Fig. 9 Preference of buying channels of respondents



unaware that the internet could be used for ideas. The industrial cluster employees also reported that they "mimicked designs" from furniture made out of materials other than B&R.

Buying Online. When asked which buying channel will they first explore if they had to buy a coffee table, 42% of the users said that they will first look at online retailers such as Amazon, Fab Furnish, etc. (Fig. 9). While high end showrooms and economy showrooms followed suit, no user chose the option of placing an order with a manufacturer. However, none of the B&Rf makers were selling online. The independent manufacturers sold their furniture to the wholesalers according to the orders placed by them. The cluster also sold directly to showrooms and through expos in various cities. Most of these makers showed willingness to learn how to sell online.

Dislike in Current B&Rf. The users assigned the highest dissatisfaction with too much of minimalism, followed by the intricacy of patterns on some furniture, absence of appropriate colors and modernity in the designs (Fig. 10). Lack of finishing also figured as a cause of dissatisfaction. The intricate designs on B&Rf often do not appeal to most users. It is also reported to be "Difficult to clean". Though users liked the raw color of B&R, but adding colors and finesse to these products might give a new feel and break the stereotype that they are 'natural products' only suitable for outdoor purposes.

Branding. The users were asked whether they thought about the environment while buying utility products. Around 32% of the users said that they always thought about the environment, while 53% said that they did not always take this factor into consideration (Fig. 11). The users also reported that 'Reusability of the material' and 'Low carbon footprint of the product' were factors that inspired them to go green. 53% users also said they connected with a product more if it told the story of the community making it and 36% said that it depended on where the product originated from. On the other hand, the manufacturers only stressed on strength and longevity of the product as marketing tools (Fig. 12).

To analyze the effect of income on the buying decisions, the respondents were divided into two groups, namely High Income (>1,000,000 INR p.a. ~15,000 USD

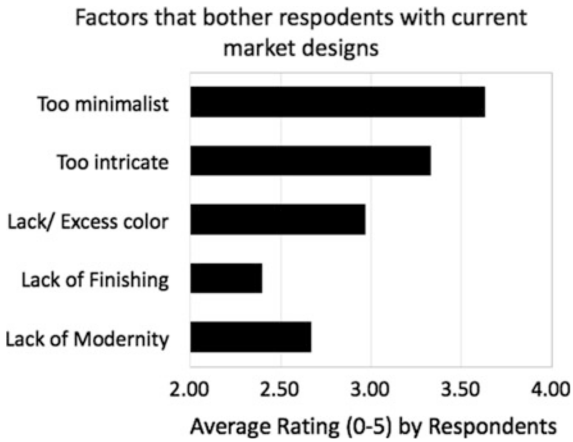


Fig. 10 Factors that respondents dislike about current furniture designs in market

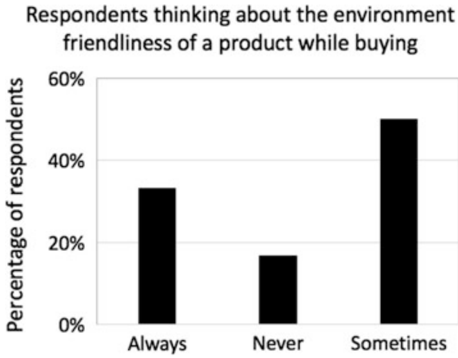


Fig. 11 Effectiveness of 'Eco-Branding'

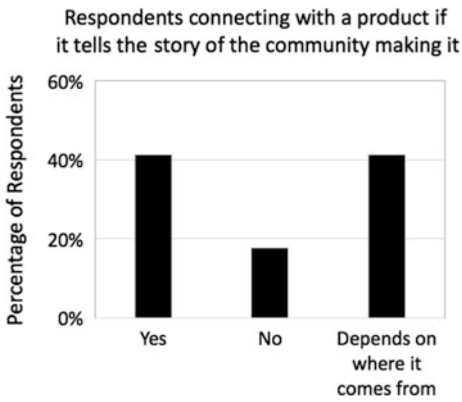


Fig. 12 Effectiveness of 'Ethnic-Branding'

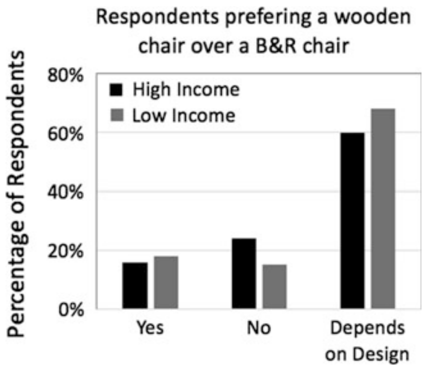


Fig. 13 Preference of wood over B&R

p.a.) and Low Income (<1,000,000 INR p.a.). The High Income group showed slightly higher sensitivity to Ethnic Branding versus the Low Income group which demonstrated slightly higher sensitivity to Eco Branding. The high income group also showed slightly higher likeliness to buy a B&R chair (Figs. 13, 14, and 15).

B&R Manufacturers. There was a marked difference amongst the manufacturers in terms of knowledge of customization of products, pricing and Government aids based on their mode of operation. Individual manufacturers are not part of any network, exhibited low understanding of market demands, pricing and Government aids. They carry out production on the basis of orders received from wholesale suppliers and do not sell their products in exhibitions directly. They also complain about stagnant prices of finished products and economic exploitation by suppliers. Self-help group organized manufacturers take part in exhibitions and demonstrate some amount of understanding of market demands through the sales analytics that they gather. They do knowledge sharing and have greater knowledge of training and government aid programs. Notably, some of them also used the internet to get ideas for new designs. The Industrial Cluster in Barpeta demonstrated the highest amount of knowledge in pricing, market demand and government aids available. They divide labor based on expertise and have the highest participation in

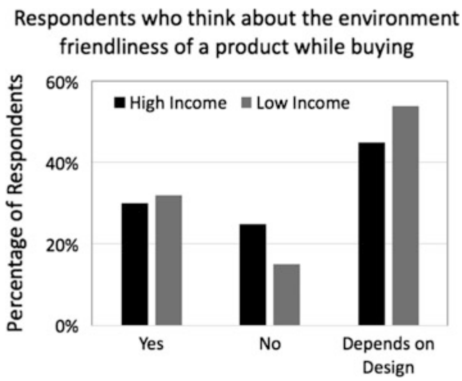


Fig. 14 Effectiveness of Eco-Branding

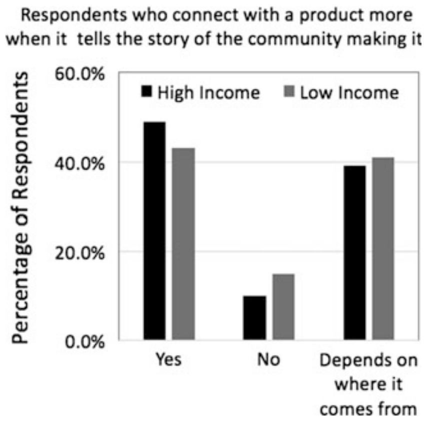


Fig. 15 Effectiveness of ethnic branding

exhibitions and the biggest sale volumes. They use the internet frequently to get new ideas and replicate them. Usually, clustered actors find it easier to obtain government funding due to higher credibility. Hence, functioning as a cluster can help the manufacturers to venture into new modes of production and selling.

Higher co-operation among the manufacturers clearly has an impact on the market orientation of the manufacturers. The poor knowledge of pricing is also a cause of concern as the individual manufacturers expressed discontent that the prices of raw materials were steadily increasing, but the offer price of suppliers have remained stagnant. They showed reluctance in adopting furniture making as their family trade and encouraging their next generation to continue the same. The B&Rf makers, who, in general, demonstrate good manual as well as machining skills, depend heavily on the training programs of the NGO's and the Government Block offices.

4 Conclusion

The B&Rf of NER have not grown outside in non-local markets due to high shipping costs and an underdeveloped transport system in the region. Despite Government assistance, the disconnect between the needs of the urban markets and the manufacturers in remote areas also contribute towards the inability of this industry to tap into new markets If the Government and NGO's trained the manufacturers on these aspects and ICT besides imparting skills, it will go a long way in helping these craftsmen to venture profitably out of local markets. With this study, we wish to aid in the design of training modules for rural craftsmen in Assam. The other craft industries in Assam suffer from similar deficiencies, such as inability of the craftsmen to understand the changing markets or inaptitude with the use of internet. Training modules developed for such industries also need to focus on these deficiencies.

Recent years have seen considerable technological developments in the context of B&Rf. Van der Lugt [15] emphasize on the possibility of design by using bamboo ply boards and composites for fine-finished surfaces and techniques like coiling instead of weaving for alternate finishes. Our future research on design intervention to develop more viable products for the B&R industry in NER will focus on the needs and wants of the consumers recognized in this study. Clusters with higher access to government financing, can take to making such market oriented products. They can also work to create their own online store and create an identifiable brand.

Acknowledgements Our sincere thanks to all the craftsmen and their families, cluster officials and consumers who participated in the study and provided us with valuable information.

Appendix

Link to online questionnaire filled by consumer respondents:
https://www.surveymonkey.com/r/canebamboofurniture

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Exploring the Purchase Experience of Assam Silk as a Memento Among the Tourists to Strengthen the Bond Between Visitors and Native People

Hitesh Sharma, Sougata Karmakar and Debkumar Chakrabarti

Abstract Assam Tourism has a potential to provide a unique experience to tourists in addition to the known pilgrimage and forest resort to explore distinctive culture of the native people. Visitors purchase mementos like tea, bamboo crafts and they are always attracted towards silk products of Assam. Plenty reported researches are available on general retail management but it is generally found that very less focus has been on how the tourists perceive the exterior environment and what their responses to shopping locations are. In spite of excellent quality of Assam silk products, due to poor service design, purchase experience is not up to the mark. Based on a survey of tourist response to the service design and showrooms located in the Panbazar area of Guwahati owned by local silk weavers' societies, an idea of developing a 'Silk Promotion Hub' where tourists may spend some time to get experience of silk rearing, various handloom activities and appreciate/purchase the fine quality silk products have been conceived. Entire collected information from questioner, interview and videography was studied thoroughly and a brainstorm session was conducted with a small expert group containing 4 designers/design academicians, to identify the key considerations for the proposed park. Following brainstorming and discussions, some two-dimensional (2D) schematic diagrams were conceptualized for the 'Silk Promotion Hub'. It is expected that the intended design layout of the silk promotion hub/park would be beneficial for hassle free informative purchase experience of the tourist. Most of the tourist might be tempted to buy the product. Moreover, informative experience and memory of the park would influence them deeply. This in turn would help in strengthening the bond between visitors and native people for a harmonious relation.

Keywords Assam silk · Tourist mementoes · Purchase-experience promotion hub

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1 Introduction

Assam, the ‘Gateway of North-east India’ is very rich in traditional Art and craft that shows the rich heritage of the cottage industry i.e. sericulture, handloom, bamboo and cane industry, pottery, gold jewelry making etc. [1] that attracts tourists. A Lot of purchase specifically silk items are done during the trip [2] that reminds of the experience [3–5] and would like to keep it as a treasure memento and such attention, care and interest binds the people with the visited place. Silk after weaving with abstract figures of animals, birds, human forms, creepers, flowers, diamonds, etc. [6] gives a unique product that everybody wants to have it as a memento. All together 4,463,479 tourists visited Assam during 2013–14 out of which 44,44,393 were domestic and 19086 were foreigners, which is very high as compare to 3,479,870 in 2006–07 [7]. It is also observed that most of the tourists coming to Assam are staying in Guwahati for one day [8]. Shopping is perceived as one of the most immersive leisure activities experienced by the tourists in a foreign location [9]. Research states that 24.5% of expenditure made by foreign tourist and 14% of expenditure by domestic tourist goes in shopping. Shopping is gaining importance as a tourist activity due to actual consumption of goods purchased by the tourists, and as a source of enjoyment and satisfaction for them [10] in which garments, mementos, paintings and handicrafts are purchased as reminders experiences of their travel [11, 12]. This not only contributes to the market around but also promotes local available products [13].

Assam silk may become a convenient memento that may help the tourists and their friends and relatives create a favourable image of Assam through the sharing of experiences along with other reminders of their travel like photos and videos of Assam, and other items they have purchased from Assam [14]. With such multiplier affect tourism shopping in Guwahati may form an integral part of the overall development in tourism sector and marketing strategy as a tourist destination. The creation of comfortable and enjoyable shopping experiences can be conceived to engage tourists more and compel them to extend their stay [15].

Improvement of product quality and customer satisfaction, which has become a source of competitive advantage in the industry, influences the entire purchase process. If the design exploration is based on customers choice and ideas can be produced by local skills, it would get buyers preference. Proper focus on the product quality and satisfaction of silk has led to the concept of customers delight [16]. Gender is also an important consideration as it is noticed that the majority of the consumers of Assam silk products are married female consumers [16] who visits shop with children and other family members, and they prefer outlets where there is a showroom, where the price is reasonable and also which provides offers such as a discount, free gifts etc. Despite the demand of silk in different markets producers are lacking for efficient marketing facilities, finding new markets, modern designs, pricing and packaging [17]. To support the requirements of the silk market a new outlet for the producer are to be developed.

Various Government and NGOs are working for upliftment of the people of Assam. Marketing of different products like tourism, handloom, handicraft etc. are done at different timings. As the department of handloom has organized 49 district level fairs, 22 Special Handloom Expos and 5 National Handloom Expo in the State during the year 2009–10 [17] for promotion of handloom products and tourism department is organizing different festival for tourism promotion through-out the year [18]. Different ministries govern the above two departments which creates lack of coordinated efforts. Development of permanent silk souvenir promotion and demonstration park may compliment efforts of both the ministries involved in and also other ministry like culture and others may join as partners. A common platform may also provide opportunity to craftsmen and other organizations such as Cooperative, NGO's, self-help groups etc. involved in silk sales to demonstrate their products. The silk production area and sericulture activity may also be demonstrated to give the tourist a unique experience and silk production knowledge to students, designers and various other concern people.

This leads to an idea of developing a 'Silk Promotion Hub' where tourist may spend some quality time to get experience of silk rearing, various handloom activities and appreciate/purchase the fine quality silk products. Among products Assam is known for its tea; silk products are very popular among the local people but not presented well to the tourists. This study finds the feasibility of creating a mini tourist spot that exchanges a total silk experience between the tourists and artisans.

2 Methodology

To understand the present state of service design, field visits were conducted to 12 silk shops located in the Panbazar area (where most of such shops are located) of the Guwahati city. From the tourist point of view exteriors of these shops were analyzed. Main concern was on an approach of the shop, visibility of signboard, customer entry/exist path, etc. Inside the shop direct observation was conducted to analyze customer area, merchandise visibility, merchandise display table, trial rooms, etc. Other customer amenities like car parking area, a kids area (as most of the customer are female accompanying kids and other family members), payment options (nearby ATM or Credit/debit card swapping machine), the washroom, food stall (other than providing food which may serve as a relaxing and discussion area for customers) etc. were analyzed.

In order to know the tourists' view regarding above-mentioned facts, an exploratory inquiry was conducted with 65 female tourists visiting Guwahati silk shops using random sampling methods. A self-administered questioner (predominantly open-ended) was developed based on available information in various literature resources [16, 18] and used for this purpose. To understand the seller's point of view, 10 numbers of shopkeepers and sales persons were interviewed and documented to know their demography, understanding about the product and experience with the tourists (customers).

Entire collected information from questioner, interview and spot survey/documentation was studied thoroughly and a brainstorm session was conducted with a small expert group containing 4 designers/design academicians, to identify the key considerations for the proposed park. Following brainstorming and discussions, three numbers of two-dimensional (2D) schematic diagrams were conceptualized for further development of the idea.

3 Results and Discussion

3.1 Demographic Data of Tourists Visiting Silk Shops

Demographic data suggests 73% of tourist buyers of silk were females; 43% of the respondents were between 28 and 37 years old followed by 35% from 18 to 27 years and remaining 22% were aged between 38 and 45 years; 44% were up to graduation qualified; 52% were housewives; 86% were domestic tourist; 71% were visiting with family members/friends; 82% were unaware of the silk product before arriving in Assam and 60% of them came to know about the silk product from family members or friends. This led to make an attempt to create awareness among the tourists and the means and methods to study for this.

3.2 Tourist View on Silk Shops

Exterior: Views of respondents about the silk shops exterior suggests 86% of tourists reported that shops were not clearly visible from the road as vehicles were parked in front of the shops; 68% faced inconvenience in getting down from taxi as the road was very busy with no parking space; 85% found approach of the shop was very inconvenient.

Shops interior and amenities: Views on silk shops interior and amenities suggests 92% of the respondents don't find silk shop size convenient (from entry exit point of view); 89% found product visibility inconvenient; 65% product display table inconvenient (from product visibility in full spared point of view); 86% found arrangements for product trial room facility not in place; 71% reported wearing inconvenience of available products; 69% were uncomfortable with the wearing assistants available in the shops (they prefer woman assistance over man); 72% said that they were not prepared to buy such high price products; 57% want to have more payment options or ATM nearby. In other amenities 53% said that most of the shops were away from food stalls and 48% said about non-availability of washroom within/near the shops.

Muga silk products: All the tourist reported about excellent quality of Assam silk products; 78% of them rated the craftsmanship of the product high (which is driven by inner instinct of individual); 64% percent of the respondent were not satisfied with the product verity; 71% shown interest in knowing about making of silk product; 82% of them will prescribe these products to friends; 78% opined that good purchase experience along with knowledge about craftsmanship and production process of silk product will be helpful in building cordial/friendly relationship between tourists and native people (host).

3.3 Direct Observation of Shops

Panbazar, the market place under study, is situated in the heart of Guwahati city has a lot of silk handloom shops. These shops were observed and documented from tourist ease point of view. The area is having around 30 silk shops having an average three customers at a time accompanied by an average two persons observed at many times of day. The shops are on both the side of the Hem Baruah road, which starts from Dighali Pukhri, and expanded up to Fancy Bazar area requires considerations for attention to the tourists' needs and comfort (Fig. 1).

Fig. 1 Observation snaps showing the prevalent state of the shops; from the *top left* **a** on the Google map the study site at Panbazar, *red* marked stretch, **b** Improper visibility of shops due to parked vehicle, **c** Narrow approach to the shops, **d** Small size of the shop, improper entry/exit, **e** An obscure display of products, **f** Improper display table, **g** Non availability of the trial room **h** Improper billing desk and **i** Non availability of space for kids and other family members as well as conveniences facilities

3.4 Views of Sellers

Sellers demography data suggests that 70% of them belong to the age group of 35–50 years and remaining fall in the age group of 22–35 years; all male; 80% of them were graduates; 70% of them were not proficient in other then mother tongue. It suggests that proficiency in handling varieties of tourists there is a need for awareness cum training. About the products, all of them having sufficient knowledge of product quality but 60% of them did not have sufficient knowledge about various stages of silk production. They reported about insufficient customer amenities.

3.5 Views of Sellers

Sellers/salesman demography data suggests that 70% of shopkeepers belong to the age group of 35–50 years and remaining fall in the age group of 22–35 years; all of them were male; 80% of them were graduates or below education level; 70% of them were not proficient in other than the mother tongue. It suggests that proficiency in handling varieties of tourists there is a need for awareness cum training. About the products, they stated that all of them having sufficient knowledge of product quality and 60% of them were not having sufficient knowledge about various stages of silk production. Some of them also reported about insufficient customer amenities.

3.6 Concept Generation for a Silk Promotion Hub

To have a free and larger space, outskirts may be used for such development, considering communication facilities between Guwahati central areas to the specific location. To have a local flavour in the proposed hub, Assamese architecture style monuments like Rang Ghar, Talatal Ghar etc. were visited for references. Several alternate sketches were made for accommodating all the essential amenities out of which three 2D models of possible Silk Promotion and Demonstration Park, Fig. 2, have been prepared.

Key consideration of Models taken were:

1. An area of 220 ft × 169 ft. was taken for accommodating 270 people at a time.
2. Single gate for entry and exit is kept for the secure and relaxed environment.
3. The architecture of the gate will have elements of Assamese culture.
4. Big parking spaces were kept for the vehicles of the tourists.
5. Shop sizes were also kept big for good service design.
6. The architecture of the shop is kept like Rang Ghar (a house entertainment) a well-known monument of Assam.

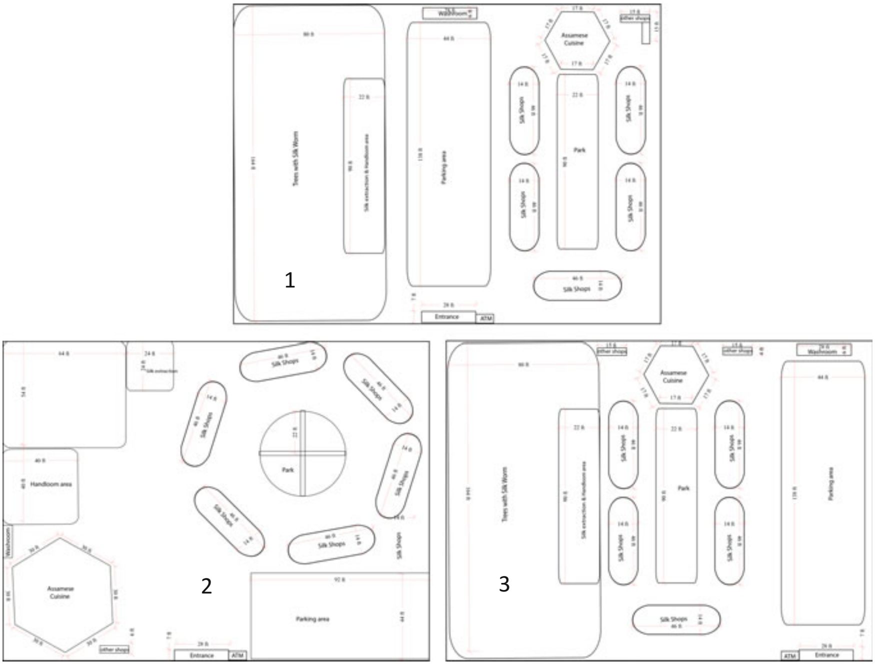

Fig. 2 Model 1, expresses the selling-buying area in a parallel arrangement along with the parking area and silk experience areas; Model 2, provides a concentric pattern of selling and buying area with other amenities in one side; and Model 3, where the selling-buying is sandwiched between parking and other facilities

7. Shop colors will also be taken from the Assamese tradition where light shade of pink is used in buildings.
8. Murals related to Assamese culture will be made on the walls.
9. Shops are kept in round or oval shape for making it naturally lit during the day.
10. Som (Machilus bombycina) and sualu (Litsaea polyantha) plantation were done in a corner of the proposed park where silkworm can be kept.
11. The silk extraction area was kept for the demonstration of silkworm extracting.
12. The Weaving area was also kept nearby for the demonstration of weaving.
13. The park for kids and other accompanying persons were proposed in the center of the shops for better visibility from the shops.
14. The Dining area with traditional Assamese cuisine will be kept in traditional serving style.
15. Proper washrooms were planned for all the possible users.
16. A baby care zone is planned for infant care.
17. The other shops were planned for other utility items.
18. ATM is planned on the main gate for both inside and outside users.
19. All the amenities will be planned in such a way so that tourist could pass one half day at a park.

A well-planned high quality display shops with product variety and shopping environment are necessary to consider. This place should have a uniqueness of identity along with other amenities that enhances the appeal of the place in terms of engagement (such as eateries, clubs and entertainment facilities within a close proximity, good access to pedestrians and availability of parking facilities) ensures liveliness in that place [19]. Moreover, it is found that the environment surrounding the shop from the exterior plays an important role too and it must be perceived as acceptable and pleasing before even experiencing the interiors of the shop [20] which is the motivating factor to attract tourists. Further as observed by Yuksel [20], in addition to this, respondents are highly willing to talk to salespersons, spend engage in activities like surfing through and exploring the products, extend their cap on their expenditure when the climate of the Tourist Shopping Habits is considered as encouraging.

One very important consideration is that the visitors want to visit lively places. This need is considered in all the three proposed space layouts in current research to make the place dynamic. Apart from the aforesaid basic amenities, various other design considerations were deliberated in the model for the cluster of shops. Inspired from nature, rounded or oval shapes have been planned for the shops which sends a positive emotional message of harmony, protection gracefulness, integrity, perfection and completeness. As most of the visitors of silk shops are found female so curves are used instead of the sharp line and rectangle shapes, which are more feminine in nature. Moreover, round and smooth curvature in the furniture and space-layout design will be safe for the product as well as buyers. In the 'Model-1', the demonstration area and sale area are divided by parking space. If any visitor just wants to see from informative perspective, he can visit the silkworm rearing, silk extraction and handloom area without visiting the sale area. In the 'Model-2' visitors can directly land in the silk shop area and they also have an option to visit the silkworm area, the silk extraction area and Handloom area. In the 'Model-3' sale area is dominating as it is adjoining the parking area. Here, silkworm rearing and handloom demonstration area is for visitors who want more information about the product making.

Since the environment surrounding the shop from the exterior plays a pivotal role, this thought was conceived while planning of the space layout. Moreover, popular elements of Assam architecture incorporated in the planning. Space layouts of present planning for "silk promotion hub", also provides an opportunity to spend more time in the park to harness the stimulating buying. Souvenir shopping is a very emotional decision on part of tourists, the experience deals with visual appeal of the space where tourists are able to assess and correctly choose by feeling and thinking about items even though shopping is not a principal reason for their travel. In present research, the proposed model is also for giving long lasting and pleasing and user experience, rather than the only sale of products in the proposed park. Some researchers found that tourism increases chance to develop sympathy, tolerance and understanding between people and souvenir reminds place or person. This creates an invisible bond between the host and visitors. If Assam silk is purchased as souvenir, due to its longer lasting quality, satisfaction and natural golden color might create a bond between the people.

The present manuscript has been aimed to demonstrate the designing of a silk promotion hub based on available scientific knowledge from the literature as well as from the results of the questionnaire based survey from tourists and sellers. During design of the silk promotion hub, due consideration has been given regarding the local cultural elements (local architectural form, colors, special greeting pots on the door, depicting festivals and stories on the mural), basic amenities (provision of the trial room, local cuisines with traditional serving style, kids zone, ATM's, parking area, washrooms), a comfortable ambience (inviting shop exterior, specious shop, improved product demonstration, convenient entry and exit, the oval shape for naturally light during day time), experience of different stages of silk yarn rearing and making of silk cloths, etc. It has been planned to provide a new type of shopping experience by developing a market-place with the flavor of local identity. This market-place (hub) would resemble the villages of the silk-weavers with local architectural forms, natural habitats and cultural elements. This would be different from concrete based high-rise shopping complexes in the cities.

It is generally found that plenty reported researches are available on general management in the retail sector and very less importance has bee given to what the actually tourists' perceives in terms of what they see in the surrounding environment and their the image created about the shopping locations [21]. Hence, in the present research, an attempt has been made to address this unexplored area of design and development of promotional hub based on perception and feedback from the tourist and sellers, apart from purchasers to enhance the overall shopping experience. Researchers [22–24] stated that due to its economic, social and psychological benefits, authorities are paying more attentions towards the development of such relaxing yet engaging shopping places at tourist destinations, so that it can ignite the customer's desire to visit and even stay more than they had planned. Present research is the same line to provide better shopping experience with extended stay and desire for re-visit.

Researcher [22] mentioned shopping malls are able to increase the time spent in the store, increase the expenditure, and evoke impulsive buying and the increased likability of the store, due the positive emotions evoked within the customer. Moreover, it is found that the overall store ambience plays a significant role in development of customers' thoughts and actions [25] as the impression formed on the customer in the first glance, is likely to be in part generated by the macro-environment to which they are immersed in [25]. All these aforesaid aspects have considered during the design of silk promotion hub which has been reported in present paper.

The proposed design of the silk promotion hub would facilitate the tourist to see and appreciate personally the highly skilled work of the artisans with traditional looms. By this arrangement artisans would get due admiration which is very essential for strengthening inter-personal relationship between tourist and host. The deeper understanding of the artisan and their products by tourists would help the weaver to get justified value for their products. It is found that similar types of promotional hubs have already been designed by various designers in different parts of the world but the present design concept is unique in terms of its cultural elements, attempts undertaken to strengthen the bond of inter-personal relationship among tourists and hosts (sellers, silk-weavers and local people).

4 Conclusion

It is expected that the intended planning and design of the silk promotion hub Park would be beneficial for hassle free informative purchase experience of the tourist. Most of the tourist may tempt to buy the product but informative experience and memory of the park will influence them deeply, which is good for strengthening the bond between visitors and native people. Tourist department, local silk producers and agencies involved in silk product promotion are being contacted for feedback and possibility of implementation through public private partnership at the outskirt of the city towards the Hajo/Sualkuchi road where visitors and local people from Guwahati and around can visit easily.

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Towards an Automatized Generation of Rule-Based Systems for Architecting Eco-Industrial Parks

Andreas M. Hein, Bernard Yannou, Marija Jankovic and Romain Farel

Abstract In this article we present the matchmaking problem in industrial symbiosis where wastes from one company are matched with resources of another company that could be substituted. Identifying potential matches is difficult, as it is based on knowledge that certain wastes can substitute certain resources. Capturing this knowledge in the form of waste-resource matching rules manually is time-consuming. Therefore, we argue that a Natural Language Processing (NLP)-based approach of semi-automatically extracting rules from domain-specific data sets could be a viable approach to solving this problem. The basic NLP problem to solve is to find similar concepts (synonyms), part-whole relationships (meronyms), and "is a" relationships (hyponyms). Synonyms are important for finding wastes and resources that are named differently but refer to the same object. For example, water and its chemical formula H_2O are often used interchangeably. Meronyms are part-whole relationships that may help to identify wastes with components that could be used as a resource. For example, methane is a component of natural gas. Hyponyms allow for building taxonomies. For example, wood *is a* kind of biomass. We present the results of an initial literature survey of algorithms that are able to find these relationships in large sets of unstructured text documents. Furthermore, we propose a research approach for further extending the literature survey and testing the existing algorithms on small test cases and a realistic matchmaking case. For future work, additional problems that fall into the NLP category can be addressed such as semi-automatically identifying processes for converting wastes into resources.

Keywords Eco-industrial parks · Industrial symbiosis · Natural language processing · Rule-based systems · Expert systems

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1 Introduction

An eco-industrial park is a set of companies within an industrial zone that share resources and thereby increase economic profitability and decrease environmental impact. One of the key underlying concepts of eco-industrial parks is “industrial symbiosis”. An industrial symbiosis is the use of an underutilized resource from one actor, such as wastes, as a substitute for a new resource of another actor. The concept is therefore related to waste recycling. Figure 1 shows an example of an industrial symbiosis from the eco-industrial park in Kalundborg, Denmark. Instead of using fresh water from a local lake, the coal power plant uses waste water from a close-by oil refinery. The coal power plant saves money, as fresh water is expensive and the oil refinery can save the capital cost for constructing a waste water treatment plant.

An eco-industrial park is commonly based on a whole network of industrial symbioses. One of the challenges of creating industrial symbioses is that it is knowledge-intensive: It depends on the plant-specific processes if a waste can substitute for a resource or not. Usually, this problem is solved by bringing together process engineering experts. However, this approach is no longer feasible when a large number of potential symbioses need to be assessed, such as in a large industrial zone. For solving this problem, we previously developed a prototype of a rule-based system that captured some of the rules and heuristics for identifying symbiosis opportunities without the need of collecting proprietary company data and only using publicly available data [1]. The system is intended to automatically identify promising industrial symbiosis opportunities that can be further investigated by experts.

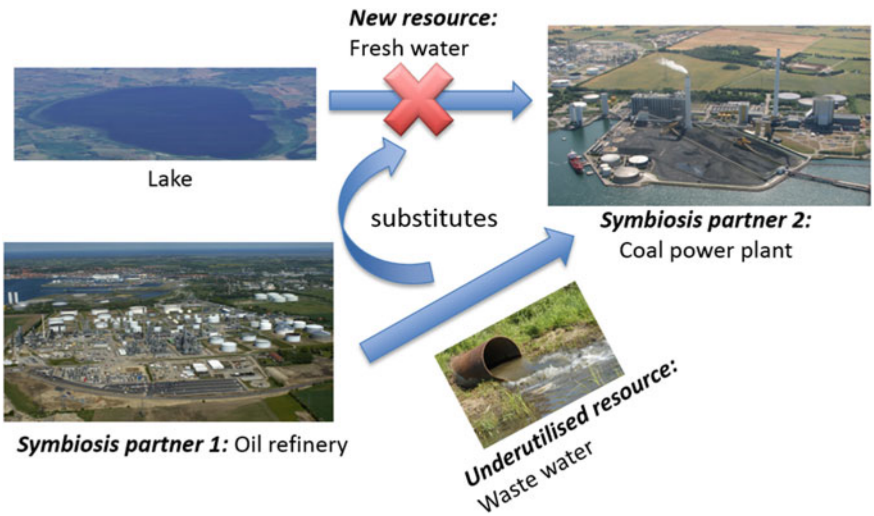

Fig. 1 Example of an industrial symbiosis at the eco-industrial park of Kalundborg [1]

One of the drawbacks of a rule-based system that is based on a static rule base is its maintenance and updating [2–4]. As new technologies and processes for implementing industrial symbioses are constantly developed, it is important to keep the rule-base up to date. Currently, this is done manually, which is time-consuming and expensive, as the knowledge has to be "mined" via extensive literature surveys and expert interviews. However, recent developments in natural language processing (NLP) could significantly improve the updating of rule-bases, underlying taxonomies, and ontologies [5–7].

In this paper, we provide an overview of areas where NLP could add value to rule-based systems.

We start with a literature survey, covering the current state of the art in finding waste—resource pairs in industrial symbiosis and subsequently provide an overview of existing NLP and big data analytics approaches.

2 Problem Formulation

One of the shortcomings of existing matchmaking tools is that they require direct input from industrial companies, which presupposes that there is an initial motivation to share data. Another shortcoming is that existing matchmaking systems match wastes and resources based on string identity. It means that if one company creates "plastic" as a waste and another company needs "plastic" as a resource, a match is identified. However, if instead of "plastic" the company creates "plastic bottles", no match is identified. The e-Symbiosis project [8] aims at improving the current state of the art by adding waste and resource taxonomies and allowing for semantic matching. They use a taxonomic distance metric in order to quantify the likelihood that a waste can be matched with a resource.

In our research, we combined several approaches that were already introduced in the literature but are extending these approaches. As presented in [1], we propose a system where no input from companies is needed for identifying symbiosis opportunities. Instead, we use so-called meta-models of industrial plants, where types of plants and their usual inputs and outputs are described. It allows for an a priori identification of symbiosis opportunities that can be later refined by more accurate data from companies. Furthermore, as in the e-Symbiosis tool, we use taxonomies and a set of knowledge-based rules that describe when a certain waste can substitute for a resource.

Our proposal is to improve on this current system by introducing approaches to automatize the generation of rules in order to allow for an automated or at least semi-automated approach to creating matchmaking rules. Such a system would not only be interesting for the area of industrial symbiosis but for recycling markets in general. Figure 2 shows the architecture of the proposed matchmaking system. From publicly accessible data bases such as books, patent databases, and Wikipedia, synonyms for wastes and resources are identified. In particular, we are interested in:

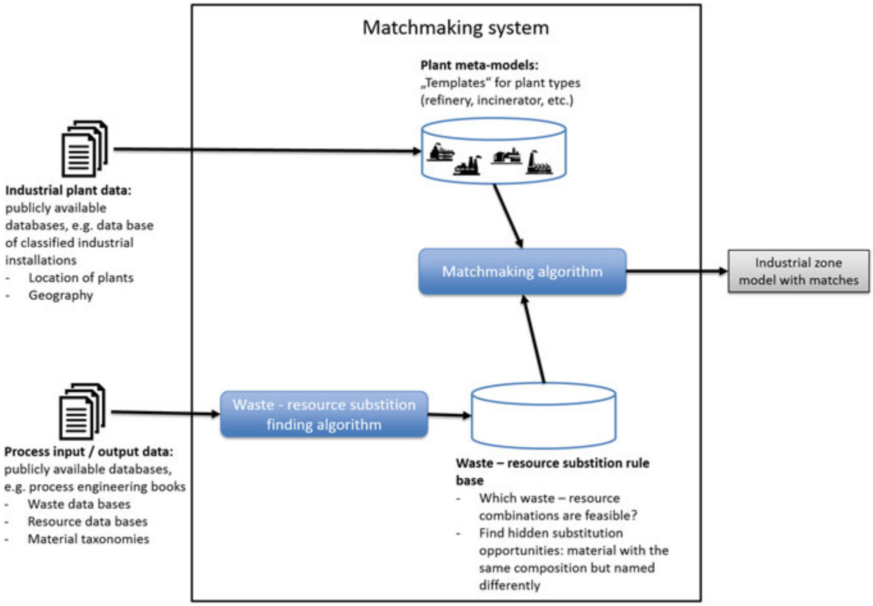

Fig. 2 Architecture of the matchmaking system

- Waste and resource compositions that are often introduced in online dictionaries and Wikipedia.
- Identify synonymous terms, e.g. lime is equivalent to calcium oxide or calcium hydroxide.

3 Literature Survey

Natural Language Processing (NLP) "employs computational techniques for the purpose of learning, understanding, and producing human language content [5]." NLP is of interest for us, as finding synonyms and related terms in a corpus of literature is one of the problems for which NLP approaches exist. In the following, we provide a quick overview of the NLP literature in order to identify approaches that are suitable for addressing our before-stated problem [5, 6]. provide overviews of current NLP approaches and outline possible future trends.

First approaches to NLP date back to the 1950s. First NLP approaches were mostly based on hand-coded rules for automated translation etc. Recent approaches rely on machine learning, mostly grounded in statistical inference-making using large bodies of annotated text. The statistical approaches seem to be better suited for capturing the highly contextual, fuzzy, ambiguous, and dynamic nature of natural languages.

According to [5] NLP can be defined as "the subfield of computer science concerned with using computational techniques to learn, understand, and produce human language content." An up-to-date overview of NLP approaches is presented in [5, 6].

The general problem we are dealing with is the automatic or semi-automatic identification of ontological (lexical) relationships. More specifically we are interested in identifying waste or resources that have different names but have the same meaning (synonyms), part-whole relationships (meronyms) for matching components of a waste or resource, and "is a" relationships (hyponyms) that can be used for building up taxonomies.

Methodologies for creating ontologies from text have been proposed such as in [9–13]. An overview of algorithms for identifying synonyms from large bodies of text is shown in Table 1. Latent semantic analysis (LSA) is based on the "distributional hypothesis" [14]. The key idea of the distributional hypothesis is that words with a similar meaning tend to appear in similar contexts [15]. However, LSA has shortcomings. As it uses a least-square fitting, it is based on the assumption that language data is normally distributed. Normal distribution is a precondition for least-square fitting. However, language data is not normally distributed [16]. Furthermore, LSA is a purely statistic method. By contrast, Word2Vec is a machine learning approach, based on a 2-layered neural network [17, 18]. The neural network is trained on a text corpus to predict the words that appear in its context. This approach is also based on the distributional hypothesis. Hence, Word2Vec can be used for comparing contexts of different concepts. The more similar the contexts, the more likely the concepts have the same meaning. As Word2Vec is based on a neural network, extensive training data is required. A third approach, called DFEAT, is based on supervised learning and distributional features [19]. The value of the distributional feature indicates the commonality of the context of a word pair. Using a pattern-matching algorithm, the algorithm is trained with a test set of words. Compared to other synonym classifiers on the test set, the DFEAT algorithm showed a superior performance.

Table 1 NLP algorithms for detecting synonyms

NLP approach	Input	Algorithm	Output	Key references
Latent semantic analysis	Documents	Singular value decomposition	Term set from document with reduced dimensionality	[20, 21]
Word2Vec	Candidate concept	2-layered neural network	Ranked list of synonyms	[22]
DFEAT	Training documents and application documents	Supervised learning and distributional features	Ranked list of synonyms	[19]

A number of algorithms have been proposed for identifying part-whole relationships, so-called meronyms, as shown in Table 2. Ittoo et al. [23] present an approach for finding meronyms in domain-specific data. Meronyms in domain-specific data is more difficult to address than in general language, as the amount of data is much smaller. As a consequence, it is more difficult to train machine learning algorithms. The approach proposed in [23] leverages on meronyms extracted from an open-domain corpus and extends these relationships by domain-specific relationships. Berland and Charniak [24] is arguably the first automatic part extraction from a large, unlabeled, corpus with a precision of 0.55 for the used data set. The purpose of the method is to add the discovered meronyms to an existing ontology or to a semantic lexicon. The algorithm rank-orders words that are candidates for parts of a whole, e.g. "speedometer" as part of a "car". Roberts [25] presents an algorithm for identifying meronyms in biomedical text. They use the PartEx unsupervised learning algorithm that learns part-whole patterns from biomedical knowledge bases and infers part-whole relationships in yet unknown data. In its reported version it achieves a recall of 0.73 and a precision of 0.58. The author claims that no manual labelling of the corpus and no manual selection of patterns is required.

Regarding hyponyms, [26] presents an algorithm for identifying hyponyms in large corpora. Maedche and Staab [27] present a semi-automatic approach for creating taxonomies from text on websites. Kietz et al. [28] present a method for extracting ontologies from semi-structured information and text documents in domain-specific corporate intranets. An overview of the underlying algorithm is presented in Table 3.

Integrating these algorithms with other powerful NLP algorithms such as parsers has become easier due to the availability of several open source NLP tools such as GATE NLP, Stanford Core NLP Suite, Apache OpenNLP, and the Natural Language Toolkit. Furthermore, the availability of extensive material, resources, and waste taxonomies provide the data on which the algorithms can be run.

Table 2 NLP algorithms for detecting meronyms

NLP approach	Input	Algorithm	Output	Key references
Domain-specific meronym extraction	Open-domain corpus, part-whole pairs, domain-specific textual databases	Pattern identification and generalization	New meronyms	[23, 25]
Meronym extraction from large corpora	Whole object, large corpus	Pattern identification	Ranked list of parts	[24]

Table 3 NLP algorithms for detecting hyponyms

NLP approach	Input	Algorithm	Output	Key references
Pattern identification	Unstructured text, manually identified hyponyms	Lexico-syntactic pattern identification	New hyponyms	[26–28]

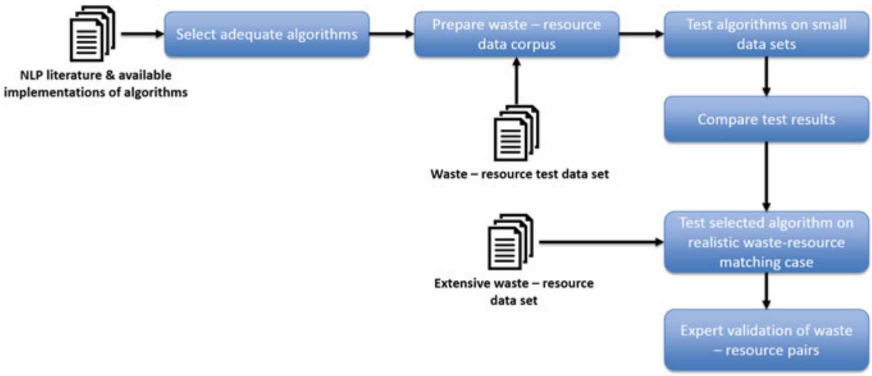

Fig. 3 Research approach for finding and testing matchmaking algorithms

4 Proposed Research Approach

Based on the initial literature survey presented in the previous section, we propose a research approach that is based on an automated or semi-automated data base of waste—resource substitution relationships. Figure 3 depicts the steps of the research approach. First, a more extended literature survey on existing algorithms for finding synonyms, meronyms, and hyponyms is conducted. In case these algorithms are open source or can be rapidly implemented, they may be tested on small data sets for verifying their applicability to the matchmaking problem. The test results are compared and the most adequate algorithms in terms of applicability and efficiency selected. This subset of algorithms is then applied to a more realistic data set with waste—resource data. The resulting waste—resource pairs are then validated by experts. On the basis of the validation the algorithms precision with respect to the data set can be calculated.

5 Conclusions

In this article we presented the matchmaking problem in industrial symbiosis. Identifying potential matches is difficult, as it is based on process-specific knowledge that certain wastes can be used for specific processes. However, capturing this knowledge in waste-resource matching rules manually is time-consuming. Therefore, we propose a NLP-based approach of semi-automatically extracting ontological relationships from domain-specific data sets that can be used as a basis for matching rules. We presented the results of an initial literature survey of algorithms that are able to find ontological relationships in large sets of unstructured text documents. Furthermore, we proposed a research approach for further extending the literature survey and to test the existing algorithms on small test cases and a realistic matchmaking case. For future work, additional problems that fall into the NLP category can be addressed such as semi-automatically identifying processes for converting wastes to resources.

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Participatory Innovation in SMEs: Innov'ensemble Project

Fabien Geniaux, Nicolas Maranzana and Ahmed Cheriat

Abstract Innovation is an indispensable knowledge for performance improvement of companies. Whether innovation was limited in the past to R&D services for product development, companies are now willing to integrate the employee's knowledge to extend the field of innovation to larger domains. In this study we propose a progressive model of innovation strategy relying on active participation and autonomy of employees for the expansion of ideas. We will describe the first steps of creation and implementation through a participative innovation project within a SME firm.

Keywords Innovation management · Participatory innovation · Innovation process · Culture of innovation

1 Introduction

Choosing and driving innovation strategy is challenging for many companies, especially those with limited resources. Moreover, innovation mainly focuses on the development of new products while the business improvement does not only reside in this area often dedicated to R&D services. Indeed, processes, organizations and most of the services and expertise of a business are also essential to ensure the success of a company. Relying on the definition given by Berkun [1], "innovation is namely a positive and significant change", we are able to state that innovation can be incorporated into the entire company and not confined to a

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particular service. In this context, implementing innovation within a corporate strategy involving all its players represents a great challenge for the industry [2].

The environment of this study is the market of services to councils which is now in a maturity phase. Consequently, this is represents a real challenge in terms of differentiation and enhanced benefits. However, overtaken by daily stress and short term challenges, exploiting the wealth of the ideas of the employees in order to generate innovative projects is sometimes difficult. Moreover, innovation is often restricted to the marketing department for the benefits of the customer or the development of new offers. In this difficult context, extending the approach of innovation to all services and in application fields such as improving processes or organizations represents a real challenge.

In this paper we present a progressive model of innovation strategy based on active participation and autonomy of employees for the development of new ideas. We particularly detail the early stages of its creation and implementation through an experiment around a project of participatory innovation within a SME service firm. We first present the state of the art and the objectives of the research, then we detail the research issues, the method and the protocol of the experiment that have been carried out and finally we discuss the results and conclude.

2 State of the Art and Research Objectives

2.1 Objectives of the Study

At the beginning of the project, for the main goal of the company was to use the potential of all its employees to generate new sources of innovation. From a scientific point of view, we wanted to propose a theoretical model for the integration of the innovation culture within a SME service firm. With a limited time period of six months we chose to define short term objectives necessary and achievable to build the foundations of a new strategy of innovation. These objectives may be summarized as follows:

– Laying the groundwork by performing a first experience of innovation within the company.
– Ensuring the continuity and the generalization of the approach at the end of the project.

Importantly, we wanted to include these short term objectives in a long term strategic insight to ensure the sustainability and the further development of the innovation activity within the company. Before setting up the experiment, understanding the tools and the issues related to the management of innovation indispensable.

2.2 Management of Innovation

Innovation appears as a complex notion due to its diversity and typologies, and defining the management of innovation is even more complicated. Indeed, the field of innovation management is difficult to organize due to the multiplicity of inputs in the literature but also because its borders are really blurry [3]. The scheme proposed by Rosenbloom offers a representation of this problem by distinguishing various levels of analysis (environment, organization an innovation process) and within these levels, different research issues [4]. Thus the notion of innovation management highlights four main research and optimization areas: the innovation process (process problem), the organization and structure of a company (structure problem), the management of human resources (human problem) and finally the adaption to change problem (adaption to change problem). These axes identified by Van de Ven correspond in fact to the four major problems posed by the management of innovation [5].

2.3 Models of Innovation Process

The innovation process must allow the generation of ideas, their development and their setting up. It is worth noticing that there is a difference between the process of innovation and the design process. Indeed, an innovation process matches a global approach which involves changes of structure, of organization, and in the culture of the company. In order to provide answers to the problems posed by the management of innovation, many models of innovation process were formalized in the literature such as Aoussat's model [6], Roozenburg and Eekels [7], and Kline and Rosenberg [8] for instance.

The multiplicity of existing theoretical models renders the choice difficult for a company. Nevertheless, we can rely on the summary of Delas et al. [6], which display the contribution of the main existing innovation processes (Fig. 1).

Although these models partially contribute to the resolution of some problems of the management of innovation, only the Vortex model responds to the human

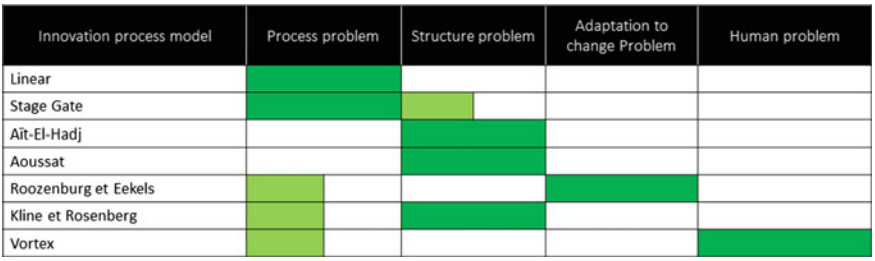

Fig. 1 Synthesis of the contribution of the main existing innovation processes [9]

problem. Indeed, it facilitates the involvement of all employees in the innovation process and therefore the Bottom-up aspect. However, this model (and all others) is primarily designed for the development of product innovation and provides steps as basic research that is not always necessary for the implementation of incremental innovation.

2.4 Participatory Innovation

Le Masson et al. [10] stated that "Putting progress and technology at the heart of the issue of innovation, companies often reduced their innovation activity almost exclusively in R&D". Thus, innovation is reserved to R&D services for improvement of products (this justifies the theoretical models described previously) and Lean management for the improvement of manufactural processes and production lines. However, innovation has different typologies and can easily find his interest around organizational issues affecting all employees [2]. Nowadays the creative dynamism of employees starts to be exploited as participatory innovation. In fact, innovation is no longer driven by the technology, the market, or even the customer but by the creativity of employees themselves [11]. This concept of participatory innovation is associated with the idea that innovation comes from a high involvement of the employees. It means that each employee has the ability to solve problems and sufficient creative skills to support innovation.

Based on the examples provided by Teglborg-Lefevre [12], and those of the association "innov' actors" (bringing together all French companies setting up of participatory innovation processes), French companies tend to focus on structured approaches for participatory innovation at the expense of more informal approaches such as pure Bottom-up management. Indeed, even when using a participative innovation management, playing on certain criteria such as the mode of organization of participatory projects which may also be due to the direction that left to the initiative of employees, participatory innovation may be an opportunity for a company to incorporate a Bottom-up approach in its management while retaining a share of its Top Down approach. [9]

2.5 The Advantages and Disadvantages of Participatory Innovation

More widely participatory innovation can contribute to the resolution of central issues of the management of innovation. Participatory innovation helps managing the human problem by promoting the involvement of the employees and contributes to the management of the tension between Top Down and Bottom Up approach. Moreover, it contributes partially to the resolution of the problem of structure by connecting services and bringing different actors of the company together around common projects. Participatory innovation also allows the detection of market changes and therefore offers a quicker adaptation. However, the establishment and conduct of a process of participatory innovation doesn't happen without brakes. The first difficulty to overcome is the lack of theoretical models for the huge number of parameters to determine in the company context and strategy [12]. Moreover, beyond the obvious risks that a company has to take in order to implement participatory innovation, it is also really expensive in terms of resources and time [13].

3 Research Issues

The industrial objective of this study is to establish an innovation model involving all of the company members while optimizing the use of its resources. This request is the issue of the innovation management and is linked to the resolution of its central problems of process, organization, management and human adaptation to change. The approach of participatory innovation seems to bring answers to the problems of staff involvement, connection between services and helps encouraging the organizational innovation. Although there are many empirical examples of application, models explaining its setting and its integration in the enterprise are absent from the literature [14]. To generate a complete and comprehensive model we integrated into our approach other spheres of knowledge that are not initial components of participatory innovation such as creativity and the change management. We also take into account the particularities of our industrial context: a climate of economic strength and self-censorship of employees caused by stress and lack of time. This brings us to anticipate the following research issues: how to design and integrate an innovation process involving all the company members in order to optimize its performance while taking into account its economic context and promoting the use of its internal resources?

4 Methods

4.1 Overall Strategy

To enable a gradual transition to an innovation strategy, we chose to rely on the model proposed by Delas et al. It presents the need for progressivity in the implementation of the innovation process [6]. Indeed, it is important to take into account the fact that the degree of novelty of innovation is directly related to the resources mobilized to generate it. Before a strategy can be implemented in an SME, the risks linked to human or financial investments should be limited as they

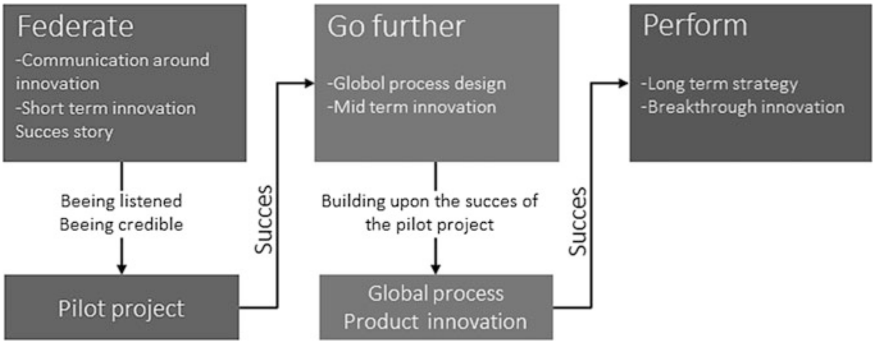

Fig. 2 Approach of the innovation strategy ([12], according to the author)

might be too expensive for the company. This model does not include our need to unite all of the business around a 'success story' showing employees that innovation may be a key to solve their problems of everyday life and generally the need for success as milestone between each phase. Furthermore, this model, focused on the development of products, does not take into account a necessary transition from a purely Top Down management towards a management combining the Top Down and Bottom Up from the approach of participatory innovation approach. This justifies the implementation of the global approach shown in Fig. 2.

This new model should allow to implement a new innovation strategy while taking into account the change management. The purpose of this theoretical model corresponding to the last step "perform" should ensure a very large involvement of employees and optimal agility of the company. This model indeed place innovation at the heart of the company's strategy and should by its form and its contents contribute to the resolution of the four problems of the management of innovation:

- Management of the tension between Top Down and Bottom Up approach (process problem)
- Involvement and autonomy of employees (human problem)
- Improvement of the relationship and the connection between the various services (structure problem)
- Responsiveness and agility in innovations (problem of adaptation to change).

5 Experiments

This part concerns the experimental protocol developed for the implementation of a pilot project of participatory innovation corresponding to the first phase of the theoretical model proposed above. In order to disseminate the culture of innovation within the services of the company, we have chosen "how to improve the business through innovation" as the theme of the project. The objective was to generate and implement short-term innovations, without limiting the scope of the ideas. In order to achieve this goal, we decided to launch a pilot project of participatory innovation called "Innov'ensemble" ("innovate together" in French). This project was deployed during 2 months and composed of the followings steps:

- The "teasing" step (one week) was thought to inform employees of the implementation of a new project and stimulate their curiosity. We have chosen to make a mascot to represent the project in a fun way. The mascot was deployed as posters highlighting innovation and as an animated video for the launch of the project through a ludic and metaphorical story. The idea of this step is to introduce innovation in a playful and positive way by breaking some codes and showing "offset" with the daily life of the company.
- The "communication" step (3 days). After having incited the curiosity of the collaborators, clear and transparent objectives of the project have to be revealed. This can be done by using emails as well as setting up informal meetings for the presentation of the project. This type of meeting clusters motivated people, creates links and raise potential uncertainties and misunderstanding about the project.
- The "analysis" step (2 weeks). Although absent in the processes of participatory innovation we studied we wished to implement in our approach the mechanism of divergence-convergence from the classic process of creativity. We believed that this has two major advantages. On one hand it allows the emergence of new ideas and make the opinions of employees on specific or broad topics visible (for the project Innov'ensemble results have shown that employees really wished the internal communication to be improved). On the other hand, this analysis step requires less time and involvement that the proposal of ideas, it allows the participation of a greater number of employees to the participatory innovation project. Participatory posters such as "challenge board" on which everyone can express his ideas with post-its proved to be particularly well suited to this work.
- The "convergence" step (3 weeks) was intended to gather and formalize the ideas of the employees. We achieved some "challenge boards" that have to be completed in a fun way using post-it to promote ideas. During the challenge, idea cards and lunchtime workshops were planned to help employees towards the formulation of concrete ideas. In function of resources, participation and the context of the company this task can be done orally and/or by mail or through a computer system of management of ideas. The objective of this phase was to help and challenge the employees to precise their idea in the most extensive way possible so that it can be approved by decision-makers. The establishment of templates containing topics such as the objective of the idea, necessary resources, estimated gain etc. facilitated this interaction work (Figs. 3, 4).

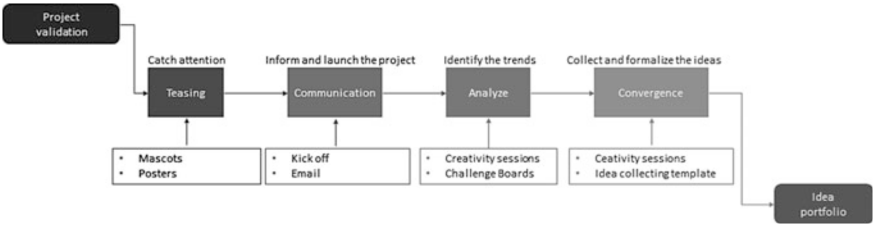

Fig. 3 Project progress of Innov'ensemble (a participatory innovation pilot project)

Fig. 4 Teasing poster and challenge boards deployed during the experiment

6 Results and Generalization

In terms of participation the assessment of this project remains mixed since, as we expected, only a small number of employees (approximately 11%) was actually involved in the project. At the end of the project 10 ideas were proposed by the employees and two were effectively implemented in the company. However, this project was also an opportunity to lay the first foundations for the participatory innovation in the company.

6.1 Global Process

The experimentation carried out around the project Innov'ensemble was the starting point for the formalization of a general process for the diffusion of innovation that can apply to many industrial cases. For our case study this process will enable the company to implement new challenges of participatory innovation and push its approach forward while relying on tools which have already been designed and tested. This process consists of seven main phases punctuated by deliverables. The first step consists in defining the strategy and the needs of the company in terms of innovation. Then, the project of participatory innovation is designed, formalized and validated by the stakeholders allowing its deployment within the company. At the end of the animation stage of the project, a portfolio of the employee's ideas is collected and formalized in details. These ideas are then submitted to the stakeholders who decide on their implementation. As a result, the selected ideas are highlighted and the participants rewarded. An implementation and monitoring plan of the selected projects is also written. Finally, a general assessment is carried out in order to learn the necessary lessons to the refinement of the company's strategy for the implementation of future projects (Fig. 5).

6.2 Continuous Improvement

A research work was also done to define what were the major improvements and developments to be considered in order to go on with the deployment of the experimental model formalized in Sect. 6.1. Inspired by the Deming wheel that presents a model of continuous improvement, the innovation wheel presents a set of actions to perform in a cyclical way (form of wheel) and progress at each iteration (symbol '+' in the center of the wheel). It therefore allows the company to consider future developments in its strategy of innovation in a gradual and incremental manner depending on the growing participation of employees (Fig. 6).

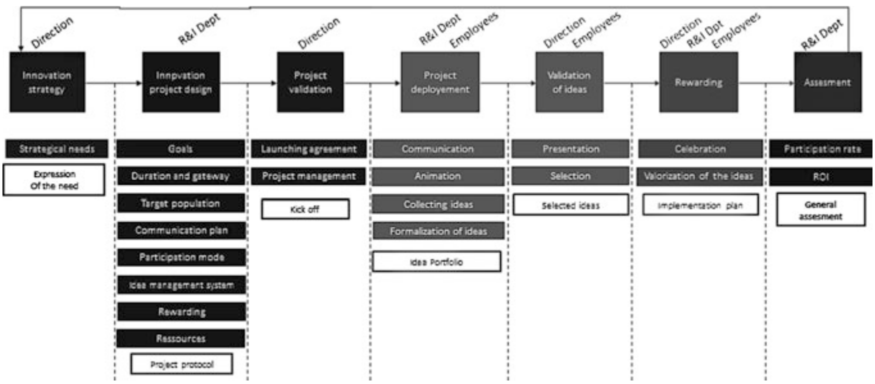

Fig. 5 Global process of design and animation of participatory innovation projects

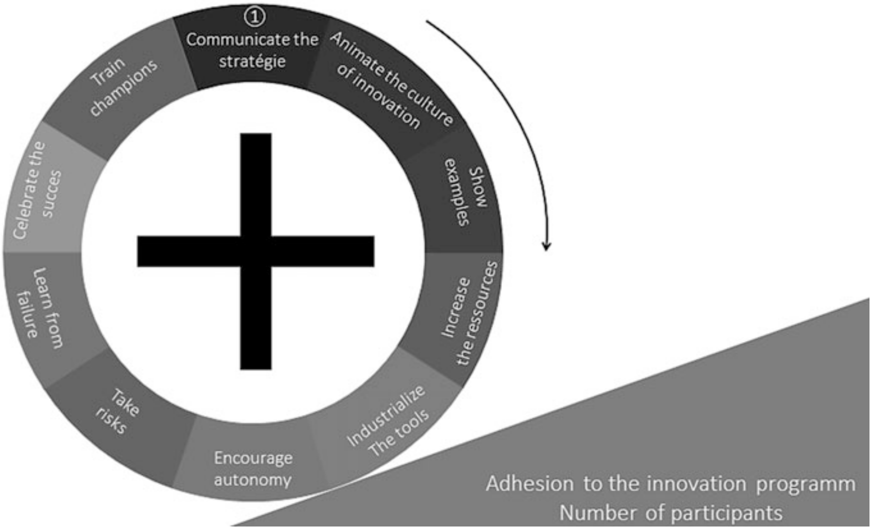

Fig. 6 Improvement of the global innovation strategy: the wheel of innovation

7 Conclusion

At the beginning of our study it was expected to build the foundations of a new strategy of innovation in directing a first experience of participatory innovation within a company. Our analysis on the subject raised evidence of many difficulties for the implementation of this approach in the company. The absence of theoretical model of participatory innovation in literature led us set up our own models and strategies taking into account other issues such as creativity or change management that were not present in the empirical application examples that we could list. That is why we chose to define a general strategy in order to integrate the culture of innovation in a progressive and global way within the company. Once this general strategy was formalized, we tested its deployment in a company by implementing a pilot project of participatory innovation for the first phase of our model: federate. We have reached the first objective of this project by providing a portfolio of ideas for the improvement of the company. Then we focused our effort on the generalization and extension of this first experience in order to provide the company with the elements required for the future deployment of our global strategy. We defined a process for the design and implementation of participatory innovation as an unprecedented contribution in the literature (to our knowledge and according to the state of the art made by Smith [14]). We also defined the axes of development and future missions of the research and innovation pole using the dissemination of knowledge related to creativity and change management. In combining and extrapolating the knowledge of our state of the art as well as our field experiments we therefore could define a unique model to integrate the culture of innovation in enterprises by mobilizing all of their actors so that they can use it as a lever in their performance. We must, however, specify that the duration of this project only allowed testing a small part of this experimental model. Other iterations of the participatory innovation project "Innov'ensemble" must be carried out to check if our model effectively increases the dissemination of the culture of innovation in the company. This can be measured by the rise in the number of participants, the number of ideas generated and implemented but also by the evolution of the budget and the importance of research and innovation center in the company.

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A Software Tool for the Graph-Based Visualization of Complex Relations Between Product Properties and Characteristics

Thomas Luft, Patricia Schuh and Sandro Wartzack

Abstract As products have to meet many different and contradictory requirements, product developers are facing major challenges. The fundamental prerequisite for developing successful products is to understand how desired product properties can be realized by setting appropriate product characteristics. The objective of this paper is to develop a software tool that supports product developers by visualizing the complex network of relations between properties and characteristics. This gives developers a better understanding of the many different relations in product models and can thus make more efficient and more targeted decisions.

Keywords Design management · Design evaluation · Decision making · Product visualization · Complexity management

1 Introduction

1.1 Problem Statement and Motivation

The main task of developers is to meet the ever increasing demands on quality, cost and functionality of technical products by setting the appropriate characteristics in order to realize the product properties desired by the customer. The properties of a product (e.g. stiffness, weight) cannot be determined directly. Instead, properties are the result of defining various characteristics (e.g. length, width, height). Characteristics are determined directly by developers. Therefore, they are the direct "setscrews" of product developers for determining the product's property profile. So, large and complex networks between characteristics (=causes) and resulting properties (=effects) quickly occur [1, 2].

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The desired requirements or product's properties, which have to be realized, relate to each other in different ways (e.g. complementary, conflictory, indifferent). Thereby, especially conflicting properties are a major challenge for product developers as they have to set product's characteristics that are hard or not compatible. Thus, product developers have to completely model, analyze and understand the complex relations (e.g. dependencies, interactions) between all elements of a product (e.g. properties, characteristics) as well as between themselves. Otherwise, they are not able to set the most appropriate characteristics in order to achieve the required properties of the product to be developed.

1.2 Objectives

The authors' overall objective is to develop a user-friendly software tool that represents the complex network of relations between product elements (in particular properties and characteristics) in a visually attractive, clear and compact way to product developers. This tool should contribute to a comprehensive understanding of existing dependencies between the desired properties of products and the characteristics, which have to be specified by product developers. This should enable developers to identify the required and appropriate characteristics purposefully in order to achieve the desired properties [3]. Furthermore, it should be possible with this visualization tool to identify conflicting properties and characteristics. As a consequence, it will be easier for developers to derive targeted action alternatives for the determination of the characteristics to realize the corresponding properties.

Therefore, we summarize the main fundamentals of the state of the art as well as some related approach in Sect. 2. In Sect. 3, we present the developed visualization concept as well as its implementation with Matlab. The practical application of the tool is shown in a use case in Sect. 4. Finally, we conclude with a short evaluation of the visualization tool, a conclusion and a short outlook.

2 State of the Art and Related Work

2.1 Matrix Based Product Model

The matrix based product model is basically a multi domain matrix (MDM) [1]. It is composed of a variety of design structure matrices (DSM) that describe relations between two elements of the same domain and domain mapping matrices (DMM) that describe relations between two elements of different domains [4, 5]. By using this matrix based product model, dependencies between REQ, the behaviors (B) of the product, the product's properties (P), the functional structure (FS) and the active structure (AS) as well as the characteristics (C) can be modeled systematically (see Fig. 1) during the product development process [1, 2, 6].

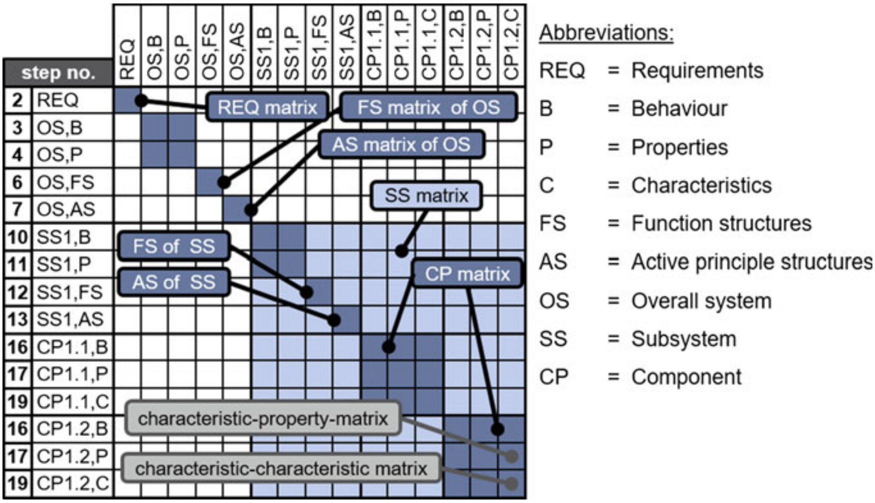

Fig. 1 Simplified and schematic overview of the matrix based product model [1]

For instance, developers have to create characteristic-property matrices for all components because properties can be realized only through the determination of characteristics [7, 8]. Subsequently, all required characteristics (e.g. radius, material) are defined for all components (e.g. wheel hub) in characteristic-characteristic matrices. Thereby, the effects of characteristic changes on product properties become visible and traceable as well as the numerous REQ are set into relation with the properties and characteristics of the product at the overall system (OS) level, subsystem (SS) level and component (CP) level (details are provided in e.g. [1–3, 7, 8]).

The modeling of the matrix based product model is clearly arranged because of the pairwise comparison and the standardized matrix structure. Thereby, the error rate is reduced and the model quality is increased. However, a quick interpretation of all information in the matrix based product model is very difficult for the developer (especially with many elements and relations) [7, 8]. For this reason, the matrix methods are increasingly supported by the closely related graph and network theory. Graphical visualizations of complex product models are often easier to understand by developers [4].

2.2 Selected Tools for the Visualization of Product Models

In graph theory, elements (e.g. properties, characteristics) are represented by nodes and linked by edges which describe their relations to each other. The transformation of a matrix in a graph can be performed with various algorithms that are implemented in different tools. Three of these tools are exemplarily explained. They were chosen by the authors because they have often been used within previous researches and thereby turned out to fit best to the matrix based product modelling and visualization.

The software Loomeo from Teseon GmbH is focused on structural complexity management and particularly used for the documentation, analysis and visualization of complex systems. Matrices can be transformed with Loomeo in force-directed graphs and other diagrams. Furthermore, all system elements and their relations can be represented and manipulated. Loomeo allows developers to create a MDM because it is based on the DSM terminology. In addition to setting up the matrix based product model, Loomeo can also be used to support the analysis and improvement of the product model. Therefore, not only algorithms but also different forms of graphical representations are suitable to identify and measure interactions between elements. These visualized structures or networks of the matrix based product model are much easier and more intuitive to interpret by developers. Therefore, these graphical visualization forms are more suitable to get a "picture" of the entire matrix based product model with all its relations.

Another tool is the Cambridge Advanced Modeller (CAM) from the Cambridge EDC. CAM is a configurable software platform and provides different functionality to visualize and manipulate matrices and representation forms (e.g. force-directed layouts) as well as various views for modeling, analyzing and visualizing models of complex systems [9]. CAM includes implementations of many modelling languages, simulation methods and further analytical tools proposed in the literature, for example, system dynamics stock-and-flow simulation, DSM manipulation algorithms (e.g. clustering, partitioning, banding), applied signposting modelling and discrete-event simulation, change prediction modelling. CAM-based tools are easy to customize or to extend because only knowledge of the modeling approach is required and not knowledge of programming code [9].

The third tool developed by Bauer is Balance3D for supporting multi-criteria decisions in the context of Design for X [10]. This tool visualizes interactively the relations between product properties and characteristics in the three-dimensional space. The application of visualization tool can be divided into three main phases: Preprocessing (preparing of the decision task), processing (visualization), post processing (interpretation of the visualization). The basic idea of Balance3D is to represent all relations of properties and characteristics in an easy and comprehensible manner. Therefore, desired properties are represented as balls in a three-dimensional space and their relations are represented by their distances. Conflicting properties have long distances and complementary properties are close to each other. The characteristics required for realizing the properties are represented by dimensions (i.e. as axes or lines). So, each dimension represents the interval of the values of a characteristic and this means that each end of a dimension stands for either the minimum or maximum value of the characteristic. Thus, the position of a property to a dimension indicates which value of the corresponding characteristic is necessary for realizing this property.

Apart from certain benefits, these three tools all have several disadvantages and therefore are not able to come along with the problems mentioned above (for a detailed assessment see [11]). Loomeo combines all elements and relations of one

MDM in a single graph which makes especially intra-domain relations difficult to identify. Furthermore, capturing conflicting elements is hardly possible. CAM has disadvantages regarding the analysis of indirect dependencies. Balance3D should be understood as a qualitative representation that only visualizes tendencies of the relations as, among others, the calculation of the visualization is based on an optimization. Thus, this three-dimensional view cannot show the relations in a very detailed and comprehensible manner [10].

3 A Concept for a Tool for the Visualization of Relations Between Characteristics and Properties

As a result of the three described tools' weaknesses, the authors developed a new tool which combines advantages of the existing tools with new ideas. Based on the structure of a MDM, the aim of the concept is to visualize all relations with different views—one according to each matrix field and to the whole matrix—to product developers:

- an overall view of all product properties and characteristics as well as their relations
- a partial view of the relations between characteristics
- a partial view of the relations between properties
- a partial view of the relations between characteristics and properties

This allows the product developer to select an appropriate view depending on the specific purpose. Moreover, the developer is able to get a comprehensive overview of the varied networks between properties (P) and characteristics (C) by using several views and graphical representations simultaneously [8].

3.1 Overall View of All Relations

The first visualization view is an overview of the dependencies between characteristics and properties as well as between only characteristics or properties. This view gives product developers a first general understanding of the complex relation network of the product elements. In the overall view, conflicting properties are positioned far away from each other (e.g. P1 and P3 depicted as circles in Fig. 2). In contrast, complementary properties are close to each other (e.g. P2 and P5). Subsequently, the "characteristic intervals" (e.g. C1 depicted as green line in Fig. 2) are arranged in such a way that the respective maximum/minimum value is close to the properties which are fulfilled by it. For instance, in Fig. 2 P1, P4 and P6 are achieved by setting the maximum value of characteristic 1 (C1), whereas P3 and P7 are realized by its minimum value. The position of one characteristic interval to

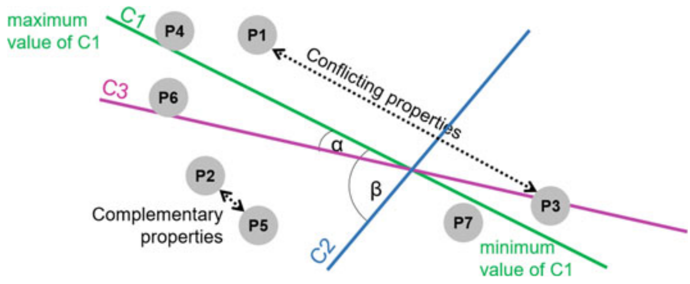

Fig. 2 Overall view of all product properties and characteristics as well as their relations

another provides information about the dependency of these characteristics. Interval lines with a very sharp angle (α) represent dependent characteristics (e.g. C1 and C3). An angle of 90 (β) between two interval lines indicates independent characteristics (e.g. C1 and C2).

This view represents all existing relations of product properties and corresponding characteristics. Since all of these product elements are visualized just in one view, it is not possible to align every circle and line very precisely. Consequently, this view is only an approximation, which provides a good overview.

3.2 *Partial View of the Relations Between Characteristics or Properties*

Graph theory has a high potential for analyzing and visualizing of ratios between characteristics and properties. Thereby, the characteristics (depicted as blue rectangles) and properties (depicted as grey circles) are represented as nodes and the relations between them as edges. Weighted and directed graph representations are particularly relevant for the visualization of the interactions between characteristics or between properties. The graph of the dependencies between characteristics in Fig. 3 (left) shows that this layout allows to identify immediately clusters of strongly interconnected (C3, C4, C6) as well as weakly or non-interconnected (C1, C2, C5) characteristics. The direction of each dependency is represented by the arrow direction of the edge (e.g. in Fig. 3 C3 influences C4 and C6, only C6 also influences C3).

The visualization of relations between properties (Fig. 3, right) is similar to the partial view of dependencies between characteristics. By using edges, dependent (e.g. P1 and P2) and indifferent (e.g. P1 and P3) properties are clearly identifiable—in contrast to the overall view (Sect. 3.1). The color of an edge provides information about the type of relation (conflicting, complementary). Conflicts between properties are represented by a red-colored edge (e.g. P1 and P2). Complementary

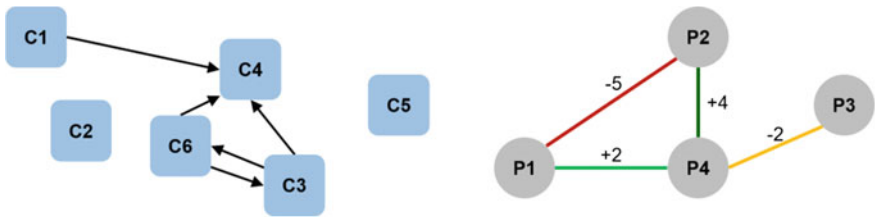

Fig. 3 Partial view of the relations between characteristics or properties

properties (P2 and P4) are linked by a green-colored one. It is also possible to express the strength of the relation numerically (e.g. on a scale from −5 to +5) by using different color nuances and edge labels. For instance, P1 and P3 are very conflicting properties that cannot realized at the same time (dark red edge, label "−5"). Instead, the interaction between P2 and P4 is very positive (dark green edge, label "+4"), which means that an improvement of the property value of P2 also leads to an improvement of the property value of P4.

3.3 Partial View of the Relations Between Characteristics and Properties

The relations between characteristics and properties are shown in an additional partial view (Fig. 4, left). For instance, the edge between C1 and P1 (dark red line, label "−5") represents a strong negative relation. This means that with an increase of the characteristic C1 (in direction of maximum value) the property P1 strongly decreases (in direction of minimum value). In contrast, P3 is strongly positive dependent on C1 (green line, label "+4") and so the maximum value of P3 can be realized with the maximum value of C1.

Figure 4 (right) shows another possible option for the representation of dependencies between characteristics and properties. As intra-domain dependencies are neglected in this partial view, the graph can be interpreted as a bipartite graph.

Fig. 4 Partial view of the relations between characteristics and properties

By splitting all characteristics and properties on two different sides, the developer can easily recognize which characteristics influence which properties or vice versa.

4 Practical Application of the Visualization Tool

4.1 Description of the Tool and Input

The development of a computer-aided tool is crucial for the practical application of the visualization concept. The concept was implemented with Matlab.

Input for the tool is a MDM of characteristics and properties created in Excel (see Fig. 5). Thereby, it is possible to fill out all three single matrices (i.e. DSM of characteristics, DSM of properties, DMM of characteristics and properties) or to let the DSM of properties empty. This DSM will be calculated automatically by the tool. After importing, the user can, if required, display and modify the MDM.

Then, the user has different visualization options (see Sect. 3).

4.2 Practical Application of the Tool in Use Cases

The applicability and usefulness of the tool is shown by a practical (simplified) case study. Thereby, concrete questions of product developers are answered with the help of the tool by using the example of a wheel hub. As part of the development of a wheel hub, different properties have to be realized. So, developers have to

	Simplified MDM of a wheel hub (Read direction)	Characteristics					Properties					
		C1	C2	C3	C4	C5	P1	P2	P3	P4	P5	P6
Characteristics	C1 Inner diameter of the hub		X				**2**	**-2**	**-3**	**0**	**-2**	**-2**
	C2 Outer diameter of the shaft connection	X					**-4**	**4**	**5**	**0**	**5**	**5**
	C3 Length of the hub						**-1**	**1**	**1**	**1**	**0**	**0**
	C4 Bolt circle diameter					X	**1**	**-1**	**0**	**-1**	**0**	**0**
	C5 Outer diameter of the hub	X			X		**-1**	**1**	**0**	**1**	**0**	**0**
Properties	P1 Low total weight						0	-4	-4	-2	-4	-4
	P2 High total volume						-4	0	4	2	4	4
	P3 High volume of the hub						-4	4	0	1	5	5
	P4 High volume of the wheel rim						-2	2	1	0	0	0
	P5 High moment of inertia of the hub body						-4	4	5	0	0	5
	P6 High bending stiffness of the hub body						-4	4	5	0	5	0

Fig. 5 Simplified MDM of a wheel hub

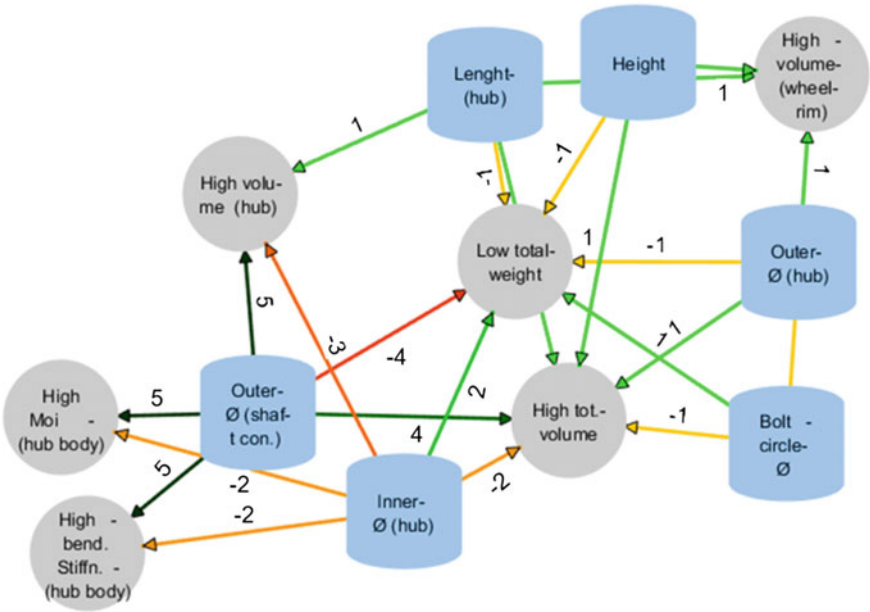

Fig. 6 Force-directed graph of relations between characteristics and properties of the hub

determine or modify appropriate characteristics. Thereby, the subsequent two questions arise. Both are answered with the tool effectively and efficiently.

Question 1: *Which characteristics are necessary to realize the properties?*

This question can be answered by selecting the partial view of characteristics and properties (cf. Sect. 3.3). Figure 6 visualizes the force-directed graph of relations between characteristics (blue rectangles) and properties (gray circles).

This detailed view shows all existing relations between characteristics and properties. Due to the color and the numerical value of the relations (edges), the developer recognizes the direction and the strength of all dependencies. For instance, the characteristic *outer diameter of the shaft connection* has a higher positive influence on the property *high bending stiffness of the hub body* (+5) than on the property *high total volume* (+4). In contrast, this characteristic has a negative relation (−4) to the property l*ow total weight* (see Fig. 6).

By this visualization, the developer can intuitively recognize conflicts between the determination of characteristics and properties. For instance, in setting the characteristic *outer diameter of the shaft connection* a conflict arises between the realization of the property *high bending stiffness of the hub body* (+5) and the property *low total weight* (−4). The reason for this is that these two properties are depended on the characteristic *outer diameter of the shaft connection* with a different direction of influence.

These conflicts have to be considered more precisely. Therefore, the tool offers two further options. The first option is that the user can choose the partial view of

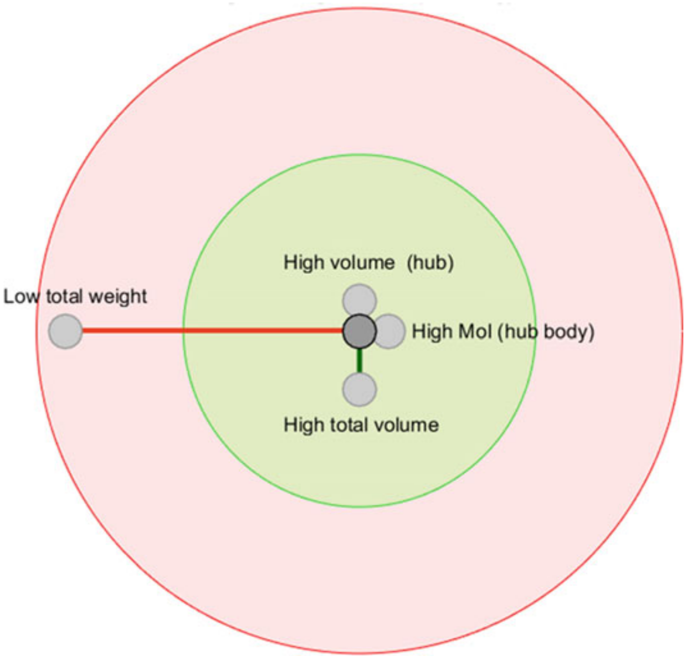

Fig. 7 Dependencies of a high bending stiffness of the hub body to other properties

dependencies between properties (cf. Sect. 3.2) for considering all properties and their relations. The second option is to use a selection function and analyze the relations of one or more selected properties. This is useful if, for example, the product developer wants to increase the *bending stiffness of the hub body* but does not know which other properties will be negatively influenced by this property. By using the tool´s selection functionality, the user can select this property and the following graph is visualized (see Fig. 7). Using this visualization, the following question can be answered:

Question 2: *Which of the other properties are in conflict with a high bending stiffness and how strong are these conflicts?*

In this visualization, the property of interest (e.g. *high bending stiffness of the hub body*) is in the center (represented by a dark gray circle). All other properties are arranged circularly around this property (if they dependent on it). Thereby, the following principle applies: The stronger the realization of a desired property (e.g. *low total weight*) is in the conflict to the property in the center, the greater is the distance from the center. Consequently, these two properties have a large distance and are connected by a red edge. Furthermore, the conflicting property is in the red, circular ring. This means, that by increasing the bending stiffness of the wheel hub, the product developer has to expect an unintended higher weight. All the other desired properties (e.g. *high volume of the hub*) are located in the green circle, have a short distance to the property *high bending stiffness of the hub body* in the middle and are connected by green edges. Thus, there are complementary relations to these properties. So, they can be fulfilled more or less at the same time. The property *high volume of the wheel rim* does not appear in this view. Consequently, there is an indifferent relation between this property and the property *high bending stiffness of the hub body*, so they can be reached independently of each other.

5 Findings, Conclusion and Outlook

The user only needs to import the matrix based product model (e.g. an Excel file). Thereafter, the developer has a variety of visualization options for different needs and purposes. With the help of the first view of dependencies between characteristics, possible restrictions regarding the determination of the respective characteristic values are pointed out. The second partial view visualizes only relations between the product′s properties whereby the conflicting objectives between desired properties become apparent. The consideration of the relations between characteristics, which have to be defined, and the properties, which have to be realized, is very important during the product development. These relations are visualized in the third partial view of the dependencies between properties and characteristics. By this view, developers get useful and essential information regarding the characteristics which are necessary to achieve the desired property profile of the product.

The developed software tool proves to be useful in tackling problems described in Sect. 1. The different visualization views support developers in the definition and modification of characteristics to realize the desired properties and in taking targeted decisions. In the future, further investigations and evaluations for ensuring the practicality of the tool are useful and therefore planned within product developments use cases at the chair as well as with industrial partners (compare [3, 6, 12]).

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Challenges and Some Potential Strategies for Relating Engineering Issues with Their Causes in Text

N. Madhusudanan, Amaresh Chakrabarti and B. Gurumoorthy

Abstract This work is targeted towards achieving knowledge reuse by acquiring diagnostic knowledge about assembly from documents, and feeding it back for subsequent use in the design/assembly planning stage. Towards this objective, this paper looks at some challenges that have been identified in finding in text causal relations between issues and their causes. The analysis is carried out from the perspective of using the logical form of the text, which provides a computer-based representation of natural language text. By analyzing examples, a set of generalizations are made about the structure of possible classes into which text expressing both issues and causes may be classified. Then we show a simple example for which identifying the cause and effect is possible. However, we also show that it gets more difficult for more complex cases. Hence a method based on pattern matching in text is proposed and explained with further examples. Future directions are then discussed.

Keywords Causality · Natural language understanding · Assembly

1 Introduction

Knowledge is an important entity in current organizations. It is important to retain knowledge that is produced within an organization, and reuse it wherever possible. As part of one such effort, we attempt to automatically acquire documented knowledge in an organization so as to reuse this acquired knowledge from documents

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to minimize issues. The source of knowledge are documents about problems in the assembly stage of manufacturing. The application of this acquired knowledge would be in the design/planning stages of the assembly process. As an application domain, the field of aircraft assembly has been chosen.

1.1 Issues and Their Causes

As mentioned before, the objective of the research reported in this paper is to reuse knowledge about issues that have arisen in a later part of a product's lifecycle (e.g. during actual assembly of a product) to predict similar issues in an earlier part of the product's lifecycle (e.g. during design of the product or its manufacturing so as to prevent such issues). The method proposed for acquiring knowledge about issues is shown in Fig. 1. In the figure, the block shown with a dotted rectangle is the work reported in this paper. Relevant portions of documents are first segregated, which are then scanned for content about issues. This knowledge about issue is then expanded to its causes and the related parameters behind the causes. The causes and parameters are important from the perspective of applying the knowledge so acquired. The acquired knowledge is structured using the causes, effects and parameters, and represented as rules of a knowledge base. The rules are fed back to assembly planning stage where they would be evaluated. This amounts to reusing the previously acquired knowledge from documents. During this stage (knowledge application), the current state of the world is evaluated using the parameters, and whether the causes of an issue are triggered. If so, potential occurrence of the issue can be predicted. This is why the causes related to issues are such crucial links in the stages of knowledge acquisition and representation.

1.2 Logical Form of Text

Since the overall objective is to identify issues, their causes, and solutions, it is necessary to understand the content of documents. This means the entities involved, the relationships between them, and the events related to them need to be known. Discourse Representation Theory (DRT) [1] has already been identified as a suitable means for such an understanding [2]. Due to availability of Open tools that

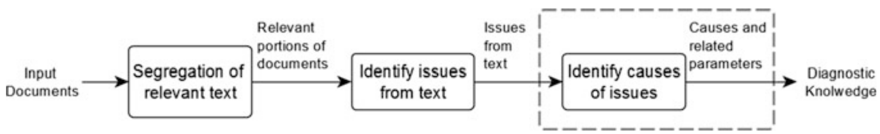

Fig. 1 Overview of the research procedure—the current focus is shown in the dotted box

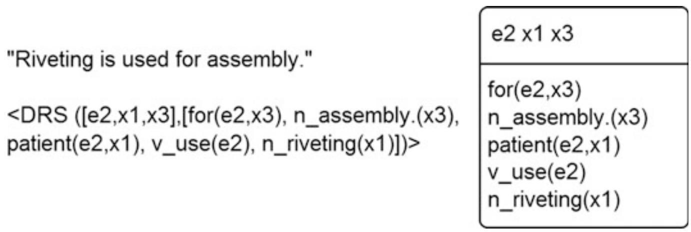

Fig. 2 An example of the DRS form of text, both in text and graphical forms

help discourse understanding with reasonable accuracy [3], DRT is seen as a practical solution.

The process of acquisition of issues and their causes, therefore, has to be compatible with the logical form being used, which currently is the DRS (Discourse representation structure) form of representation. An example of this representation obtained using the DRS interpretation module NLTK Boxer is shown in Fig. 2. In this example, the entities involved are shown at the top of the boxed representation, while conditions that connect them are shown in the lower part of the box.

As mentioned before, as after acquiring issues from a given text, the causes of these issues have to be identified. However, it is not necessary to capture all possible causalities to model the domain. For example, '*The bucking of rivet head causes the plates to be held in place*' is not of direct interest here. We focus only on the causalities related to issues in the immediate neighborhood of the text about issues being considered, for example, '*The tool could not be started, because of a voltage drop*'. When this tool is to be used for an assembly, monitoring of the voltage while the tool is in use would be recommended by a rule in the knowledge base. A method for detecting portions of text that are about issues has already been implemented, and readers are referred to [4] for more details.

2 Methods in Literature

Literature on analyzing cause and effects exists, and various attempts are reported to determine causality, both in text and non-text sources.

To determine causality in systems, methods like Root Cause Analysis and Fault Tree Analysis could be used [5, 6]. These are, however, manual methods that have to be performed based on available data. There are also representations of cause-effect structures, such as the Ishikawa diagram.

Regarding the methods to identify causality in text, Kaplan and Berry-Rogghe [7] developed the TAKT system to derive causal relations by using knowledge of text propositions and performing semantic analyses. The system was able to derive constraints from the text and identify all causal relations. However, the system needs a proposition set for the English sentences to be built and used. Instead, we use the logical form produced by DRS. Girju [8] built a system to detect causality patterns in two steps. In the first step, it identified lexico-syntactic patterns of causation, by looking at causal relations between WordNet glosses (definitions provided with WordNet entries). These patterns are then used to construct a training set so that the patterns can be learnt. Building a training set, is again, not a practical consideration in this work, given the small amount of test data available in our domain. Also, it considered only single sentences. Garcia [9] developed the COATIS system to relate causality of actions in French text, but our work needs to look beyond actions—to more complex events. Perrin et al. [10] constructed causal networks for dynamics of global events by first extracting patterns of words, then sentences and then visualizing the network. It relies on searching through a very large corpus of information, such as the Web, and our domain of application is unlikely to have a comparable corpus. Blanco et al. [11] use a supervised method using patterns in text, which also requires training and test data sets. Pragmatic analysis has also been used to analyse communication such as email to extract knowledge [12], in this case, about requests during design projects. It requires prior knowledge in the domain such as roles and skills of participants of the email threads.

We see that due to the current requirements (identification of causes of issues only) and information constraints (lack of large amounts of data), these methods are not useful in our case. However, they do share some common elements with the work discussed here, and these are indicated in later sections.

3 Causes of Issues—An Observational Study

To understand the various possibilities of describing issues and their causes, a number of text examples were examined from both real-life and synthesised examples. We are only interested in examining a causal chain of text, without considering ways to determine if the text describes issues or not, as pointed in Sect. 1.

The first step is to identify possible ways in which such a causal explanation may be expressed in text. This analysis was done from the perspective of identifying elements of the cause-effect relations from text. After obtaining the DRS interpretations of text fragments that expressed causes and effects, these were analysed for connections among the logical conditions in the DRS. The text fragments were also independently analysed for patterns of descriptions of causes and effects in text. Based on this analysis, we propose that, for arriving at a classification of such possibilities, the dimensions to be considered are the following:

1. Span of the description: (Also mentioned in [10])

- Within a single sentence (ssnt)
- Across multiple sentences (msnt)

2. Nature of causal description in text (Also mentioned by [8])

- Explicit cue phrases (exp)
- Implicit indication using sentences in proximity (imp)

3. Physical positioning of the cause with respect to the described effect (issue)

- The *cause* is described first, leading up to the *issue* (ce)
- The effect (*issue*) is described first, followed by an explanation of the *cause* (ec)
- A combination of both of the above (cec)

The third dimension was necessary, since there were marked differences in the DRS structures depending on how the same cause-effect text was written—an example is shown in Fig. 3. Also, as an alternative, the text patterns expressing the cause-effect relation differs based on the physical positioning.

Based on the above dimensions, we propose a classification scheme for issue-cause descriptions are found in text. These classes are formed by combinations of the above dimensions. Hence, there could be *ssnt-exp-ce, ssnt-exp-ec, msnt-exp-ce, msnt-exp-ec*, and so on. Some examples are:

- 'The riveting gun does not work *since* the voltage is less than 240 Volts.' This example can be classified as a case of *ssnt-exp-ec* because it is a single sentence where there is an explicit word ('since') connecting the cause, which is preceded by the effect here.
- 'The applied force on the rivet head was less than the required force. *Hence* the riveting was not completed.' This is a case of *msnt-exp-ce*, as it spans more than one sentence, and uses an explicit indication '*hence*' to connect the cause, which comes first with the effect.
- 'There was a shortage of fasteners in toolkit. The assembly could not be completed'. This is a case of *msnt-imp-ce*, as there is no explicit word to say that these sentences follow each other logically, but is rather inferred from reading them together, in sequence.

In this work, we discuss only explicit, cue-phrase cases, since implicit cases require more sophisticated approaches like use of background knowledge, detection of proximal sentences, and possibly, the role of pragmatics.

4 Example Strategies to Identify Causality

In Sect. 3, we described classifications based on differences in both written and DRS forms of text. The rationale behind this classification was to group similar patterns indicating causality. In this section, we discuss possible strategies for some of the feasible classes. As mentioned before, we do not consider the implicit cases, since these involve a deeper understanding of the use of background knowledge, making analysis more complicated. Explicit cue phrase patterns, as well as single

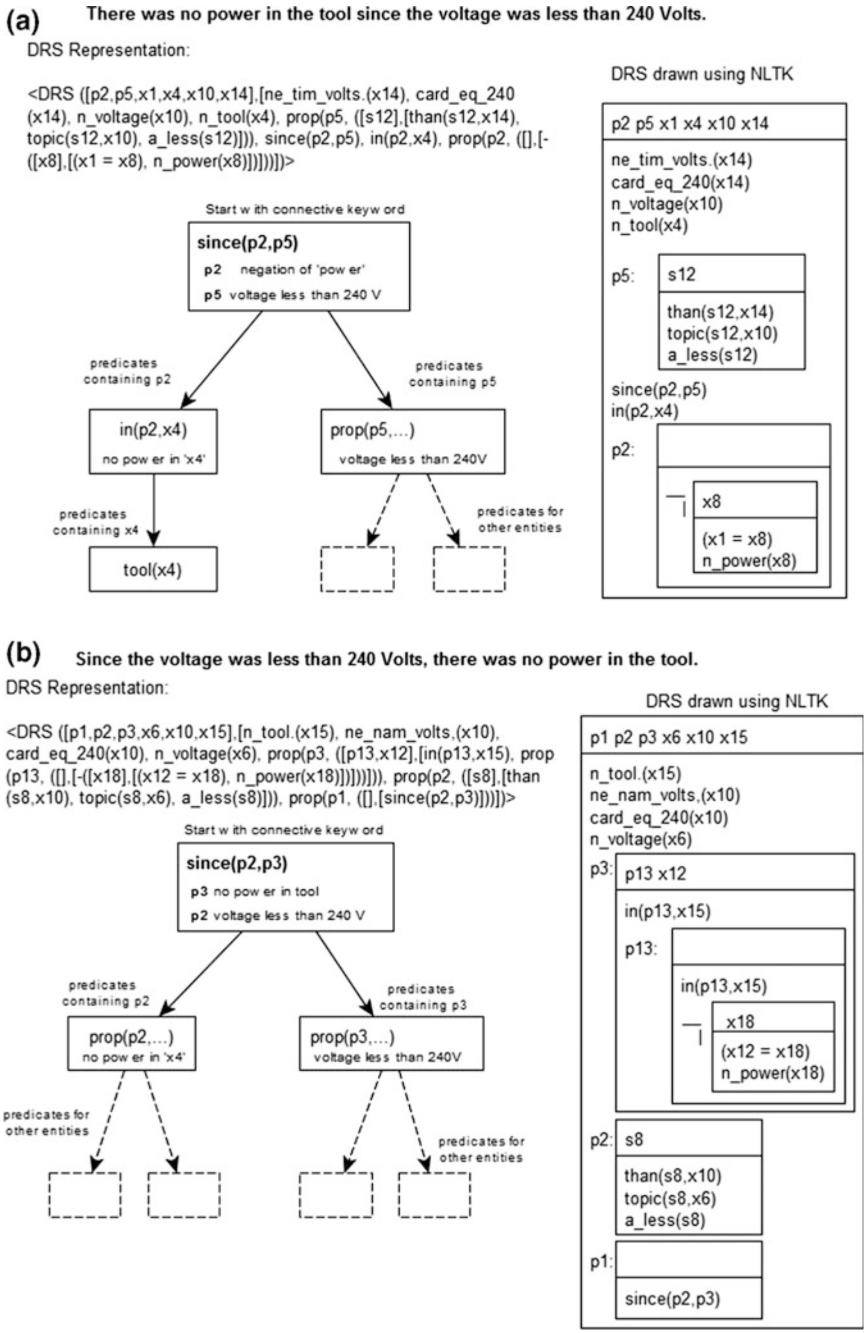

Fig. 3 **a, b** Examples of similar sentences but with a change in the order of cause-effect

sentence cases (and their combinations) are the most trivial. We now list out possible strategies that were tried for the complex cases—the multi-sentence explicit cue word cases:

- Infer causality directly from DRS form: Here we checked whether implication, or causation could be directly obtained from the DRS form. However, no examples gave this directly, except in the most trivial cases. Consider the patterns shown in Fig. 3. A strategy to derive causal information from the DRS form is described, along with the DRS. The keyword for causality ('*hence*') is the starting point of a search process. The variables used in the predicate for this word are iteratively searched for, in the DRS form. Since this is a trivial case, there are only two direct propositions that are the cause and the effect respectively. There does not seem to be a difference even when the order of cause and effect is changed, as demonstrated in Fig. 3b. However, when we extend this to more complex cases, the procedure does not hold good anymore.
- Start with keywords that indicate causal effect and search through conditions: Consider the multi-sentence examples shown in Fig. 4a. The goal was to track the chain of predicates indicating thematic roles such as *agent* and *theme*, all the way till the proposition (prop (p5,…)) is reached. Thematic roles are semantic predicates describing the part played by various words in text e.g. *patient* indicates something on which an action is performed. Other examples are *topic*, *agent*, *theme*, etc. We attempted to use these roles to identify what action is being described, what the causing agent is, and what is affected. Even in these two sentences, it is not immediately clear whether the cause (prop (p5,…)) can be automatically identified as the cause, since various other predicates precede it (Unlike Fig. 3 where causes were immediately below the keyword predicate). Also, it is not verified if this can be generalized, and when to stop the search.
- Execute parallel search for keyword and topic, leading to thematic roles (Fig. 4b): We performed a parallel search of the issue keyword, in conjunction with the topic role (the parallel search is because these two searches did not meet at a common variable). Once again there was no identifiable pattern for cause and effect.

4.1 Patterns in Text

The inability to consistently detect issue-cause patterns using the logical form was discussed in the previous subsection. A workaround to this is now discussed.

It was mentioned previously that this work aims to identify issues and their causes, and that recognition of negative sentiment has been identified as the means to recognize issues. Based on this, we propose a set of patterns for four explicit classes of issue-patterns, as mentioned in Sect. 3. The patterns are based on the use of cue words/phrases (similar to causal verbs mentioned in [8]) in combination with the sentiment value of the surrounding text. We explain this for each class in Fig. 5.

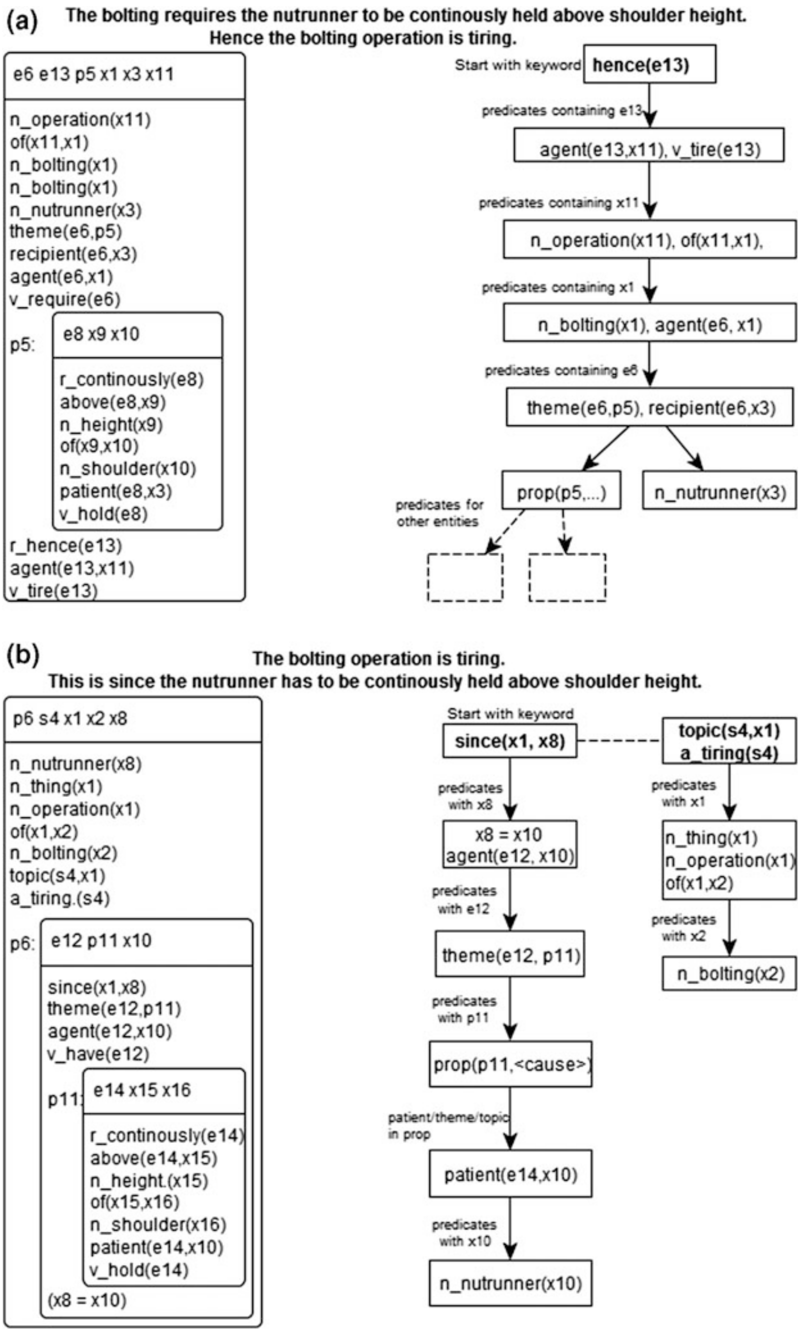

Fig. 4 **a, b** Examples of multiple sentence cases, where there is no clear strategy to follow

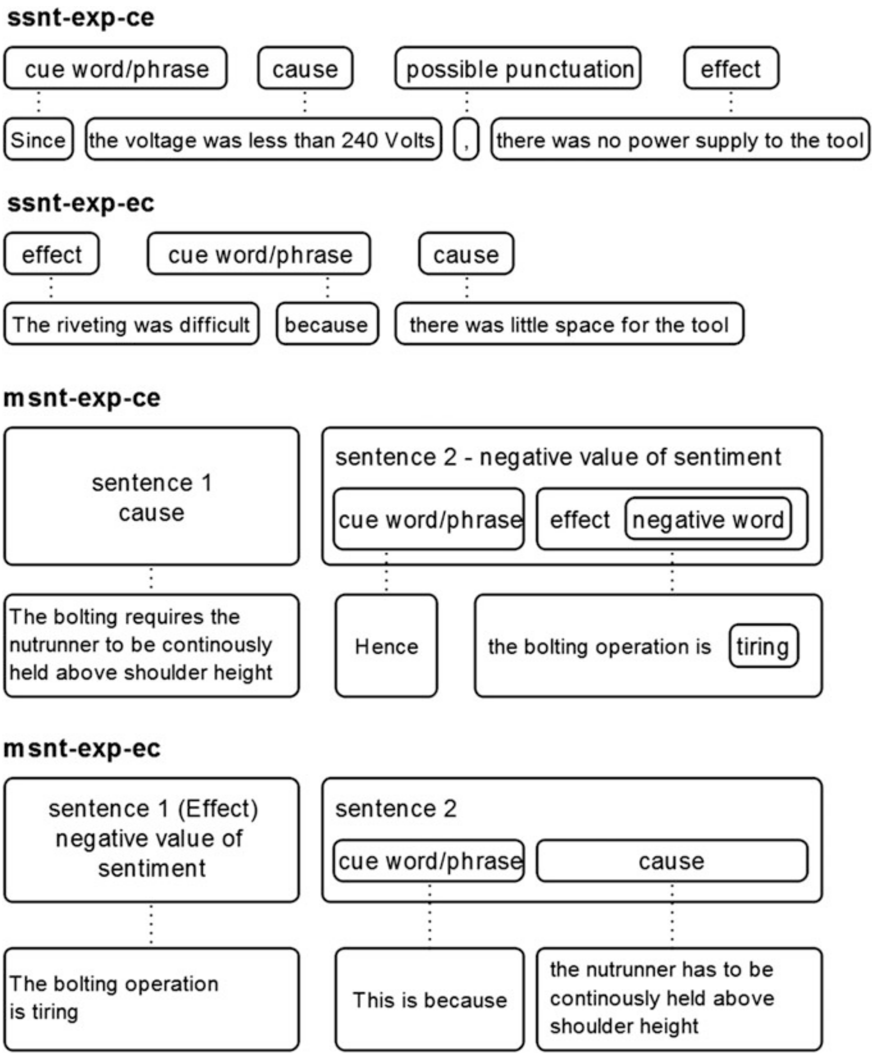

Fig. 5 Strategies to extract text patterns to identify cause-effect relations for issues

The patterns are meant to identify both the class (e.g. *msnt-exp-ce, msnt-exp-ec*) as well as the components of issue-cause descriptions from text.

A combination of patterns of text, such as cue words and sentiment orientation, is used to identify the boundaries between cause and issue. In the final implementation, the intention is to use regular expressions, which is a powerful means to recognize patterns in texts with which to carry out pattern matching.

5 Conclusions and Future Work

We have presented a study of the variety of expressions of cause-issue relations in texts, and proposed a broad classification scheme. The classification is based currently on three factors—namely the span of the cause-effect description, whether or not cue words are used, and the order in which the cause and the effect are discussed. We hope that the classification might provide guidelines to structure the logical form and extract meaningful patterns, such that intended knowledge acquisition can occur. The approach to find a pattern of cause and effect using logical forms has been found to be useful only in trivial cases. In attempting to extend this pattern, the difficulty faced in non-trivial cases highlighted that the logical form cannot be used for this purpose. Hence another strategy, which looks at text patterns in combination with the sentiment orientation of text, is proposed. Implementation and validation of this approach is reserved for future work.

The immediate challenge faced when these sentences are part of a larger text, is to decide where to start. This might require the use of a window of sentences, and probably the use of anaphoric (back-references to words) links.

The classification scheme might grow, as we have not established that the above approaches together are exhaustive. However, we do not expect it to drastically change from the current scheme. As for the strategies, the next step is to implement the strategies that we have proposed as a computer program and validate its usefulness. The strategies have been currently proposed only for four classes that have explicit cue words. Such an implementation would also involve building sets of cue words, as shown in the examples. Once these are done, the plan is to create a computational implementation for causal link detection. The other part of future work would be to concentrate on paragraph level, rather than only between two adjacent sentences. It is also useful to see if anaphora can be used as an indicator of causal links. Beyond this, a long-term goal is also to look at methods that can cover the cases where implicit cause-effect can be inferred. Another potential scope for extending this work is to include emails for analysis, by using appropriate modeling of email exchanges, and tracing the causes and solutions for problems under discussion.

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Unlocking Design Teams' Experimentation and Go-No-Go Decision-Making: Case Study on Bangle Packaging Design Project

Gajanan Pratap Kulkarni and Mary Mathew

Abstract The experimentation helps in getting preliminary answers to inquiries that allows learning to happen in knowledge pursuit. Product centric organizations follow systematic as well as disorganized experimentation process for innovative product development. It is crucial activity for R&D value creation. Thus, cleverly conducting experiments and strategically looking into designers' experimentation phenomenon can prove boon for designers. An effective experimentation driving strategy can help in many ways to unlock the potential of experimentation. The specific objectives of this paper are, (1) to descriptively understand, capture, and report designers' experimentation phenomenon happening in realistic design environment; (2) to figure out decision-making constituents from experimentation process that leads to Go-No-Go decision making. The database collected from bangle packaging design project is systematically coded and analyzed to develop Combined IP-SR-GP theoretical model. The developed model is validated for its application by doing post facto analysis of packaging design cases. This paper will theoretically contribute towards advancement of designers' experimental design thinking and look into decision-making constituents.

Keywords New product development · Experimentation · Go-No-Go decision-making · Inquiry propagation · Search representation of a problem · Gestalt school of psychology

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1 Introduction

Experimentation is regarded as one of the ways of problem solving leading to innovation and handling design project as an experiment is possible [14]. Awareness, usage, and knowledge of experimental design techniques (EDT) is poor among designers [15]. Designers face difficulties while using EDT in practice because of its stringent nature [4].

The strategic role of experimentation during NPD has fewer discussions in literature. Scientific methods of experimental design were used to solve a problem in design engineering and design education field [8]. According to Rylander [12] designers have imported methods for conducting experiments from other disciplines and they have rarely reflected on their underpinning mindsets for bringing original experimental approaches. The design field should stay away from borrowing research in experimentation from art and science field without neglecting these fields [6].

Fewer descriptive qualitative NPD case studies on experimentation are reported in current literature. Most of the times designers' experimentation phenomenon is studied through a prescriptive method like statistical experimental design techniques (EDT). This limits understanding of designers' real-time and rich experimentation process happening during NPD. The explanation on experimental questions lacks in literature. These questions can be; what kind of inquiries leads to experimentation? How do experiments happen in realistic design environment? When it ends or should end? What is the outcome of experimentation process? What experimental results lead to decision-making? And what patterns of experiments? Taking this as trigger, the two exploratory and open-ended questions are addressed in this paper,

(1) How to understand, capture, and report designers' experimentation phenomenon?
(2) What constitutes from this phenomenon leads to Go-No-Go decision making?

2 Research Methodology

The following steps are carried out to undertake research objectives,

Step 1: Engagement in packaging design project environment for data collection

Step 2: *Semi Structured Qualitative Studies (SSQS) and PRETAR tool*: The case study is positioned under SSQS category, as the data collection has happened in semi-structured manner. PRETAR tool proposed by Blandford et al. [1, 2] is used to systematically design, conduct, and report SSQS.

Step 3: *Grounded Theory (GT)*: GT, a qualitative research methodology is used to make sense out of SSQS and to develop theoretical model.

Step 4: *Theoretical model development*: As understanding about central themes progressed, three approaches were rationally integrated to develop theoretical model.

Step 5: *Theoretical model validation and evaluation*: The theoretical model is validated for its application through post-facto analysis of packaging design cases.

3 Packaging Design Project Description

Bangle packaging design project was an evaluation component for graduate level three-credit course titled '*Product Design*' conducted at Centre for Product Design and Manufacturing (CPDM), Indian Institute of Science, Bangalore (IISc). At the beginning of project, the instructor briefly explained packaging design problem to the design class and divided sixteen student designers into four teams.

The four teams (4 designers in each team) generated novel packaging ideas, came up with interesting concepts, explored creative packaging forms, experienced experimentation, made Go-No-Go decisions, and used their skills to make final packaging products. Table 1 shows problem brief [P1].

4 Theoretical Framework

The construction of a good theory as an outcome happens only when a set of steps are carefully executed and theory gets verified [3]. Glaser and Strauss [7] have proposed Grounded theory (GT) which is a qualitative research methodology. In this paper, Charmaz's [5] GT version is adopted as it gives emphasis on constructivists' qualitative research tradition. GT steps are systematically followed and applied to collected data. The stepwise application of GT strategies with data analysis results are shown in Table 2.

Table 1 Packaging design problem brief

P1	**Project objective**: Design and develop packaging for holding 12 glass bangles **Description**: Packaging must hold 12 glass bangles. Teams must use paper of thickness 100–200 GSM. Packaging must sustain to drop height of 1.5–2 m. Packaging should be easy to use (open and close). It should be aesthetically pleasing. Teams should disclose what they have used in making this packaging (other material like glue, thread etc.) Teams should mention the cost of prototype and consider mass manufacturing aspect. Dimensions of glass bangles were common for all teams **Evaluation**: Peer review by course instructor and customer review was done by ladies in CPDM department and through voting **Project duration**: 3 week

Table 2 Application of GT to packaging design project

Data collection	*Textual data:* semi-structured interviews, questionnaire, field notes, observational notes, designers' diaries, memos, annotations, insights *Non-textual data:* Audio recordings of interviews, photographs, sketches, quick and dirty mockups, and final packaging prototypes
Data coding	The four data coding phases followed were, • *Familiarize with the data* • *Generating initial codes:* Anchors (key elements) were identified. The identified anchors were—*Inquiries, States, Searches, Actions, Patterns* • *Labeling of core variables:* The five anchors present in the data were playing the role of core variables or tentative core variables • *Selective coding:* The textual data was selectively coded
Conceptualization	• The coded data was marked into key phrases such as—*types of inquiries, development states, types of searches, actions, and patterns* • The identified central concepts were - *flow of inquiries, state spaces, search spaces, action spaces, and patterns of psychology* • After identification of key concepts, theoretical memoing of the concepts were carried out. This was related to figuring out theoretical relationships in between key concepts that aroused from main data content
Data categories	The data categorization was carried out with two intents—creating analytic notes and grouping of similar ideas, concepts, and key elements. The data was categorized into *family of inquiries, family of states, family of searches, family of actions and making of patterns*
Conceptual categories	We have come across three independent, prospective, and unique approaches from literature, *Inquiry propagation* [IP], *Search representation of a problem* [SR], and *Gestalt school of psychology* [GP]
Construct theory	Integration, refinement of conceptual categories into *Combined IP-SR-GP Theoretical Model*

5 Combined IP-SR-GP Theoretical Model

In this section, the three approaches and development of Combined IP-SR-GP Theoretical Model is explained in detail.

5.1 Inquiry Propagation [IP]

The principle of inquiry propagation has been proposed by German philosopher Immanuel Kant (1724–1804). The principle states, "*Every answer given on principle of experience begets a fresh question, which likewise requires its answer.*" An inquiry gives birth to unanswered new inquiries i.e. answers evokes new questions

[11]. '*Inquiry propagation*' approach has been adopted in the designers' context after observing and documenting the flow of inquiries during the packaging design project.

5.2 Search Representation of a Problem [SR]

Newell and Simon [10] have proposed '*search representation of a problem*' approach. This approach talks about internal representation of a problem solver as 'state-space search' process in problem solving environment. The structure of task environment can be expressed in terms of state language and process language. The researchers have adopted SR approach (Fig. 1) and used it in designers' context as their internal representation of design problem. In this representation, the problem comprises of—state spaces, search spaces, and action spaces.

[IS]: An initial state; [N1, N2]: Intermediate states; [GS]: Goal state
IS → GS: Solution path, Solution-action-sequence
[Sr1, Sr2, and Sr3]: Search spaces
[A1, A2, and A3]: Action space: The actions that changed one state into another state

Operator(s): The means used by problem solver to generate the possible *solution path, solution-action-sequence path,* and *solution-object.* This solution can be a point in the problem state-space or a path from initial state.

5.3 Gestalt School of Psychology [GP]

GP approach talks about pattern-seeking nature of human being to organize their perception by applying various Gestalt principles like—similarity, law of figure and ground, proximity, the totality concept etc. Using Gestalt principles one can recognize how different elements helps in learning and reorganizing [9]. These principles are based on the observation that people actively and subconsciously organize the things into patterns and objects. GP approach is employed in designers' context to investigate perceptual organization of experimental and decision-making activities.

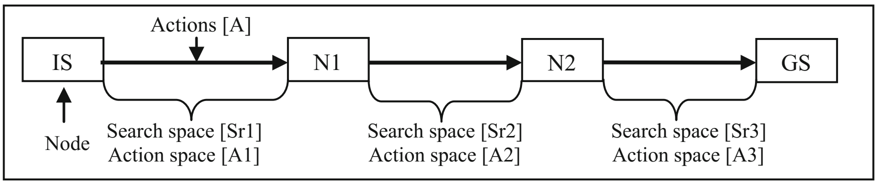

Fig. 1 Search representation of a problem

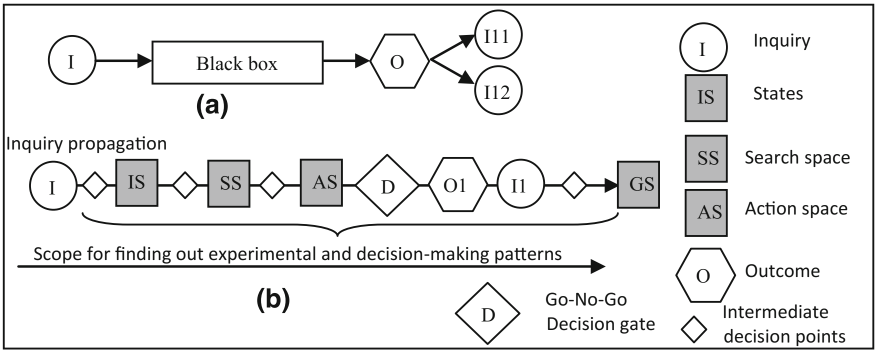

Fig. 2 Combined IP-SR-GP theoretical model

5.4 *Combined IP-SR-GP Theoretical Model*

According to Kant's [IP] principle, the designers are considered as inquirers. The designers' inquiries are considered as stimulus and outcome to these inquiries as response. The outcomes can be in the form of answer or solution to inquiry. See Fig. 2a.

To understand the process within 'black-box' [SR] approach is used. In this approach, the designers are considered as problem solvers and their internal representation of a problem as a 'state-space search' process. This 'black-box' is divided into state spaces [IS, N1, GS], search spaces [SS], and action spaces [AS]; see Fig. 2b. Within action spaces, the designers generated solutions using various operators and carried out experiments to test these solutions. The designers used experimental results to make more informed Go-No-Go decisions at decision gates [D] and to come up with outcome [O].

Considering *Gestalt school of Psychology* [GP], the designers are considered as pattern seekers. They actively and subconsciously used Gestalt principles from initial state [IS] to goal state [GS] to figure out experimental and decision-making patterns. Figure 2 shows logical sequential application of three approaches—IP, SR, and GP to conceptualize and develop *Combined IP-SR-GP Theoretical Model* as a whole. The vital modifications in theoretical model are made by going backward and forward into relevant literature and including it in existing model.

6 Application of PRETAR Framework to Design Project

The six steps mentioned in the Blandford's et al. [1, 2] PRETAR framework has provided with a useful structure and guidelines in organizing, designing, conducting and reporting of the NPD case study. The coherency of steps helped in evolving the study purpose and addressing the research questions. The researchers' understanding about the objectives became mature as the data gathering and post facto analysis of the design case study progressed.

6.1 Analysis [A] and Reporting [R]

These are the fifth and sixth components of the PRETAR framework. In this section, a post facto analysis of one packaging design case of one team is reported. Figure 3 shows packaging development stages followed by the team T1.

Application of Combined IP-SR-GP Theoretical Model

Combined IP-SR-GP Theoretical Model is validated for its application. The one representative packaging design cases of teams [T1] is reported below.

6.2 Inquiry Propagation [IP]

The teams enrolled in project were dealing with unique, uncertain and on the spot situations. The team's inquiries related to experiments were experiment propagation inquiries (EPI) and related to decision making were decision propagation inquiries (DPI). EPI's were categorized into four relevant design aspects of packaging—functionality, ergonomics, aesthetics, and fabrication of initial and final prototypes. The EPI of teams were further categorized into OEPI—Open type EPI, NEPI—Navigational EPI, and HEPI—Hypothetical EPI. The examples EPI for design aspects—functionality is given in Table 3.

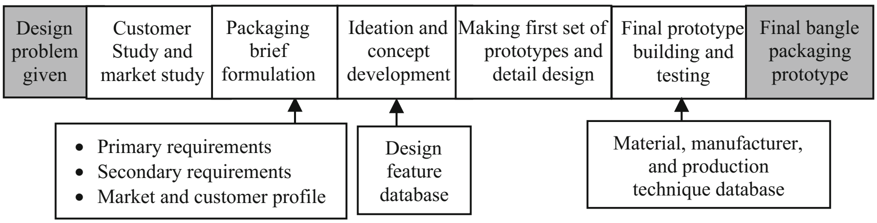

Fig. 3 Bangle packaging development stages

Table 3 Four design aspects, their features, and EPI related to packaging

Packaging design aspect	Features of packaging aspects	Examples of experiment propagation inquiries (EPI)
Functionality	Break proof packaging Durable package	OEPI: How can we prevent bangles from breaking? NEPI: How to constraint relative motion of bangles? HEPI: What if we use paper dampers to hold bangles?

6.3 Search Representation of a Problem [SR]

[SR] is considered as the design teams' internal representation of packaging design problem environment. EPI and DPI acted as a sequence of stimulus at each packaging development stage. The researchers have considered the design teams' problem solving as '*state-space search*' process to accomplish the final packaging prototype. This design project is treated as a whole experiment, and reported the experimentation process performed by the teams T1.

Team T1: Experimentation during ideation, concept attainment, first and final set of prototype development

Experimental instances captured from the designers are presented to explain experimentation phenomenon of Team T1. Figure 4 show first and final set of packaging prototypes and drop test performed. Tables 4 and 5 shows instances of various types of experiments captured from team [T1]. The designers' experiments are classified into exploratory, move testing, and hpothesis testing testing experiments as proposed by Schön [13].

6.4 Understanding Go-No-Go Decision-Making

The design teams made Go-No-Go decisions at the end of every packaging development stage. This decision-making process was consisted of number of stages followed by the decision gates. The researchers have figured out four groups of constituents that affected, contributed, and helped the design teams in making Go-No-Go decisions. The key phrase in the constituents has not emerged in single 'observation-analysis' attempt but it was iterative and repetitive cycle of 'observation-analysis'. These groups of constituents are given below,

First set of prototypes made by team T1 in second week	Drop test
  	
Final prototypes of teamT1 in third week	Drop test
 	

Fig. 4 Bangle packaging initial set and final set of prototype [T1] (Courtesy: S. Anup Chander, Ashok chary and Siddharta SS)

Table 4 Instances of thought and physical experiments designer [D1]

Thought experiments (TE)	Physical tinkering (PT)
• Can I wrap the bangles with a paper tape? • Experiments on type of paper can be used • Can bubble wrap made of paper be used? • A parachute deploying when bangles fall • Put all bangles in a fluid where it floats and impact is less when falls on ground	• Made a flower resembling natural flower to give. more feminine look The flower model with cardboard does not work and the material was changed • Changed the model using damper in box casing (spiral damper)

Table 5 Instances of EE, MTE, and HTE from designer [D1]

States	Exploratory experiments (EE)	Move testing experiments (MTE)	Hypothesis testing experiments (HTE)
State 1	What if I use parachute made with polythene cover?	Just put the bangles formed in the shape of sphere	Spring damper can prevent bangles from breaking
Actions taken to test/validate solution	Drop test of 2 m	Drop test of 2 m	Drop test of 2 m
Results (positive/negative/success/failure)	Failure	Failure	Tested ok
Learning/knowledge gained	Deployment time was more	Shape can't prevent bangles from breaking	Incorporated in final prototype
State 2	What if I use various mechanisms to close the casing of Model?	What if I use satin ribbon to tie ends of outer casing?	Using of cushion material will reduce impact.
Actions taken to test/validate solution	Tried belt mechanism on casing	Used satin ribbon	Cushion of paper stack kept around bangles, drop tested
Results (positive/negative/success/failure)	Failure	Positive	Positive, Confirmed hypothesis
Learning/knowledge gained	Looked masculine	Looked feminine	Paper cushioning can save bangles from breaking

(a) ***Performance parameters and critical factors (PP and CF)***: The performance parameters were the key factors considered common to all packaging development stages by the design teams and indirectly affected the critical factors. The critical factors were the factors/features considered completely exclusive to individual packaging development stages. Table 6 shows examples of PP and CF.

Table 6 Performance parameters and critical factors

Performance parameters (PP)
Break proof packaging: Packaging should safely protect bangles in drop test of 2 m
Packaging impact strength: Packaging must sustain to drop height of 2 m and it must be strong enough to safe 12 bangles
Feminine aspect: The packaging should give feminine aspect in its form and appealing
Ease of handling: The packaging should be easy to handle, open and close, easy to take bangles out and keep it in, ergonomically designed for female consumer
Mass manufacturability: Mass manufacturing aspect should be taken into account
Cost effectiveness: The packaging cost should not exceed the cost of glass bangles
Critical factors for selection of ideas and concepts (CF)
Satisfy one/few requirements: The ideas should satisfy one or few listed requirements
Newness of ideas: The packaging ideas should be novel
Variety of ideas: The diversity of packaging ideas
Idea transforming viability: Potential of idea(s) to transform into packaging concept
Satisfy listed requirements: The concept must satisfy all the listed requirements
Concept novelty: The packaging concept should be novel
Concept variety: The diversity of packaging concepts towards achieving functionality
Concept transforming viability: Practicability of concept transforming into actual packaging prototype taking into account its functionality and manufacturability

(b) ***Causes***: These were the prime reasons given by the designers of the teams, which affected the teams' process of rational inference while making Go-No-Go decisions.
(c) ***Decision-making heuristics***: The teams used various heuristics while making judgments and Go-No-Go decisions.
(d) ***Factors from mental models***: The shared mental models helped the teams in making predictions using their existing knowledge in unique unfamiliar decision-making situations.

Figure 5 shows example of stage-gate flowchart during one of the packaging development stage. The diamond shape represents decision gate.

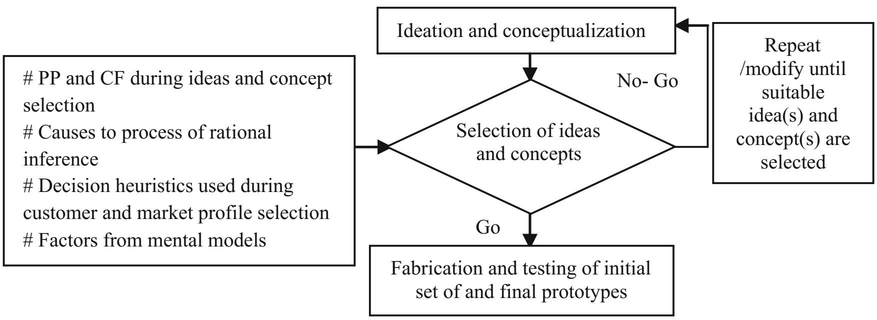

Fig. 5 Flow diagram of Go-No-Go decisions making

6.5 Gestalt School of Psychology [GP]

The design teams natural tendencies and behaviors allowed them to seek patterns. The experimentation and decision-making activities during packaging design project were perceived as an overall pattern and depending on the teams' interest, they analyzed it in details. These sample evidences are reported below.

6.5.1 Patterns Found During Experimentation Process

Grouping: The teams involuntary grouped the broad category experiments into thought, physical tinkering and virtual experiments.

E.g. the teams involuntarily tried and tested the similar packaging ideas and concepts using thought, physical tinkering and virtual experiments.

6.5.2 Patterns Found During Decision-Making

The totality concept: Go and No-Go decisions at the stage gates were considered as whole decisions which were consisted of number of small Go and No-Go decisions.

E.g. accepting the desired final packaging prototype was completely Go decisions. This decision was comprised of number of No-Go decisions for other prototypes, which were rejected by the teams.

7 Evaluation of Combined IP-SR-GP Theoretical Model

Glaser and Strauss's (1967) four evaluation criteria specified for grounded theory assessment in the context of packaging design case study are—Fit, Relevance, Workability and Modifiability.

(1) **Fit**: [IP] approach has not forced to the project data or to fit the teams' EPI and DPI with preconceived understanding. [SR] approach helped in capturing the teams', solution action sequences, and relevant experimental instances from design sessions. [GP] approach captured apt evidences of experimental and decision-making patterns.
(2) **Relevance**: Combined IP-SR-GP theoretical model, as a whole was found applicable to the experimental and decision- making situations. The three approaches served the purpose for which they employed. It contributed

valuable insights, findings towards the design teams' on the spot experimentation process and group of constituents as inputs to decision-making activity.

(3) **Workability**: The model is applied to four packaging design cases of four teams. In this paper, one case is reported to understand how the theoretical model works and handles the variation in the cases and captures design teams' experimentation process.

This model was able to capture the design teams' serial and parallel experimentation phenomenon. This model was able to capture the four groups of decision making constituents. But it was not able to capture the weightage of four decision-making constituents and this was the weakness of developed theoretical model.

(4) **Modifiability**: The theoretical model is modified by including following,

Design teams' EPI from four packaging aspects (functionality, ergonomics, aesthetics, and fabrication). Learning gained by the design teams while performing experiments (EE, MTE and HTE). Apart from performance parameters and critical factors (generated from the design teams' experimentation process) the three groups of decision-making constituents were taken into account while Go-No-Go decision-making.

8 Summary

The packaging design project was falling under SSQS. PRETAR framework is used to design, conduct, and report the case study. This project is managed like a whole experiment. Combined IP-SR-GP theoretical model is used to understand the teams' experimentation phenomenon and their Go-No-Go decision-making. The theoretical model is validated by applying it to four packaging design cases of the four teams. IP approach is employed to figure out the teams' flow of inquiries at individual development stages. SR approach is used to understand the search trees, experiment trees, and solution action sequences performed by the teams while going from initial state to goal stage. The four groups of decision-making constituents are identified which acted as inputs to decision gates and helped the teams in making Go-No-Go decisions. GP approach was employed to understand the teams' pattern seeking process. Combined IP-SR-GP theoretical model is assessed against the four evaluation criteria—fit, relevance, workability, and modifiability.

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Domain Specific Named Entity Extraction for Modeling and Populating Ontologies

B. Damayanthi Jesudas and B. Gurumoorthy

Abstract Automatic extraction of knowledge in modeling/enriching ontologies for domain specific applications play key role owing to the huge amount of data available in the form of documents. As manually extracting information is a tedious task, there is a need for automating this process. Use of automatic information extraction processes not only reduce the time, but also retrieves the information in a useful format. This paper proposes the use of parts of speech (POS) tagging, a Natural Language Processing (NLP) task, to group the words or entities in a text into pre-defined domain specific concepts. For the purpose of extraction, the domain concepts from available Engineering Ontology related to mechanical domain from the literature is considered. The methodology involves, parsing the text for POS tagging and then analyzing it, for grouping them into specific categories such as device, material and so on. Data required for automatic extraction is taken from various online sources describing the mechanical components, the material and process used for manufacturing those. As a start in using NLP techniques, automatic extraction of four domain concepts, device, material and process is addressed and the benefit of using it in automatic extraction of the conceptual information corresponding to an ontology is presented.

Keywords Parts of speech (POS) · Natural language processing (NLP) · Engineering ontology · Information extraction

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1 Introduction

Information extraction (IE) involves automatic extraction of information from documents and Ontologies structure the knowledge of a domain in terms of concepts and relations between them. Ontologies are used in assisting information extraction process as they provide better insight of the unstructured data. In the modeling and enrichment of ontologies, knowledge from different sources particularly documents are used. As the data available on a particular subject is huge, there is a need for intelligent processing of information in acquiring concepts and relationships between them defining a domain for modeling ontologies. The important facet in modeling ontologies is the acquisition process. Manual acquisition is a tedious and time consuming process and there is a need to automate it, to speed up the acquisition process. In extracting information, NLP techniques can be used and the use of a particular technique depends on the problem to be solved. It is feasible to use NLP-based learning approaches to automate the knowledge extraction process [1].

Named entity recognizers is a technique that can be used for automatic information extraction from texts. Named Entity Recognition (NER) is a "subtask of information extraction that seeks to locate and classify elements in text into pre-defined categories such as the names of persons, organizations, locations, expressions of times, quantities, monetary values, percentages, etc." [2]. NER systems are developed for English and there are classifiers like Stanford NER [3] developed for training models related to a particular domain on labeled data. The NER classifiers are trained on labeled data relating to the domain for which named entities are to be extracted, by providing labels to be extracted to the word tokens in the text. But training classifiers require huge data and the classifier developed for one domain do not give similar results for another domain.

The focus here is on applying NLP techniques in automatic extraction of concepts related to mechanical engineering domain from texts. The idea is, for a given ontology with pre-defined concepts, to automatically extract conceptual information similar to the ontology from the text using NLP techniques. For this purpose, the information to be extracted is taken from Engineering Ontology (EO) [1]. Engineering Ontology (EO) and its associated Engineering Lexicon (EL) help in indexing the documents and also to obtain semantic representation from unstructured data. EL contains list of lexical terms related to a particular concept. In this method, EO and EL are used to recognize concepts in the documents [1]. This paper presents NLP based approach to extract information from text without the aid of the ontology.

Data required for automatic extraction is taken from various online sources describing the mechanical components, the material and process used for manufacturing those. The methodology involves parsing text for parts of speech tagging. Stanford parser [4] is used for parts of speech tagging. The tagged words with their corresponding preceding and succeeding tagged words are analyzed for extracting information from texts. In EO, there are ten taxonomies/categories with concepts/entities corresponding to each taxonomy. Out of ten, in this paper automatic extraction of three categories, device, material and process is presented. Work is in process in extracting the remaining six categories: property, shape feature, measurement unit, environment object, value type and standard.

2 Literature Review

The use of Natural Language Processing (NLP) techniques in accelerating the ontology acquisition process is quoted by Li et al. [1]. The demand of automation in information extraction is increased in different fields particularly in biomedical domain because of the unique terminologies associated in that domain. This work explores the use of NLP techniques in information extraction for mechanical engineering domain. Nédellec et al. [5] reported the relation between ontologies and information extraction (IE). Extraction of information in ontological terms is illustrated.

Kim et al. [6] proposed an approach in order to automatically extract NE, i.e. domain concepts of an ontology. Engineering Design Integrated Taxonomy (EDIT) ontology is used for this purpose. In this approach, a document is first decomposed into a set of paragraphs each of which is a collection of sentences and each sentence is then analyzed for syntactic classifications using a parser and are annotated with Part-Of-Speech (POS) tagging. For morphological conversion, each POS tagged word is normalized based on WordNet and synonyms, acronyms etc., are identified in lexical analysis. Both the syntactic and lexical analysis help Named Entity markup to check equivalence in EDIT.

Li et al. [7] developed an ontology-based document analysis and retrieval tool (ODART). This method uses processing text in an input document in two stages, syntactic analysis and semantic analysis. The domain ontology is built based on the important design issues documented by engineers and identified by the cognitive studies. The concepts such as the products or components being designed and their functions, performances, material selections, manufacturing processes, and environment are extracted. Use of NLP techniques for automatic identification of new concepts is proposed for future work.

Anantharangachar et al. [8] proposed to populate an existing ontology from an input given as natural language text that contains instance information. From the input the domain is identified using a semantic lexicon and the instance extractor module extracts the instance information, creates a RDF node and updates the ontology. Jena APIs are used for this purpose.

Many researches illustrated the use of NLP techniques in information extraction in different domains. A lexicon is used for identifying the domain concepts in the text. In this paper, automatic extraction in the absence of a lexicon of domain concepts from text is presented. This work is performed for identifying some mechanical engineering domain concepts taken from Engineering Ontology (EO).

3 Extraction of Domain Concepts from Texts

The domain concepts to be extracted from the text are device, function, material and process. Engineering components such as combustor, gas turbine, compressor etc., are device concepts. The material and process concepts are the type of materials and process used in designing and manufacturing the device. Texts used for domain concept extraction are taken from online sources [9–11]. The texts are parsed using Stanford parser for parts of speech (POS) tagging. The parser assigns each word with its corresponding parts of speech such as noun, proper noun, verb, adjective, coordinating conjunction, determiner and so on. From the POS tagged text, features are identified and an algorithm is developed for automatic extraction of domain concepts from texts. The identified word as concept is labeled with its equivalent domain concept. For example, if in a text 'combustor' is present, then 'combustor' is designated as the device. Therefore, not the domain concept, but instance of that is also extracted labeled with the domain concept. The number of texts (40) taken for identifying features is less, but the results are promising and work is in process for identifying features for some more texts. The text file containing POS tagged words for the corresponding text is the input for the program and it has been implemented in C# on a Windows platform.

3.1 Extraction of Device Concept

For the extraction of device concept, 40 texts are considered. The texts are all simple sentences. In those, 20 texts are taken for extracting features and 20 are used for testing. The 40 texts taken for this purpose are with different syntactic variations, which helps in analyzing the device concept with its preceding and succeeding words. In 20, predominantly two features are identified. As 'device' is a thing, it takes only noun forms like noun, proper noun and noun plural. A 'noun' is always preceded by determiner and as the purpose of 'device' to do a particular function, it is followed by 'verb'. 'Proper noun' is always followed by 'verb'. These are the predominant features identified based on English grammar rules. The remaining 2 texts are statements, i.e., the text starts with 'It is a—' and 'For a–'. These are taken for examining in detail the type of features, not to miss anything. In this paper, the focus is only simple sentences.

For example, in the text, '*A turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work*', the parts of speech tagged text is 'A/DT turbine/NN is/VBZ a/DT rotary/JJ mechanical/JJ device/NN that/WDT extracts/VBZ energy/NN from/IN a/DT fluid/JJ flow/NN and/CC converts/VBZ it/PRP into/IN useful/JJ work/NN'./. In the above POS tagged text, the word with POS tag 'NN' is preceded by the tag 'DT' and followed by tag 'VBZ'. In the above text, the device is 'turbine' and the tag 'NN' is the noun. In the text, '*An axial compressor is a machine that can continuously pressurize gases*,' the

POS tagged text is ‘An/DT axial/JJ compressor/NN is/VBZ a/DT machine/NN that/WDT can/MD continuously/RB pressurize/VB gases/NNS’./. In the above text, word with tag ‘NN’ is preceded by ‘JJ’ which is preceded by ‘DT’ and followed by ‘VBZ’. The device is ‘axial compressor’ and the tag ‘NN’ is noun and ‘JJ’ is adjective, which describes the noun. In the text, ‘*Fans generate noise from the rapid flow of air around blades and obstacles, and sometimes from the motor*,’ the POS tagged text is ‘Fans/NNS generate/VBP noise/NN from/IN the/DT rapid/JJ flow/NN of/IN air/NN around/IN blades/NNS and/CC obstacles/NNS,/, and/CC sometimes/RB from/IN the/DT motor/NN’./. Here, the word with tag ‘NNS’ is followed by verb ‘VBP’. The device in the above text is ‘Fans’, the tag ‘NNS’ is plural form of the noun.

In extracting device concepts from text, it is observed that, the device is always a noun or form of noun such as noun (NN), plural noun (NNS) or a proper noun (NNP). Device can occur in different ways. It can be a noun (NN) like turbine, nozzle etc. Noun preceded by adjective (JJ) which describes the noun like axial compressor, mechanical fan etc. Noun followed by noun (NN) for devices like Gas turbine, Combustion chamber etc. The two predominant features identified are, noun preceded by article (determiner) and followed by verb and ‘Proper noun’ followed by ‘verb’. Statements, i.e., the text starting with ‘It is a—’ and ‘For a–’, Compound sentences with multiple devices are not considered. But these are taken for examining in detail the type of features, not to miss anything. In this paper, the focus is only simple sentences.

The ‘device’ in between the ‘determiner (DT)’ and ‘verb (VBZ)’, has different forms. But in the pseudocode only three forms are shown. The different forms are:

- noun (NN), example: Turbine
- adjective (JJ) followed by noun (NN), example: Axial compressor (JJ+NN)
- noun followed by noun (NN NN), example: Combustion chamber (NN+NN)
- noun plural (NNS), example: Fans
- proper noun (NNP) followed by noun plural (NNS), example: Cylinder heads (NNP+NNS)
- noun (NN) followed by noun plural (NNS), example: Jet engines, Reaction turbines (NN+NNS)
- adjective (JJ) followed by noun plural (NNS), example: Blind rivets, Axial-flow compressors (JJ+NNS)

Part of pseudo code for extracting device concept is shown in Fig. 1:

The continuation of it for material and manufacturing process extraction is shown in Figs. 3 and 5 respectively. The extracted devices for a given text from the program are shown in Fig. 2.

```
Read text file;
{
  while (line in the text file! =null)
   {
    for (each word in the line)
     {
      if ((word[i] contains "NN") AND (word [i-1] contains "DT") AND (word [i+1] contains "VBZ"))
       {
        Device = "NN";
       }
      else if ((word[i] contains "NN") AND (word [i-1] contains "JJ") AND (word [i-2] contains "DT") AND (word [i+1] contains "VBZ"))
       {
        Device = "JJ" "NN"
       }
      else if ((word[i] contains "NN") AND (word [i-1] contains "DT") AND (word [i+1] contains "NN") AND (word [i+2] contains "VBZ"))
      ..............................................................................................................
      ..............................................................................................................
      ..............................................................................................................
      ..............................................continued in figure 3..........................................
      ..............................................continued in figure 5..........................................
      ..............................................................................................................
      }
   }
}
```

Fig. 1 Pseudocode for extracting device concept

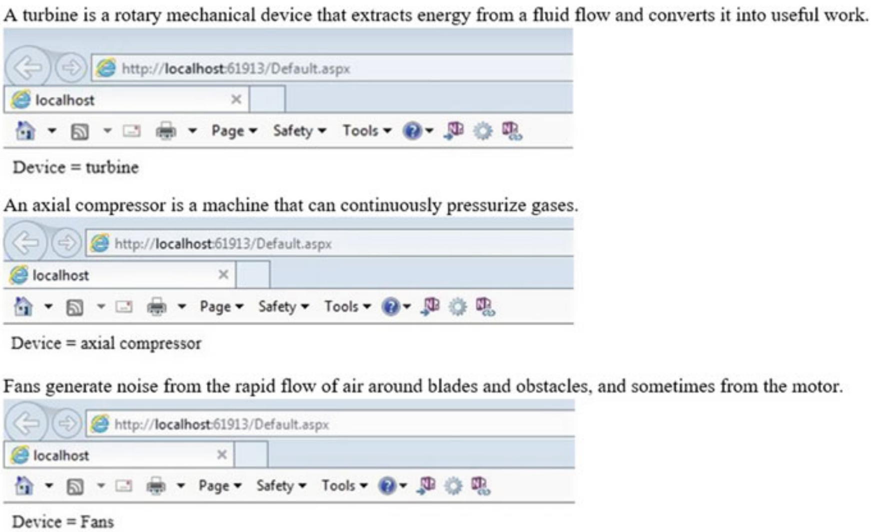

Fig. 2 Extracted devices from a given text

3.2 *Extraction of Material Concept*

Extraction of material is tricky, because material is also a noun. But close observation of the POS tags gives some extra features for material concept extraction. The key words that occur in text with material information are ‘made from’, ‘made out of’, ‘made from’, ‘used to’, ‘used for’. Therefore, in extracting material concept

```
if ((word[i] contains "NN") AND (word [i-2] contains "made") AND (word [i-1] contains "from"))
{
 Material = "NN";
}
else if ((word[i] contains "NN") AND (word [i-2] contains "made") AND (word [i-1] contains "of"))
{
 Material = "NN";
}
else if ((word[i] contains "NN") AND (word [i-3] contains "made") AND (word [i-2] contains "out") AND (word [i-1] contains "of"))
{
Material = "NN";
}
.......................................................................................................
.......................................................................................................
```

Fig. 3 Pseudocode for extracting material concept

from text, these features are to be considered. For an example text, '*Blind rivets are made from aluminum alloy, steel, copper, and Monel*,' the POS tagged text is 'Blind/JJ rivets/NNS are/VBP made/VBN from/IN soft/JJ aluminum/NN alloy/NN,/, steel/NN,/, copper/NN,/, and/CC Monel/NNP.' The material concepts are the words that occur after the key words 'made from'. Here, the materials for the device 'blind rivets' are soft aluminum alloy, steel, copper and nickel. The POS tagged text for, '*The combustion chamber is also made of nickel and titanium alloys*', is, 'The/DT combustion/NN chamber/NN is/VBZ also/RB made/VBN of/IN nickel/NN and/CC titanium/NN alloys/NNS'. The keywords are 'made of'. Therefore, the materials for the device 'combustion chamber' are 'nickel and 'titanium alloys'.

In the texts, '*Aluminum is the raw material used for making fuselage and wind panels*' and '*High tensile steels were used to manufacture aircraft skins*', the features from device conflict with material. The key words 'used for', 'raw material' and 'used to' are applied to resolve this. The material used in making device is also a noun form. But the text considered for the purpose of information extraction contain information related to device and material and the key features are the words that occur with material information. The types of POS tags that occur with material are:

- noun, example: Copper (NN)
- proper noun, example: Aluminum (NNP)
- noun followed by noun, example: Phosphor bronze (NN+NN)
- noun followed by noun plural, example: Titanium alloys (NN+NNS)
- adjective followed by noun plural, example: Nickel-based superalloys (JJ+NNS)
- adjective followed by noun, noun plural, example: High tensile steels (JJ+NN +NNS)

In the pseudocode only one form is shown. Part of pseudo code for extracting material information is as shown:

The extracted material used in making devices are shown in Fig. 4.

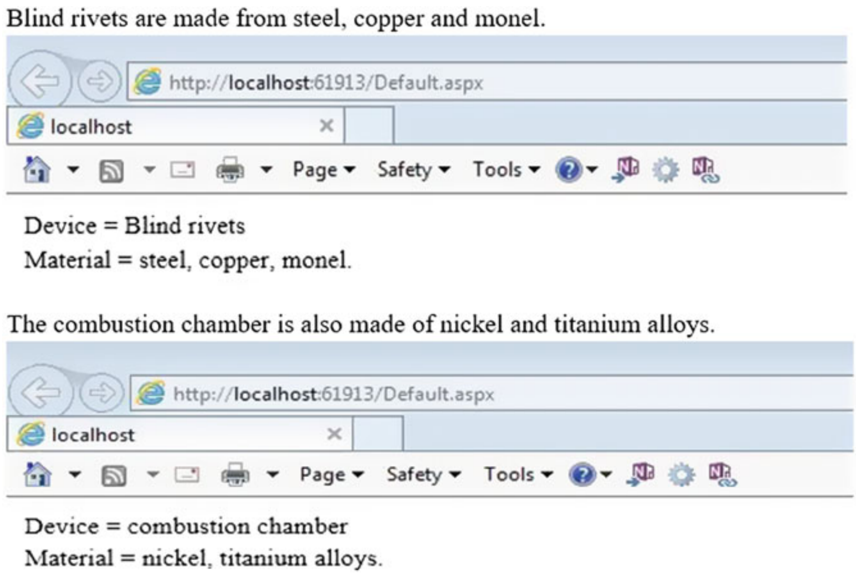

Fig. 4 Extracted materials used for making device from a given text

3.3 Extraction of Manufacturing Process Concept

The key words in extracting manufacturing process are ‘manufactured by’ and ‘made by’. The occurrence of these keywords are shown in the example texts. For an example text, ‘Turbine blades are manufactured by investment casting,’ Investment casting is the manufacturing process for turbine blades. In the text, ‘*Cylinder heads are made by shell molding*’, the process for making cylinder heads is shell molding. Part of pseudo code for extracting manufacturing process information is as shown (Fig. 5).

The above are the key features, but for another text, ‘*Extruding is used to manufacture teeth on long rods*’, the process for manufacturing nonmetallic gears is injection molding. Here, ‘used to’ conflicts with the feature in material concept. But, it is followed by ‘manufacture’. In a text containing the information about the process used for manufacturing devices, the words ‘manufactured/made by’ are present. Work is in process for identifying more features for manufacturing process which helps in resolving these conflicts. In this paper, the dominant features are detailed. The manufacturing process occur in the form of noun followed by noun (investment casting), proper noun (extruding).

The extracted information related to the type of manufacturing process used in making devices is shown in Fig. 6.

```
if ((word[i] = "NN") AND (word [i -2] = "made") AND (word [i-1] = "by"))
{
  Manufacturing process = "NN";
}
else if ((word[i] = "NN") AND (word [i -2] = "manufactured") AND (word [i-1] = "by"))
{
  Manufacturing process = "NN";
}
.................................................................................
.................................................................................
```

Fig. 5 Pseudocode for extracting manufacturing process concept

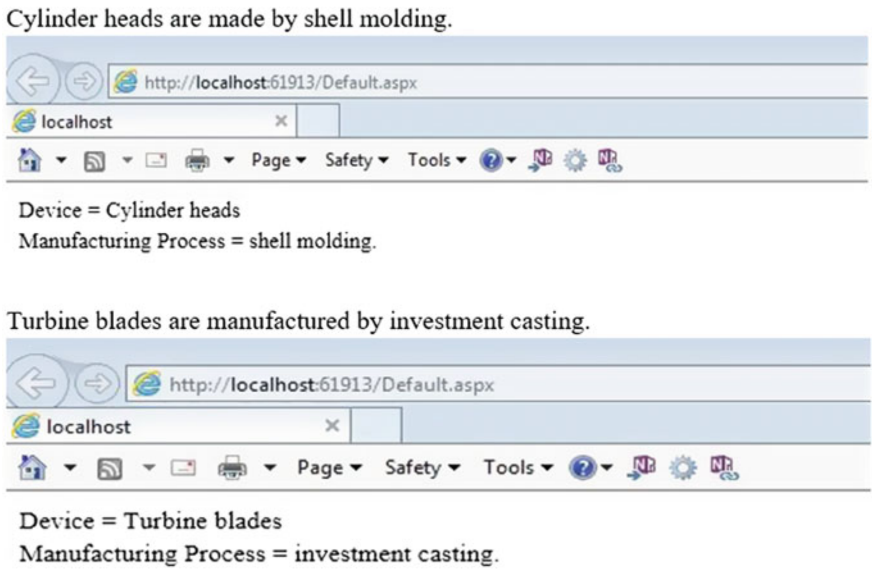

Fig. 6 Extracted manufacturing process used in manufacturing the device from a given text

4 Conclusions and Discussion

The focus of this paper is mainly on automatic extraction of conceptual information from texts for building/enriching ontologies without the aid of an ontology or a semantic lexicon and classifier which requires huge training data. Concept identification is done through rules framed from parts-of-speech tagging. As a start, features from parts of speech tagging of the texts are generated and implemented for three domain concept categories, device, material and manufacturing process. 120 texts with 40 for each domain categories are taken. The domain (engineering) ontology is not used as a lexicon but the concepts are only taken as reference in automatic identification from text in the use of Natural Language Processing (NLP) techniques in mechanical component terminology extraction. The idea of using this method is that available domain lexicons do not provide meanings and synonyms for domain specific terms which makes their use inefficient in automatic information capturing for technical terms. The results of this work is intended to be used in a larger project aimed at diagnosing problems that can arise during assembly in the planning stage itself. Also, in knowledge acquisition for diagnosing assembly uses, establishing semantic equivalence of terms is required to decide if the knowledge is new or not. The challenge here is that, text contains partial information about a concept so matching with all the attributes may not be possible. Work is in process for the same and also in extracting remaining domain categories of the engineering ontology and more features for a particular concept.

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

Design Intervention for Terrace Cultivation in the Hilly Region of North Eastern India

M. Angelus Khoh and Amarendra Kumar Das

Abstract In the North Eastern Region (NER) of India, agriculture has been a source of livelihood for majority of the population. The farmers of the region practices two distinct types of farming namely *Jhum* cultivation and *terrace* cultivation. In spite of huge potential of the region for agricultural and horticultural produce, its productivity falls below the national average. Agriculture in the hilly areas of NER faces numerous challenges due to factors such as traditional farming methods, use of poorly designed tools, tough terrains, and also lack of good agricultural practices, irrigation, mechanization, power for mechanization, transportation networks etc. This research is to facilitate terrace farming through design intervention by designing an appropriate system. Initial challenge is to design tools that can be manually used and followed by tools that can be used with small engine to form terrace.

Keywords Jhum cultivation · Terrace cultivation · Terrace forming tools · Processes

1 Introduction

Agriculture is in practice since time immemorial when human felt the need to produce and store food. It has since then been one of the oldest professions and has undergone various developments from primitive farming to modern methods of farming. In the North Eastern Region (NER) of India, agriculture has been a source of livelihood for majority of the population. The NER of India consists of eight

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states namely: Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura and comprises of both valleys and hilly terrains.

The farmers of the hilly terrains practices two distinct types of cultivation namely *Jhum or slash and burn* cultivation and *terrace* cultivation (which is a fraction of *Jhum* cultivation). In spite of huge potential of the region for agricultural and horticultural produce, the productivity of the area falls below the national average [1, 2]. Low productivity of the region is due to numerous factors, such as traditional farming methods [2], use of poorly designed tools, tough terrains, lack of good agricultural practices, lack of irrigation, demand of extreme physical labor and lack of transportation networks etc. Mechanization of agriculture in the hilly terrain remains a huge challenge due to undulating terrains, small land holdings, cost of initial investments, socio-economic conditions, lack of power for mechanization, poor infrastructure [2], lack of farm machinery, manufacturing industries etc. [3]. The NER is congenial for horticulture and growing high-value crops, therefore, full advantage must be taken of the relative strengths in fruit production, plantation horticulture and floriculture, cultivation of medicinal and aromatic plants, forest-based products, etc., without impacting sustainability. The growth engine of the region can be high-value agriculture, fish farming and tourism, especially farm/eco-tourism [2].

2 Jhum or Slash and Burn Cultivation

Jhum or shifting cultivation or *slash and burn agriculture* is a form of cultivation practiced in all the states of the region with the exception of Sikkim [4, 5]. The process involves clearing a patch of forest by cutting down the trees and vegetation. The cleared vegetation are burnt to ashes which are then used as supplementary nutrients for the soil and mixed with the soil while tilling the field. Traditionally, the cleared land is cultivated for a few years (2–3 years) and when the land becomes infertile it is left to fallow for certain period of time (10–20 years) [6] so that the soil can regain the nutrients. The fallow period varies depending on a number of factors such as soil type, region, availability of land for use etc. In recent times, the fallow period has been drastically reduced [6, 7]. Jhum cultivation has a number of disadvantages associated with it namely, ecological imbalance as well as adverse socio-economic effects [6], rendering the soil infertile after few years of cultivation, soil erosion and landslides [8], not to mention depletion of flora and fauna [6]. At present, *Jhum* cultivation is banned in many states of the region but has failed to elicit proper response from the farmers. Thus, a sustainable alternative to *Jhum* cultivation has become essential.

3 Terrace Cultivation

A Terrace is a piece of sloped plane that has been cut into a series of successively receding flat surfaces or platforms, which resemble steps, for the purposes of more effective farming. It is mainly practiced in the hilly areas of the region for its effectiveness in preventing soil erosion and conserving water [9]. As terrace cultivation is a settled form of cultivation, there is no major environmental effect as compared to *jhum* cultivation thus, proving to be a sustainable form of cultivation. A variety of crops can be grown on terrace fields, including crops such as rice which require water retention. Further, terrace cultivation helps in controlling soil erosion in hilly terrains [10]. Terrace cultivation as a settled form of cultivation requires proper planning and execution. Forming terraces is a labor intensive task and it can also take a considerable period of time for the terrace walls to settle in before crops can be grown. Due to lack of mechanization in the hilly regions, most of the work is done only by human power using traditional hand tools [3].

4 Irrigation System for Terrace Cultivation

As terrace cultivation in the region is usually with cultivation of water retaining crops such as rice, irrigation plays a major role in design of terrace fields.The region practices a number of irrigation methods to suit the local resources available and terrain type. They are usually derived from water sources running upstream of the cultivated area or rain. *Bamboo drip irrigation* [11, 12] is practiced in some parts of Meghalaya. *Zabo* [6, 10, 12] *farming system* is found in Nagaland. Apatani and *Adi* tribes of Arunachal Pradesh conserve water by constructing structures like *Yetbung Lingang and Linkum* made of locally available resources like stones/boulders and bamboo [13]. In some parts of Nagaland, *panikheti* system is practiced for rice cultivation [14]. A man-made canal irrigation system called ‘Laoh’ in Poumai Naga dialect is used for channeling water from a region of higher level to supply water to terrace fields lying in a lower region is practiced in Manipur.

5 Terrace Forming Processes

Forming terraces is a tedious process involving a lot of physical labor especially in the hilly terrains, therefore, proper planning is required. Some of the factors to be considered for constructing terrace are types of terraces, crops to be grown, soil and climatic conditions, slope of the terrain, net area for cultivation, tools and machineries to be used for construction etc. Terrace fields could be classified according to the following criteria: size of the terrace base and shape, their main function, the construction process, [9]. Three different types of terraces according to their base sizes are (a) Wide-base terrace: 600–1200 m (b) Medium-base terrace: 300–600 m and (c) Narrow-base terrace: 300 m [15].

5.1 Design Specifications

Design specifications of terrace as given by Food and Agricultural Organization of United Nations are given below:

Length: A maximum of 100 m length in one draining direction is recommended for typical conditions in a humid tropical climate. The length of a terrace is limited by the size and shape of the field, the degree of dissections and the type of soil, Width: The optimum width for handmade and manual-cultivated terraces ranges from 2.5 to 5 m; for machine-built and tractor-cultivated terraces, the range is from 3.5 to 8 m. The width of the bench is determined by the land owner's preferences, soil depth, tools to be used for cultivation, crop requirements, and the resources available.

Slopes: The horizontal gradients should range from 0.5 to 1% depending on the climate and soils.

Slope limit: Hand-made terraces should be employed if soil depths are adequate, on 7°–25° (12–47%) slopes. For machine-built terraces, it should be employed on 7°–20° (12–36%) slopes.

Risers and riser slopes: Risers may be made of either compacted earth-protected with grass, or rocks. For easy maintenance, terrace riser height should not exceed 2 m, after allowing for settling. For level terrace, Vertical Interval 'VI' equals the height of the riser. For rice paddies, a 15 cm dyke may be added to the vertical interval to get the total height (Fig. 1).

$$\mathrm{Hr} = \mathrm{VI} + \mathrm{DH} \tag{1}$$

where, Hr: height of riser, in m VI: vertical interval, in m DH: dyke height (m).

Vertical interval: The Vertical Interval (VI) can be calculated by a simple equation. VI is the elevation difference between two succeeding terraces

$$\mathrm{VI} = (\mathrm{S} \times \mathrm{Wb})/(100 - (\mathrm{S} \times \mathrm{U})) \tag{2}$$

Where, S: land slope in percent (%), Wb: width of the bench (m), and U is the slope of the terrace riser (m). A horizontal to vertical ratio can be used to put into the equation such as 1 for machine built terraces, 0.75 for hand-made terraces, and 0.5 for stone terraces [16, 17].

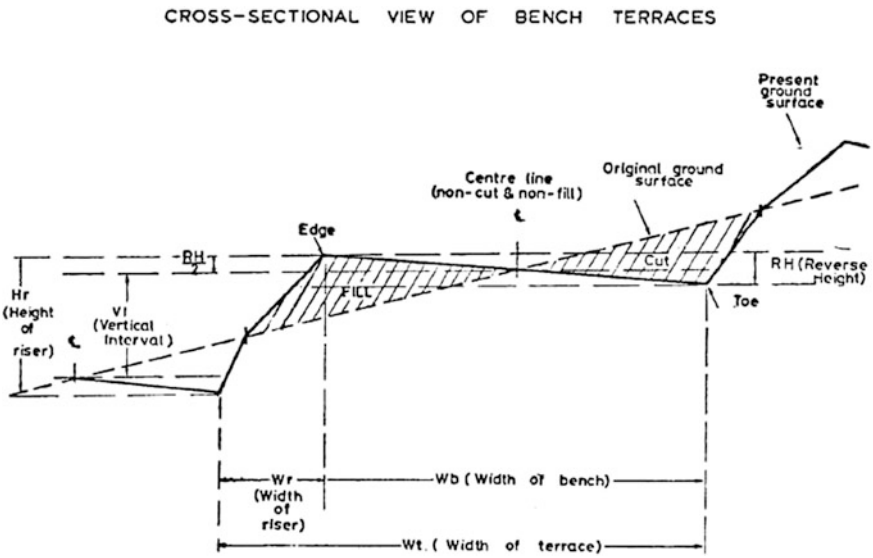

Fig. 1 Parameters considered in designing a bench terrace [16]

5.2 Construction Methods and Tools

Terrace construction in the region is usually done manually. The most common method of forming terrace is the "Cut and fill method" where the soil from a higher level is cut and then filled to a region of lower level. Cutting and filling of the terraces should be done gradually and at an equal pace so that there is neither an excess nor a lack of soil. This principle applies regardless of what kind of tools are used for the operation [16]. In NER, the terrace is mostly constructed manually, and should be built when the soil is neither too dry nor too wet. Constructing from the base of the hill helps in preserving the top soil and also prevent further soil run-off as compared to starting from the top. The formation of terrace beds in the region is usually done with the help of hand tools. A list of some of the tools normally used in the region is given in Table 1.

6 Spade Design for Terrace Formation

Spade is used as a major tool for digging and removing soil purposes. And it forms one of the primary tools in the formation of terrace fields in hilly region of North East India. Spade of different shapes and sizes are available for the said purpose. However, the standard spades available can only be used for digging or cutting soil in one direction as shown in the Fig. 2. The person usually faces the slope or the

Table 1 List of tools used in the hilly region of North Eastern India

Name	Purpose	Material	Power source
Axe	Cutting trees	Metal and wood	Human effort
Dao	Clearing trees and bushes	Metal and wood	Human effort
Spade	Digging/removing soil	Metal and wood	Human effort
Pick axe	Digging loosening soil	Metal and wood	
Digging rod or bar	Digging and loosening soil	Metal and wood	Human effort
Handheld baskets/plates	Shifting/transporting soil	Bamboo	Human effort
Sacks, gunny bags	Shifting/transporting soil	Jute, plastics	Human effort
Hammer and chisel	Breaking and removing stones, boulder/rocks etc.	Metal and wood	Human effort
Soil compacting bat/logs	Compacting loose soil	Wood, bamboo	Human effort

Fig. 2 Digging direction using a standard spade

hill while using the standard spades available. This poses a safety concern as the spade is dragged towards the person after completing the digging action. This could be in terms of the blade of the spade or the handle hitting the person or could be from the falling debris of the dug soil which may at times consist of stones, sharp rocks or tree stumps etc.

Considering these factors in mind, a modified spade blade has been designed to be used as a hand tool. This modified spade has a bend at one end providing cutting

Fig. 3 Digging in horizontal direction with the modified spade

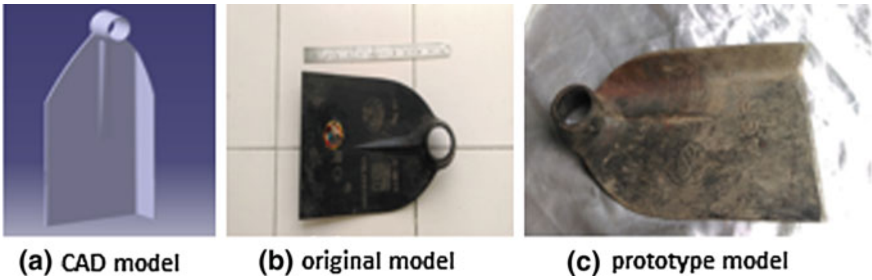

Fig. 4 Different models of the spade

edges in two directions as shown in Fig. 3. Further the risk of injuries from falling debris is minimized as the cutting action is horizontal to the slope of the hill.

The CAD model, prototype developed and the standard model is shown in Fig. 4.

6.1 Prototype Testing and Comparative Analysis

This prototype was tested for its functionality as a terrace forming hand tool after attaching it to a handle. For the terrace bank/riser, chunks of compacted soil is used to hold the loose soil from running off the slope by gradually using "cut and fill" method as and when the chunks of compacted soil are placed. A comparison between the effectiveness of the standard spade and the modified spade as a tool for forming terrace beds has been carried out as an experiment in a time bound manner (Figs. 5 and 6).

Fig. 5 Cutting the slope in two plane with the modified spade

Fig. 6 Terraces formed with standard and modified spades

6.2 Results

The results of the test are shown in Tables 2 and 3.

7 Observations and Limitations of the Experiment

The result shows that for the same duration, the modified spade covered more area in forming the terrace bed as compared to the standard spade. Hence, it can be said to be more effective and efficient than the existing standard spade. The capability of the modified spade in cutting along the horizontal direction of the slope or hill is much more as compared to the standard spade. The risk of injury from falling debris is reduced as a result of working on a flat surface along the horizontal direction of the slope. The length and diameter of the shaft or handle maybe customized to suit the user's requirement. The modified spade can be used for digging and dragging actions. It is more effective in terms of digging and dragging loose soil as compared to hard soil. Optimization of the modified spade may further be made with respect to balancing. The design of the spade is simple and customized according to the convenience of individuals without additional cost or efforts. It can be used in rural hilly areas as it can be modified from existing models and is economically viable.

Table 2 Standard spade versus modified spade summary

Parameters	Standard spade	Modified spade
Material of the spade	Iron	Iron
Diameter of the eye	45 mm	45 mm
Weight of the spade without handle	1.6 kg	1.8 kg
Material of the handle	Wood	Bamboo
Length of the handle	70 mm	80 mm
Source of power	Human power	Human Power

Table 3 Details of the terrace beds formed using standard and modified spade

Parameters	Standard spade	Modified spade
Length of terrace	5.5 m	7 m
Width of terrace	0.95 m	0.95
Height of wall (riser)	0.63 m	0.62
Construction method	Cut and fill	Cut and fill
Terrace bank material	Earth material	Earth material
Time taken to complete	1 h	1 h

8 Conclusion

In order to promote terrace cultivation in the region, further studies need to be carried out taking all the stakeholders into consideration viz., farmers, manufacturers, government agencies, etc. Further scope of this paper can be areas such as optimizing the design of tools and implement, mechanization of agriculture in the region in order to meet the increasing demands. Modern farm tools and implements need to be designed and developed considering factors such as safety, productivity, economic viability and physical stature of the people of the region.

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Development of a Precision Experimental Setup for a Flexure Based Micro-motion Amplifier

Bhagyesh Deshmukh and Sujit Pardeshi

Abstract Miniaturization has inherited the necessity of micro-mechanism. Micro-motion devices are expected to deliver high positioning accuracy and potentially have wide applications in the industry such as development of Micro factories. A flexure based joint-less pantograph is designed as a mechanical amplifier to achieve a geometric amplification of input displacement for a linear positioning system. This arrangement is useful for achieving motion amplification for a precision actuator Piezo actuator. Design and manufacturing of such system is a challenging task and the important aspect of DFMA is considered. Guidelines are suggested for researchers who intend to develop similar setups. Macro scale Wire Electric Discharge Machine (WEDM) is used for manufacturing micro-mechanism. Concept 'Do not fight with gravity' is implemented in setup development. All constraints applied in simulation, are applied on the mechanism to replicate directional motion in the setup developed. The performance of mechanism was observed under a vision based system. Setup developed has been successfully used for the performance evaluation of compliant pantograph.

Keywords Microsystems development · DFMA

1 Introduction

Miniaturization is associated with various advantages and challenges; a smaller system has lower inertia of mass enabling quick response from the system. The overall performance of the precision system is an outcome of precise and accurate

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behavior of various subsystems involved. However resulting performance obtained from such systems is decided by its dimensional accuracy, precise manufacturing and attaining them is a challenging task. Microsystems [1] involve development of micro mechanisms for desired motion or force transfer. The prevalent rigid link mechanisms have their own constraints while achieving these objectives and hence a new class of mechanisms known as compliant mechanisms has hence gathered significant importance in MEMS. For the linear positioning system, a flexure based mechanical amplifier (joint-less pantograph) is designed in order to achieve geometric amplification of input displacement [2–8]. This particular arrangement is useful for achieving motion amplification for a precision actuator such as Piezo actuator. Design and manufacturing of precision experimental setup is a difficult task and the important aspects of DFMA [9] are incorporated.

2 Compliant Pantograph

Linear motion amplifier; a Compliant pantograph (dimensions are enveloped in a rectangle of 80 mm × 45 mm) is as shown in Fig. 1. This model is simulated in ANSYS and analytical model for displacement is developed using pseudo rigid body model (PRBM) [3–8]. The design is monolithic and requires least assembly.

The compliant pantograph can transfer motion (Y_1) linearly and can be successfully implemented for amplification (Y_2) of input motion. F_{in} shown in Fig. 1 is input force that results in input displacement. The input displacement is amplified by Compliant Pantograph. Figure 1 also mentions single point constraint (point 'O') as it can result into induction of excessive stresses and the whole mechanism can rotate about the fulcrum point violating the whole cause of amplified straight line motion transfer (Y_2 parallel to Y_1). Hence a uniform thick plate of appropriate dimensions with provision for clamping at two points is incorporated. The dimensions of the extension portion needs to be adequate to accommodate 2 allen screws considering clamping principle and a provision for the clamping area of 30 mm needs to be made. Hence the length of the extension (L) is decided as 30 mm (Fig. 2). While deciding the width additional width of 2.5 mm is considered on either sides leading towards the total width (W) of 20 mm so as to avoid the

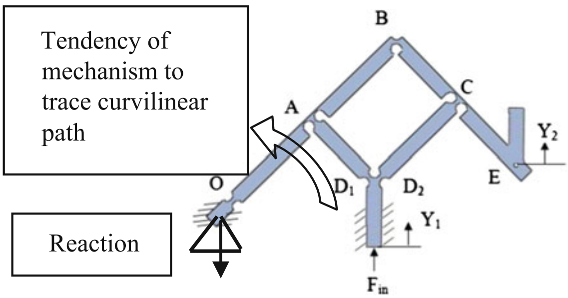


Fig. 1 Compliant pantograph

clamping pressure that may be passed to the flexure at 'O' and affect the performance of the mechanism. This extension was designed as monolithic with the mechanism to avoid possibility of error during assembly and is manufactured using the same material.

3 Assembly Considerations

3.1 Selecting the Plane of Operation

Choosing a plane of operation is a very critical task and utmost care is required for proper selection. Micromechanism performance is greatly affected if proper plane of operation is not selected.

The vertical plane of operation as illustrated in Fig. 3a is one of the choices to mount the mechanism on a base plate. The gravitational (downward) force will lead to deflection of the flexures about the sensitive axis and hence unwanted deflections will result into misleading performance of the mechanism. Assembling in vertical plane voids the rule of 'Do not fight against the gravity' [10] and hence not recommended for precision applications involving a micromechanism like a compliant pantograph. A horizontal mounting as presented in Fig. 3b orients the sensitive axis in line with the gravitational force avoiding flexing of the flexures due to self weight.

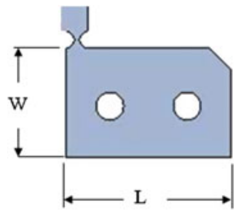


Fig. 2 Extension to mechanism

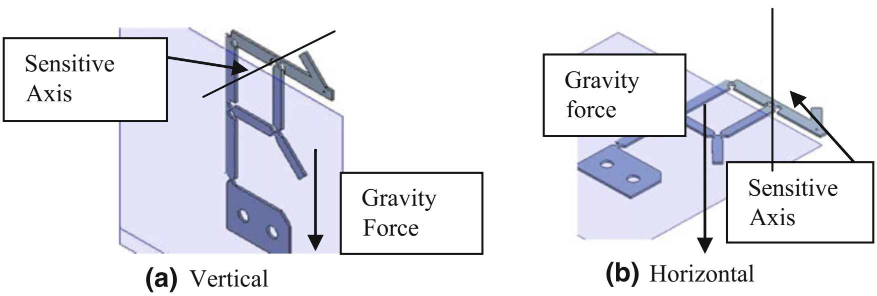


Fig. 3 Plane of operation

3.2 Selecting the Support for Planar Mechanism

Operating forces are very low (1–5 N) and hence friction forces should be kept almost negligible. The effect of friction is considered in setup development and a methodology to overcome the friction is undertaken.

The principle of confirming and non confirming interfaces is considered in order to develop a support plane. To make interfaces between mechanical components very stable, non-conforming (i.e., point or line) contacts as in Fig. 4a are preferred over conforming (i.e., areal) contacts as in Fig. 4b wherever practicable. Of course this recommendation is only applied to moving mechanical interfaces or interfaces that must be assembled and disassembled. Fixed interfaces that never require disassembly are often bonded or welded to eliminate all possibility of friction-induced slippage. At the local level, a conforming interface is a highly redundant load path since local elasticity determines the interface stress distribution as in Fig. 5a, b. In addition to the confirming and non-confirming interfaces, traction force also plays a vital role. The role of traction force is as shown in Fig. 5a where a single point sliding contact allows traction force and hence is not preferred whereas Fig. 5b indicates a Rolling-Element contact with no traction force [11]. Steel balls are the best alternative for supporting the mechanism as they provide a point contact avoiding surface to surface contact thereby reducing the inertia effect. Steel balls can be placed in between the mechanism and the base plate so as to create a frictionless virtual horizontal supporting plane (shown by red color line in Fig. 6).

The contact between mechanism and steel ball is a non-conforming type contact. Dimples (depth 1.5 mm) are created on the base plate (using drill M3) and balls (Diameter 3 mm) are placed in those dimples. These dimples allow rolling movement of the balls within the groove to avoid friction forces.

Fig. 4 Stress distributions at interfaces [11]

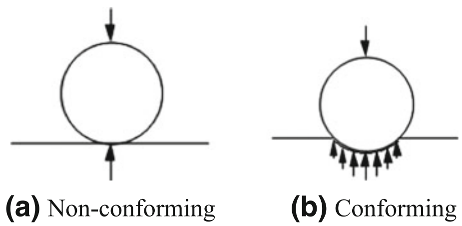
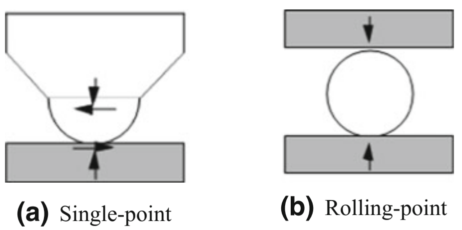


Fig. 5 Traction force at interfaces [11]



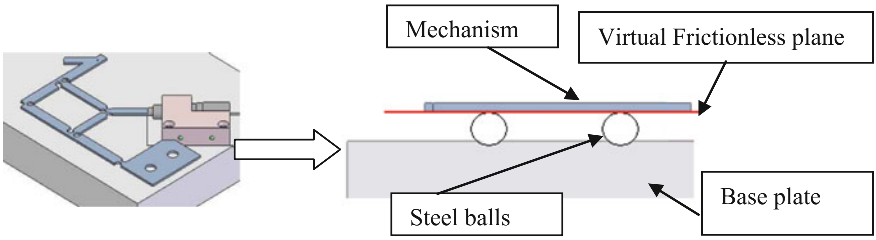


Fig. 6 Virtual horizontal supporting plane

4 Manufacturing Considerations

A single piece was manufactured using a WEDM however a dimensional error was seen in the profile of the micromechanism (desired radius was 1.5 and obtained radius is as shown in Fig. 7). A stacking method is recommended in this paper to manufacture a micromechanism using a macro scale WEDM. A stack is prepared and manufacturing is carried out and manufacturing error is minimized in stacked manufacturing. The detail processing is mentioned herewith.

4.1 Preprocessing of the Desired Stock

A flow chart indicated in Fig. 8 shows an overview of various activities to be undertaken in the preparation of the stack.

As per design, the pantograph dimensions are enveloped in a rectangle of 100 mm × 55 mm. Zones “A”, “B” and “C” as mentioned in Fig. 9 are to be removed from the plate using WEDM.

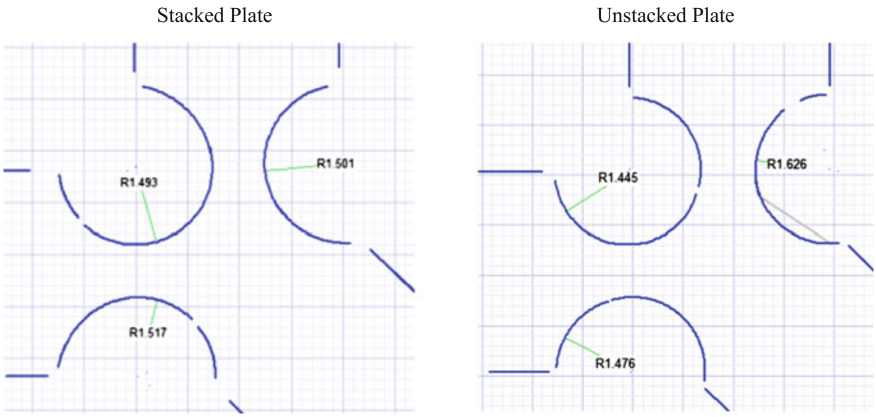


Fig. 7 Profile of flexure at ‘D_1 and D_2’ for stacked plate versus unstacked plate

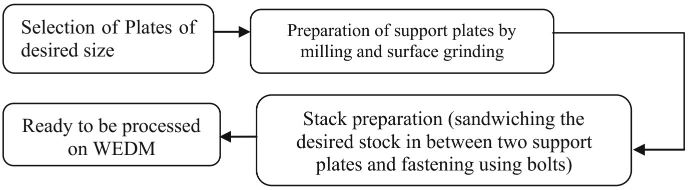


Fig. 8 Flowchart for preparing the stack of plates

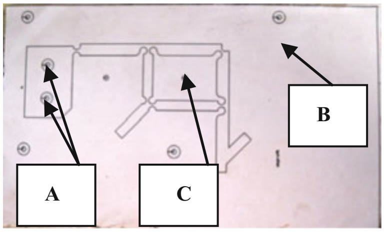


Fig. 9 Unwanted zones in plate

Stack of plates used for manufacturing micromechanism is shown in Fig. 10. The mechanism is manufactured using WEDM as there is no contact between tool and work piece (i.e. mechanical force is absent).

4.2 Manufacturing of Mechanism Using WEDM

In current profile, we need various wire entry points as die as well as punch are to be obtained at different locations.

The current micromechanism can be subdivided (Fig. 9) into three zones while manufacturing on WEDM (A) re-boring the two clamping holes to the size, (B) is a subsection of the mechanism where die is to be maintained i.e. the inner material removed is scrap, and (C), the stack of mechanism needs to be maintained and the wire compensation needs to be transferred to the scrap material i.e. die (as punch is to be maintained) in this part of manufacturing. The machined pantograph obtained is as shown in Fig. 11. As the compliant pantograph is ready, system to evaluate its performance needs to be developed and is discussed in section following.

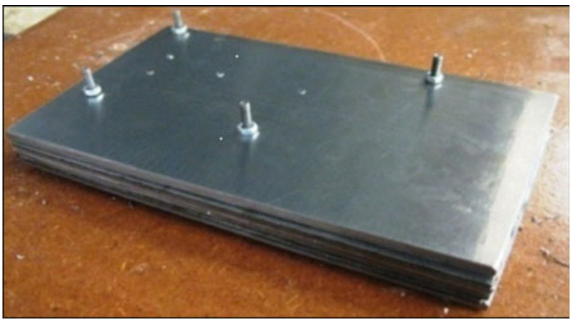
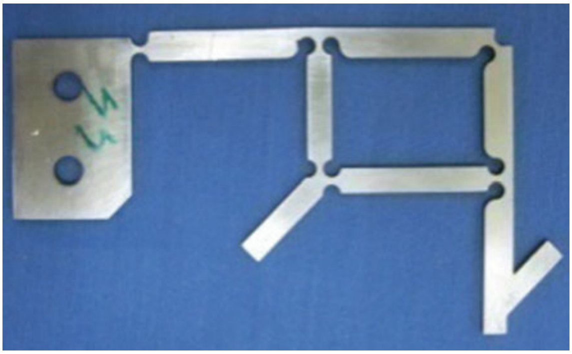


Fig. 10 Stack of plates for manufacturing on WEDM

Fig. 11 Compliant pantograph

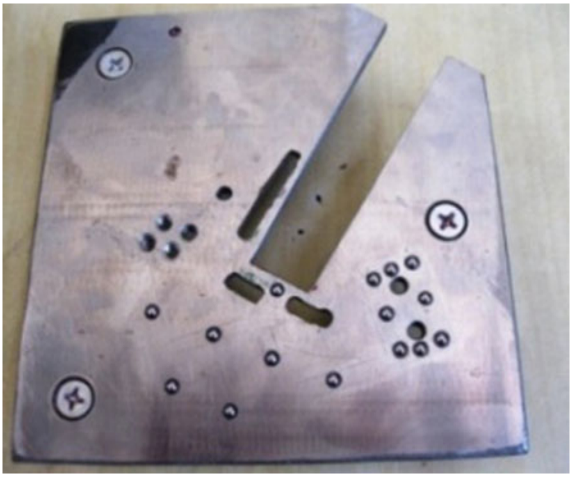


4.3 Development of Experimental Setup

A precise setup capable to evaluate performance of the micro-mechanism is required that can measure the amplification of the input displacement. The mechanism was clamped on a base plate (M.S.). The base plate is required to accommodate the pantograph and the other components such as sliding constraints at the input link (to ensure linear input), steel balls (to introduce a frictionless support to the mechanism). The support to the mechanism is required to avoid undesired bending during operation due to self weight.

The micromechanism is fixed on a flat base plate (surface is ensured flat by surface grinding). Various slots are made in order to accommodate the sliding constraints, clamping bolts, dimples to put the steel balls (Fig. 12). The constraints (Fig. 13) are designed according to the principle of Exact Constraint Design (ECD). In ECD the entire machine can be seen as kinematic chains with rigid bodies and joints as elements. Either mechanical interfaces or elastic zones of a part serve as

Fig. 12 Base plate



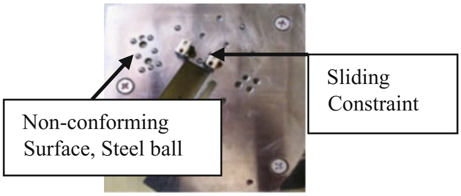


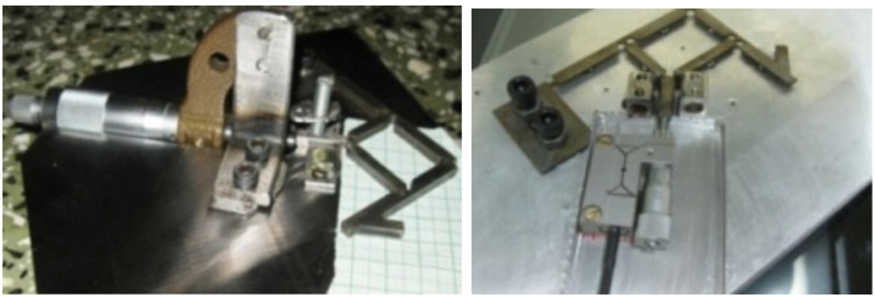
Fig. 13 Incorporated constraints

joints. Using exact constraint design, the kinematic chains or sub-chains must satisfy the desired and preliminarily specified degree of freedom [12].

4.4 Testing of a Compliant Pantograph

A conventional micrometer is used as a source of actuation as its input displacement can be easily measured. A micrometer is installed on the base plate by means of a suitable clamp as shown in Fig. 14a. Provision to adjust vertical or horizontal (undesired) misalignments of micrometer is provided in order to achieve perfect input (unidirectional) actuation.

The developed micromechanism was tested suitably for geometric amplification of about 2 for the given input displacement. Linear input is considered at point D (i.e. point of actuation) however in the trial discussed above; circular plunger of micrometer is used at the input. This circular motion at the input (via plunger) induces a lifting force on the mechanism and the results obtained were misleading or more amplified and the motion in undesired direction (parasitic) occurs affecting the results. Hence it is necessary to replace the micrometer with another precise device capable of giving purely translatory input motion. A Hybrid Piezo Actuator (make PI) as shown in Fig. 14b is used as a source of precise and controlled actuation.

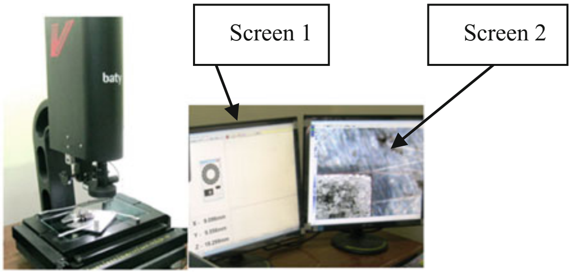


(a) Using a conventional Micrometer

(b) Using a PZT based Hybrid actuator

Fig. 14 Actuation (input displacement)

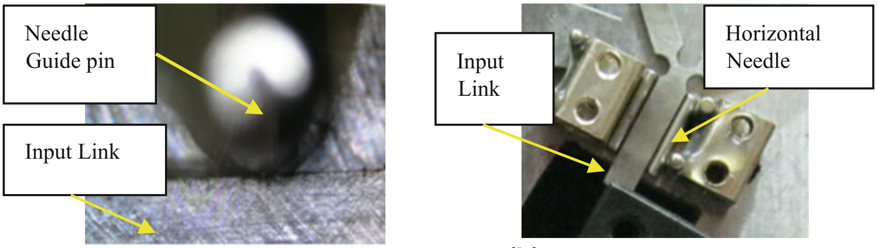
Fig. 15 3D profilometer setup



4.5 *Modifications of Experimental Setup*

The profilometer has two displays, 'Screen 1' is a calibrated screen wherein the locus of output link can be traced/located and used as a reference point for next measurement and the 'Screen 2' is for camera vision. Before proceeding with actual measurements, observation of the sliding pins for their functionality i.e. providing constraints was carried out using camera vision (as indicated in Fig. 15) of 3D profilometer (i.e. whether the needle pins are guiding the input link or any contact loss is observed). Some contact loss was observed while carrying out this trial (Fig. 16a) and this can result into undesired deflection of the output link. The needle pin has a circular topography which results into a point contact with the input link violating the sliding constraint imposed during simulation. Hence the orientation of the needle pins was changed in order to provide sliding contact/support and the setup was modified accordingly as indicated by Fig. 16b.

The modified setup was again observed under the profilometer to ensure continuous contact between input link and the sliding pins. After ensuring contact between the sliding members and input link, the setup is now ready for actual measurements. Trials conducted validated the performance of developed micromechanism.



(a) Vertical needle guide pin (Point contact)

(b) Horizontal needle guide pin (Sliding contact)

Fig. 16 Ensuring contact using 3D profilometer

5 Inferences

In the development of the precision experimental setup, following important aspects are observed.

5.1 Inferences Drawn from Assembly Developed

A horizontal mounting orients the sensitive axis in line with the gravitational force avoiding flexing of the flexures due to self weight and hence recommended.

Steel balls are the best alternative for supporting the mechanism as they provide a point contact avoiding surface to surface contact thereby reducing the inertia effect.

Proper selection of the hinge support needs to be accommodated with appropriate extension and the layout of the extension needs to be decided depending upon the effect (i.e. force) it will induce on the mechanism.

Non-conforming (i.e., point or line) contacts are proven to be very stable to make interface between compliant pantograph and base. It increases the stiffness of the assembly and also provided a frictionless support to the compliant pantograph.

Horizontal plane of operation simplifies the assembly and it becomes easy to visualize the position attained (from the top).

5.2 Inferences Drawn from Manufacturing Process Undertaken

The performance of the mechanism depends upon manufacturing using WEDM.

Due care is required in selection of the wire entry points on the basis of whether die or punch is to be maintained or otherwise undercutting/overcutting.

A macro scale WEDM can be used for manufacturing of typical micromechanisms such as compliant pantograph with due care of stacking the plates.

Stacking has prevented the cantilever action during machining on the WEDM and in turn avoided shearing of the mechanism towards the end of manufacturing process.

In case of stacking the plates during machining on the WEDM, the percentage error in the dimensions in case of stacked plates is about 0.133% from the desired value (which was 8.4% for unstacked plates).

5.3 Inferences Drawn from the Measurement System Undertaken

The displacement at the input is given by the Microslide and is amplified as well as replicated at the output point 'E'. A non contact type sensor or measurement technique was implemented in order to measure the output motion precisely and with accuracy.

The circular plunger of micrometer induces a lifting force on the mechanism. It is recommended to use precise device capable of giving purely translatory input.

A non contact type displacement measurement system is established in order to measure the micro displacements using 3D optical profilometer with a resolution of 1 μm. This has explored use of Optical Profilometer as a contactless measurement system as well as inspection tool.

6 Setup Developed

The developed precision experimental setup to record micro motion is shown in Fig. 17.

For the developed compliant micromechanism, linear input is ensured using constraints however replication of input motion (angular, in sector) can be obtained at the output end of mechanism.

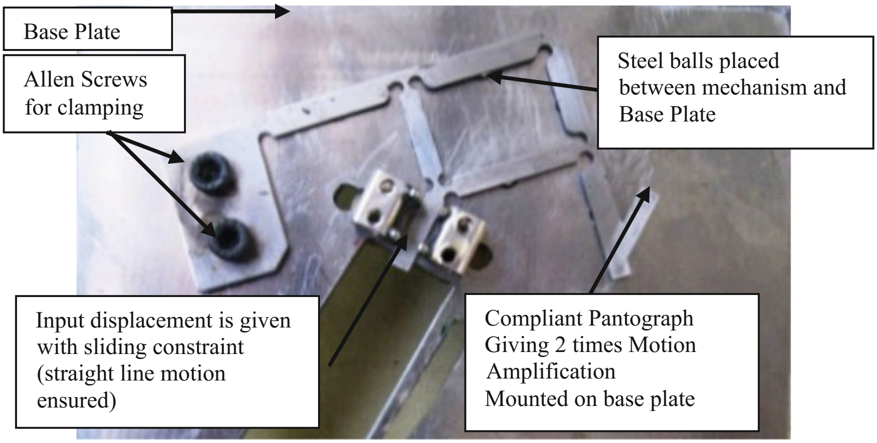


Fig. 17 Setup developed for performance evaluation of compliant pantograph

Table 1 Results obtained

Input displacement (μm)	Output displacement (μm)	Geometric amplification
40	84	2.1000
80	163	2.0375
120	244	2.0333
160	310	1.9375

7 Results and Utility

Compliant pantograph manufactured using Carbon Steel is tested for the geometric amplification (GA). Table 1 gives the detailed results during trials. Targeted Geometric amplification of 2 has been successfully attained by the pantograph.

Developed compliant pantograph can be used as a mechanical amplifier to a non-conventional micro-actuator such as a Piezo Actuator.

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Advanced Piston Technologies for Gasoline and Diesel Engine Applications to Meet EU6 Emission Norms

M. Selvaraji, K. Pramod, S. Sathishbabu, M. Rajkumar, Qi Li, Shaobo Zeng and Haixiao Chai

Abstract The Indian government announced that the country would adopt Bharat Stage VI (Euro VI) norms by 2020, skipping Euro V. In order to meet EU6 emission targets, the technologies which are available for Gasoline vehicles are; Gasoline Direct Injection (GDI) engine, Three-Way Catalytic Converter (TWC), Exhaust Gas Recirculation (EGR) and Universal wide range oxygen sensors. The vehicles with diesel engines having Common Rail Direct Injection systems (CRDI) with variable fuel timing and metering strategies and Injection pressure is up to 2100 Bar, Variable Geometry Turbocharger (VGT), cooled high-pressure EGR, Diesel Oxidation Catalysts (DOC), diesel particulate Wall-flow type filter (DPF), Lean-NO_x Traps (LNT) technology (<3.0 L) [Sanchez et al., Estimated Cost of Emission Reduction Technologies for Light-Duty, 2012, 4], Selective Catalytic Reduction (SCR) technology (>3.0 L) are used in combination to control the emissions. For gasoline applications with high peak cylinder pressures (PCP) and high specific power output (kW/L), the pistons can include a cooling gallery and/or top ring groove reinforcement with Hard Anodising or Ring carrier. To handle the high loads and particulate matter that are being re-circulated into the engine cylinder due to exhaust gas recirculation system to control NO_x formation. Diesel engine pistons include features to enhance bowl rim life like TopCast or Bowl rim remelting is applied to refine the micro structure to achieve higher fatigue strength

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at elevated temperatures, and selective area Hard anodising. For very highly loaded applications, MAHLE Monotherm, Monoweld or Monolite Steel pistons are used.

Keywords Gasoline and diesel piston technology · GDI · CRDI · Steel piston · PVD · BS6 (EU6) emission norms

1 Introduction

As per the latest announcement, BS-VI will be compulsory for all new vehicles in all states of India by April 2020. At present India has enforced BS-IV in NCR and thirteen major cities while rest of the India are still having norms below BS-IV. The major difference in fuel to go from BS-IV to BS-VI is in its Sulphur content [4]. Major OEMs have the technology for BS-VI ready as they are producing EU-VI vehicles for the European countries. The challenge lies in developing the vehicles for Indian operating conditions in the given short period, as such design changes require rigorous testing. In this paper we will be discussing briefly about the different technologies used by OEMs for EU-6 compliant vehicles. The technologies used in piston assembly design for the EU-VI compliant vehicles will be discussed in detail. The paper will conclude with the feasibility of using the technologies related to piston assembly design for BS-VI. The Bharat Stage norms have been derived from Euro norms styled to suit specific needs and demands of Indian conditions.

Figure 1 shows the implementation of EU norms and BS norms by year. Currently in Europe, EU6c norms are being used. In most of the India, BSIII norms are applied, with some cities having BSIV norms. At present India is not going to apply the CO_2 emission levels and vehicle efficiency that is being applied in Europe. RDE is the Real World Driving Emissions, which is the vehicle emissions at actual running conditions, and is being developed in Europe for implementation in the coming years. Looking at the trend of emission regulation in Europe, India will be following the same in coming years. Till now India is using Modified Indian Driving Cycle (MIDC) which is equivalent to the New European Driving Cycle (NEDC) based testing. With implementation of EU6 norms, India will be incorporating the worldwide harmonized Light Vehicle Test Cycle (WLTC) procedure.

1.1 Engine Exhaust System

The Exhaust system of any automobile in general consists of the components like (i) Exhaust Manifold, (ii) Catalytic converter, (iii) Resonator, (iv) Muffler and (v) Tail Pipe [5]. The additional devices provided in between engine and tail pipe such as the Catalytic Converter and Muffler, performs the function of removal of hazardous elements from the exhaust and noise reduction respectively. Limitations

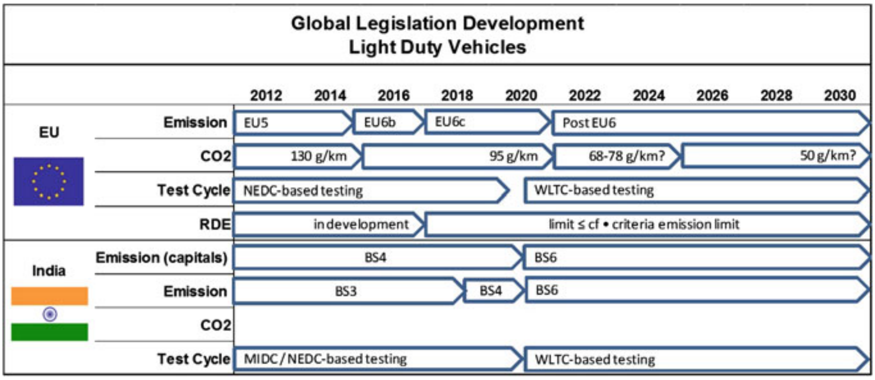

Fig. 1 Evolution of emission norms

on fuel cleanliness and the combustion process leaves some unwanted emissions from the engine that are hazardous and cannot be left untreated. The major function of the Catalytic converter is to filter and treat engine emissions like CO, NO_x and HC [6].

1.2 Emission Norms

Governments all over the world are implementing stringent norms to have cleaner air standards. Bharat stage standards are the adoption of the EURO standards. The complete guideline for BS VI norms has not been laid down by the country but it is pretty obvious that it is going to follow the EU VI norms.

It is clear from Table 1 that while moving from EU IV to EU VI, for gasoline vehicles NO_x emissions decrease by 25% and other emission levels are the same. For diesel vehicles, CO emissions reduce by 68%, NO_x by 82% and HC emission remains the same. In addition to the above, a limit on PM emissions of 0.005 and 0.009 is imposed on gasoline and diesel vehicles respectively.

Table 1 Emission levels for EU4 versus EU6 [4]

Emission targets in g/km	EU IV				EU VI				% reduction			
	CO	NO_x	HC	PM	CO	NO_x	HC	PM	CO	NO_x	HC	PM
Gasoline	1	0.08	0.1	–	1	0.06	0.1	0.005	0	25	0	–
Diesel	0.25	0.025	0.5	0.05	0.08	0.005	0.5	0.009	68	82	0	82

2 Vehicle Emissions and Control Strategies

The ideal combustion of fuel inside the combustion chamber should have CO_2 and H_2O as the by-product. However, due to the complex combustion process and presence of other gasses and contaminates, it produces undesirable gases like CO and NO_x. In addition to CO and NO_x, Hydrocarbons (HC) and Particulate matter (PM) is also present in engine exhaust gas as a result of incomplete combustion [3]. The particulate matter is present in all diesel engines and in Gasoline Direct Injection (GDI) engines. NO_x is produced as a result of a reaction between oxygen and nitrogen at high temperature. In other words we can say that a lean mixture provides enough oxygen for complete combustion of hydrocarbons but it causes high temperature in the combustion chamber and also makes extra oxygen available for NO_x formation. The emission control from an engine is a trade off between HC and NO_x. The method to reduce exhaust emission from a vehicle includes both In-cylinder control and after treatment [4]. Both these controls needs to be designed as a single unit, to work in synchronization with each other to obtain a desired and economic pollution control.

If we look at the in-cylinder combustion controls, NO_x and CO_2 are the by-products of combustion and can be reduced by controlling the combustion parameters like air management, ignition timings, fuel injection control etc. One of the major sources of hydrocarbon emission is the un-burnt fuel left in the gap between top land and cylinder. Also the lubrication oil carried by oil rings into the combustion chamber gets burned and causes pollution. The blow-by which is the leakage of hot combustion gases into the crank case contributes to the crankcase hydrocarbon emission which is a major concern in any automobile [2]. This shows that the design of a piston assembly which consists of a piston, piston rings, gudgeon pin, circlip and conrod is of utmost importance if we are looking for emission control. Besides the emissions of NO_x, CO and HC, the design of the piston assembly is also responsible for some part of the fuel economy of the vehicle, as the friction in the engine is one of the major sources of energy loss. There are two ways to control the emission produced by any engine In-cylinder and after-treatment control.

2.1 In-Cylinder Control

Gasoline Engine

The total In-cylinder emission control methods work as a system which is designed to meet emission regulations while maintaining performance of the engine. Most of the in-cylinder control strategies have the objective of reducing the temperature and extra oxygen inside the combustion chamber. The various technologies used today are namely, (i) Electronic Control Unit (ECU), (ii) Exhaust Gas Recirculation (EGR), (iii) Heated Oxygen Sensor (HO2S), (iv) Variable Valve Timings (VVT),

(v) Engine Downsizing, (vi) Gasoline Direct Injection (GDI) and (vii) Multi Point Fuel Injection (MPFI) [4].

Diesel Engine
Diesel engine In-cylinder emission control is more complex compared to the gasoline engine and this is mainly because of the difference in fuel ignition methods. In order to have a complete combustion, fuel should mix properly with the compressed air. In order to achieve this, the combustion bowl design and fuel injection system have a major role to play. The various technologies available for diesel engines are, (i) Turbo-charging (Variable Geometry Turbine VGT), (ii) Cooled EGR, (iii) Electronically Controlled IDI or DI, (iv) Common Rail Fuel Injection and (v) Variable Fuel Injection Timings [3].

2.2 After-Treatment Control

Gasoline Engine
The market trend of going towards direct injection has made a use of Gasoline Particulate Filter (GPF) and CC catalyst mandatory in many engines. Some of the after-treatment technologies are, (i) Three-Way Catalytic Converters, (ii) Closed-Coupled catalyst, (iii) Optimized Wash-Coats design and (iv) Gasoline Particulate Filters [4].

Diesel Engine
A Diesel oxidation catalyst (DOC) is used to convert incomplete combustion products (CO and HC) into CO_2 and H_2O. The particulate matter from a diesel engine is filtered using a Diesel Particulate Filter (DPF). Nitrogen traps are used to remove NO_x from an exhaust. The after treatment emission control methods for diesel engine are not independent of In-Cylinder emission control systems. They have to be synchronised. For example, the DOC needs to warm up fast in order for it to be effective similarly the DPF needs to be regenerated at certain intervals. For this purpose, fuel injection strategies need to be controlled. Some of the After-treatments for diesel engines are, (i) Diesel Oxidation Catalyst, (ii) Diesel Particulate Filter and (iii) Lean Nitrogen Trap [6].

2.3 Applicability of Different Technologies for Gasoline Engines

Table 2 shows the applicability of different technologies for different Euro norms.

Table 2 Gasoline engine technologies

Technology Matrix	Norms	<EU3	EU4	EU5	EU6
In-cylinder control	electromechanical distributors	•			
	Electronic ignition	•			
	Multipoint fuel injection (MPFI)	•	•	•	
	Gasoline direct injection (GDI)				•
	Combustion improvements through engine			•	•
	Incremental improvements in air-fuel			•	•
After-treatment systems.	Three-Way catalytic Converter (TWC)	•	•		
	single O2 sensor	•			
	underfloor (UF) catalyst	•	•		
	close-coupled (CC) catalyst for cold start	•	•		
	Exhaust Gas Recirculation (EGR)	•	•	•	•
	more responsive heated oxygen sensors	•	•		
	secondary oxygen sensors after the catalyst	•	•		
	Universal wide range oxygen sensors			•	•

2.4 *Applicability of Different Technologies for Diesel Engine*

Table 3 shows the various technologies used in EU6 compatible vehicles. From In-cylinder emission control Common Rail Injector System, Variable Geometry Turbocharger, Variable fuel timing and metering strategies, High fuel injection pressure, Cooled EGR are the some of the technologies used [7].

Table 3 Diesel engine technologies

Technology Matrix		Norms	<EU3	EU4	EU5	EU6
in-cylinder control		Mechanical rotary pump fuel injection systems	•			
		Electro-mechanical cam-controlled fuel injection	•			
		Rotary fuel injection system	•			
		Indirect fuel injection	•			
		Common-rail or unit-injector systems	•	•	•	•
		Injection pressure. Bar	<900	1600	1900	2100
		Electronic fuel timing	•			
		Naturally Aspirated (NA)	•			
	Turbocharging	Without inter-cooling	•			
		With inter-cooling		•		
		Variable Geometry Turbocharger (VGT)			•	•
		Electronic assistance for fuel metering	•	•		
		Variable fuel timing and metering strategies		•	•	•
	Exhaust Gas Recirculation (EGR)	Mechanically activated EGR circuits	•			
		Cooled EGR	•			
		Cooled, electronically controlled and solenoid-Operated EGR.	•			
		Cooled EGR with a DC motor actuator		•		
		Cooled high-pressure EGR.			•	•
After-treatment systems.	DPF.	DPF with active regeneration.			•	
		Wall-flow DPF				•
		Diesel oxidation catalysts DOC	•	•	•	•
		Lean-Nox Traps (LNT) (< 3.0L)				•
		Selective Catalytic Reduction (SCR) (> 3.0 L).				•

3 Piston Assembly

A piston assembly consists of a Piston, Piston rings, Gudgeon pin and Circlips. The function of a piston assembly is to transfer the pressure force of the hot gasses to the crankshaft, where it gets converted into the rotary movement of the crankshaft. The function of sealing the combustion chamber is done by the top and second compression ring. The second ring also does the function of scrapping extra oil off the cylinder surface. The third ring is called the oil control ring and does the function of retaining the oil in the sump and lubricating the cylinder wall. The temperature of a piston can reach as much as 350 °C dependent on the engine type, capacity, ignition timing and piston design etc. [2]. The piston with rings, pin and a part of the conrod which is towards the small end altogether becomes an oscillating mass.

3.1 Piston Design Considerations

Design of a piston is mainly a trade off between weight and strength. The piston also forms a variable combustion chamber so its design is also influenced by the emission requirements. The major parameters of the design are the compression height, ring land height, cooling of piston, combustion bowl or piston crown and pin boss. Similarly, a reduction in top land height of the piston results in reduced HC emission from the engine. Reduced hydrocarbons emissions demands the minimum possible height of the top land, but as we reduce the height of the top land it causes an increase in temperature of the ring grooves and pin bore, also it reduces the strength of the crown. Higher temperatures in the first ring groove causes burning of lube oil in the ring groove and land area and deposits carbon inside the groove resulting into clogging of the groove and soot emission. To counter the problem of high temperature, a cooling gallery can be provided. The gallery is designed in such a way that it absorbs heat from the piston in an optimised way. If the heat removed by the cooling oil in the gallery is too high, it will result in a high temperature gradient in the piston crown and can result in high thermal stresses and reduced life. In some of the pistons where specific power is high or fuel quality is affecting groove wear, a ring carrier is used to avoid micro welding etc. between the piston groove and ring.

The effective force transferred to crank reduces with increasing inertial force. This indicates that as we move to higher operating speed, the oscillating mass reduction becomes necessity for engine performance. Figure 2 shows the different types of MAHLE gasoline pistons. The EvoLite is the latest light weight design, and can be designed with Ring carrier and/or cooling gallery. The latest EvoLite design is 38% lighter than the Box type of design with increased specific power [2]. The major weight reduction is achieved through reducing overall wall thickness and improving the structural stiffness of the piston in combination with advanced materials like M174+ which is stronger than M124. Figure 3 shows the temperature

Piston	Baseline	Low weight	Ultra low weight
	Box type	Evotec 2	EvoLite
RC	x	x	x
SC	x	x	x
RSC		x	x

RC: Ring carrier
SC: Salt core
RSC: Ring carrier and salt core

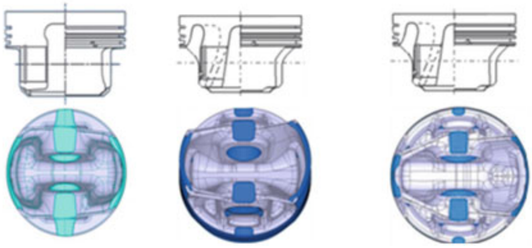

Fig. 2 Mahle piston evolution

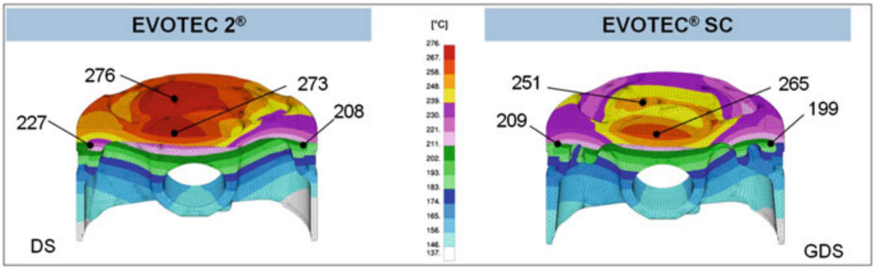

Fig. 3 Effect of SC on temperature distribution [2]

distribution in a typical Evotec2 and EvotecSC (cooling gallery type) gasoline piston.

For diesel applications, TopCast pistons are made using a special casting method combined with a heat treatment to produce a fine granular structure in the piston bowl rim resulting in improved performance of the piston. The fine distribution of grains in the bowl rim of TopCast pistons compared to standard cast pistons results in the improved life of the piston for the same level of stress amplitude. The highest temperature in the piston for diesel piston is at the bowl rim which is the failure prone area. By careful design of the bowl rim area, including TopCast, elevated cooling galleries (eSC), applying selective Hard anodising, and inspecting the rim for oxides with Eddy current inspection the life of the piston can be enhanced. Figure 4 shows the effect of MAHLE's eSC2 technology in reducing the temperature by almost 50 K. Figure 4 shows the comparison of temperature between a

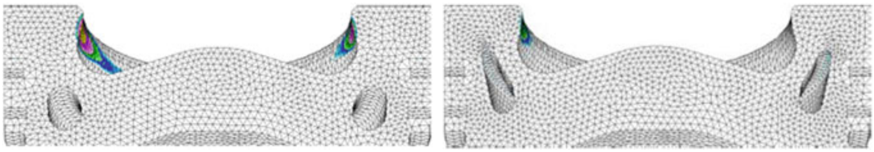

Fig. 4 Salt core and elevated salt core technologies

standard cooling gallery and eSC2 cooling gallery design. This allows the top land height to be reduced.

For very high loaded applications, the latest trend is to move towards the use of steel pistons. Steel pistons allow reductions in compression height due to their higher strength and thermal stability. This results in engine downsizing as well as improved piston life. The disadvantage of the steel piston is its weight and cost.

3.2 Piston Ring Design Considerations

Piston rings are the metallic seals used to seal the combustion chamber. They also provide the function of transferring heat from piston to cylinder. The rings also prevent lubrication oil passing from crank case to combustion chamber. The radial contact with cylinder is achieved through the spring force of the ring and it is assisted by the gas pressure on the 1st and 2nd compression rings. The contact pressure exerted by the ring on to the cylinder surface is a function of tangential force of the ring which in turn is a function of open gap of the ring is given by the below equation,

$$P = \frac{2F_t}{dh} \tag{1}$$

where, Ft is the tangential load of the ring, d is the bore diameter and h is the axial height. Also one of the important parameter while designing piston ring is the conformability, which is the ability of the piston ring to be in contact with deformed cylinder bore. Gas pressure keeps the ring sitting on the piston ring groove, hence assisting the sealing. Piston rings are one of the major unavoidable sources of friction in a piston assembly. The blow-by gasses from the combustion chamber flows to the crankcase and is one of the primary cause of crank case emissions [4]. Sealing provided by the rings prevents the oil in the crank case from entering into the combustion chamber where it would get burnt. Two things to look for while designing a ring pack is the tangential force and surface coatings of the rings. In passenger car piston assemblies the ring pack consists of three rings namely, (i) First compression Ring, (ii) Second compression ring and (iii) Oil ring. The major function of the first compression ring is to seal the combustion chamber during the combustion stroke. The second compression ring also has the function of partially sealing the combustion chamber, and in addition it also helps by scrapping the excess oil from the cylinder wall. The main function of oil control ring is to retain the lubricating oil in the sump, and it also lubricates the cylinder wall for the compression rings.

Piston Ring Coatings

The surface of the ring that faces the cylinder wall is called the running surface. First rings are usually made from steel wire, and different surface treatments and coatings applied to achieve the engine performance goals. If lower friction and increased wear resistance is needed, the ring face can be coated with two layer or three layer ion coatings. Double layered ion coatings applied by PVD (Physical Vapour Deposition) involve a first layer of chromium called as a chromium interlayer followed by a CrN layer. The thickness of the coating can be 10–20 μ. The rest of the surfaces of the rings remain as a nitride layer. The second ring is generally a Napier ring or a scrapper ring as it scrapes and removes the excess oil from the cylinder surface. The recess provided below the scrapping edge facilitates effective removal of oil. The face of the Napier ring can be coated with chrome plating in order to provide enhanced wear resistance if needed. The relative radial wear reduces by 70% due to chrome plating when compared with a base material of pearlitic grey cast iron.

The Oil ring can be a two piece ring or the three piece design. A two piece design has an I-shaped ring and a spring behind the ring which provides the additional radial force required for sealing. The i-shaped ring of a two piece design generally has a series of slots or holes provided on the inner surface to allow oil to pass. A three piece oil ring design has a spring sandwiched between two side rails. The function of an oil ring is to remove the excess oil from the cylinder surface, but provide an optimum amount for lubrication of the compression rings. Figure 5 shows the effect of total ring pack tension on CO_2.

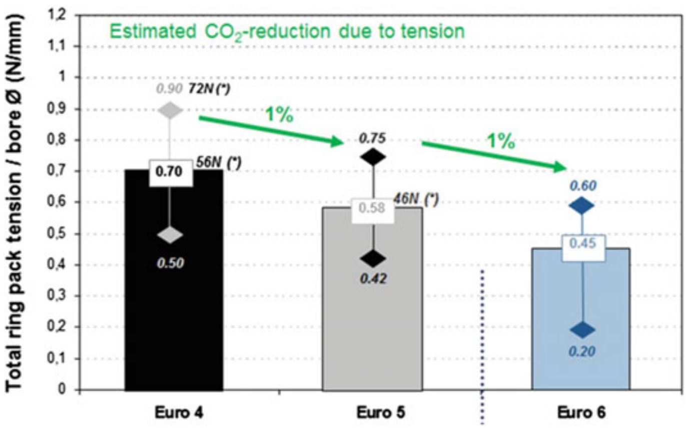

Fig. 5 Guidelines for selecting ring pack for diesel engine [4]

4 Conclusions

- Improved structural stiffness has helped reduce piston mass by 38 percent from conventional Box type to Evolite design.
- The compression height can be reduced by 10% by using Evolite design compared to a Box type piston.
- For gasoline pistons, a drop in temperature of 25 K can be achieved by providing a cooling gallery to an Evotec design piston.
- For diesel pistons, a temperature drop can be is achieved by enhanced cooling with MAHLE's eSC2 cooling gallery design.
- The durability of diesel aluminium alloy pistons is enhanced by a TopCast designed piston by up to 5 times compared to a conventional diesel piston.
- MAHLE's range of steel pistons, including Monotherm, Monoweld and Monolite has made it possible to meet high power, long oil change and high durability requirements for diesel engines.
- Ring pack frictional losses can be reduced by 20–50% with optimised rings in terms of tangential load and high wear resistant coatings (PVD and DLC).

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Design and Development of a Novel Sit-to-Stand and Mobility Assistive Device for Ambulation and Elderly

Mohammed Rajik Khan, Biswaksen Patnaik and Sonalisa Patel

Abstract The present work aims to design a novel mobility assistive device which incorporates an automated lifting technique following human sit-to-stand transfer trajectory. Experiments have been conducted to record the sit-to-stand trajectory for 10 different candidates using 3D motion capture cameras. Here, a pantograph mechanism is employed to replicate the sit-to-stand transfer trajectory. The mechanism is coupled to a structural framework which works as a walking assistive device post lifting. A prototype is fabricated to verify the design aspects of the device. For validation, the proposed design is simulated and analyzed for ergonomic consideration in a virtual CAD environment. Results in terms of body angles and comfort regions are shown at three different positions of the trajectory followed during the lift. The proposed device may help in the mobility of the patients during ambulatory care and the elderly by providing safety and preventing sudden fall, ensuring user comfort.

Keywords SIT-to-Stand transfer trajectory · Automated lifting · Walking assistive device · Ergonomic analysis

1 Introduction

Early ambulation during post-operative care exposes people with critical injuries to various mobility problems. While providing ambulatory care to the patients, the caregivers are also exposed to adverse postures which lead to various musculoskeletal

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disorders. Along with this, there are various other walking problems associated with aging caused due to functional decline and post-fall injuries and fractures. This has led to the demand for various gait belts, patient lifts and mobility assistive devices like walkers, rollators, etc. Such devices generally induces stiffness to the patients' bodies and stresses to the injuries during their use. Again, these devices are highly dependent on the caregivers requiring constant help and support. Therefore, proper ergonomic intervention is essential to design and develop novel rehabilitation devices in order to increase user comfort and to minimize pain and other postural disorders. Most of the authors have investigated on various mobility assistive devices with direct lifting techniques paying less attention towards sit-to-stand natural trajectory.

Mombaur [1] has presented a numerical study of the dynamics of unsupported sit-to-stand motions based on mechanical multi-body models and optimal control techniques. Salah et al. [2] have proposed a cost effective solution for an assistive device to monitor proper posture and movement. Bostelman et al. [3] have designed a novel home lift, position and rehabilitation (HLPR) chair which facilitates lifting and can transfer patients easily. Vena et al. [4] have investigated the differences in the biomechanics of Sit-to-Stand transfers for different pole configurations. Papa et al. [5] have discussed analytical and experimental procedures to identify the motor strategies in a sample of healthy adults. Yoshioka et al. [6] have presented a study to determine minimum peak joint moments required to perform a sit-to-stand task. Challenges are still faced in this area where transfer of patients following sit-to-stand natural trajectory is still not employed in any device, compromising the user comfort.

The new product developed in the present work has followed the design process for ideation, concept development and evaluation similar to the authors previous work from Khan et al. [7, 8]. The proposed device employs a pantograph mechanism that strives to achieve automated lifting by following the sit-to-stand (STS) transfer trajectory. By following the said trajectory a physiotherapeutic balance is maintained which prevents the user to encounter any postural imbalances or musculoskeletal disorders. A group of 10 healthy candidates (08 males and 02 females) participated for the experimentation to record the position coordinates of the shoulder joint during their movement from sitting to standing position. The pantograph mechanism driven by electro-hydraulic actuators is designed to follow the scaled-down mean trajectory in order to provide the required trajectory during the lift. Supportive structures like straps and harnesses, arm rest, etc. are attached to the designed framework of the device to provide support and to prevent sudden fall while in use. The flexibility of customizing the mechanism makes it accessible to a larger group of people. A prototype is also fabricated for physical visualization and design verification. The proposed design is verified by performing simulation and analysis for ergonomic consideration in CATIA V6 software. The device may find great usage in providing rehabilitation and for monitoring early ambulation during post-operative care and can also be utilized as a walking assistive device for day-to-day activities.

The composition of the paper is further organized as follows. Section 2 presents the design of novel automated lifting and mobility assistive device. Implementation of the proposed design in a commercial CAD application software is done in Sect. 3. Section 4 discusses the verification of design and ergonomic analysis of the mobility assistive device. Finally, conclusion and future scope are suggested in the last Section.

2 Design of a Novel Mobility Assistive Device

Mobility assistive devices help in mobility of the persons with temporary/permanent mobility impairment. Such devices are also essential for the elderly requiring mobility assistance to carry out their day-to-day activities. Here, we have designed an automated lifting and mobility assistive device that follows the sit-to-stand trajectory of a person while lifting and also assists in walking. Figure 1 depicts the two-dimensional orthographic view of the device showing the mechanism and the structural framework. L_1 and L_2 are the length and width of the base of the framework respectively. L_6 and L_3 are respectively the heights of the initial and end point of the scaled down STS trajectory from the base. L_4 is the height of the extension link of the mechanism. L_{11} and L_5 are the heights of the mechanism and actuator base points O and O' from the base of the frame respectively. L_7 is the distance of the end point of the scaled down STS trajectory from the extreme front end of the base of the framework. L_8 is the distance between the hand and the shoulder support. L_9 and L_{10} are the heights of the shoulder and hand supports respectively. L_{12} is the distance between two pantograph mechanisms on each side. L_{13} and L_{14} are the distances between the hand and shoulder supports respectively. L_a is the full length of the actuator.

The design of the proposed device is categorized as per the functions below:

(a) Automated lifting
(b) Mobility assistance
(c) Supporting structures

2.1 Design for Automated Lifting

In the proposed device, a pantograph mechanism is incorporated to replicate the sit-to-stand trajectory. The mechanism is designed to follow the scaled down trajectory which in turn helps in lifting the person to the required height. An electro-hydraulic actuator is employed in the device to drive the mechanism.

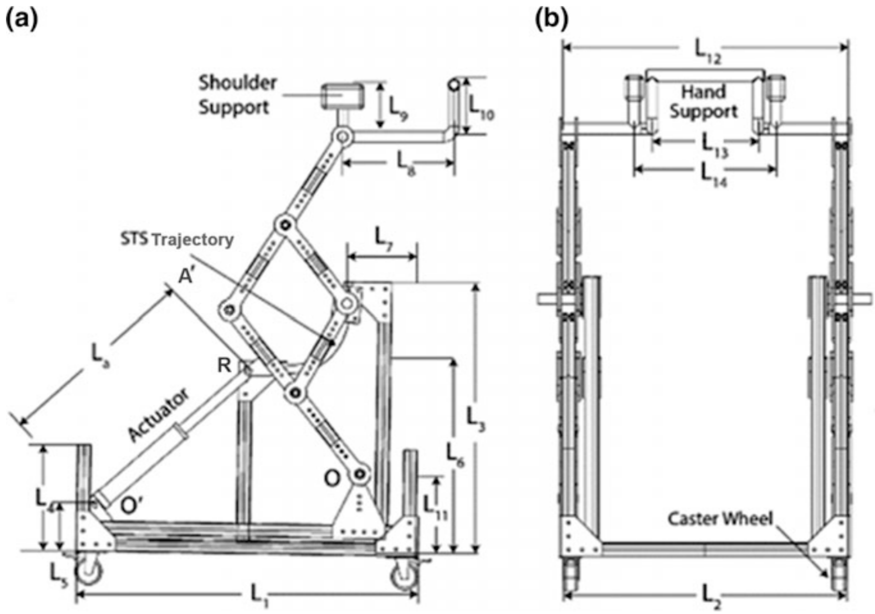

Fig. 1 Two-dimensional orthographic view of the proposed mobility assistive device **a** Side view **b** Front view

Experimentation to Obtain Sit-to-Stand Transfer Trajectory

To generate a mean sit-to-stand transfer trajectory, proper experiments have been conducted using four Oqus infrared motion capture cameras (Qualysis Oqus 3+) [7]. Ten healthy candidates (02 females and 08 males) with no neurological disorders, ranging from 5th to 95th percentile, participated in the experimentation. An informed consent for their participation prior to the study were provided. Reflective markers were attached to the shoulder joint of the candidates and they were made to sit on a chair at a certain height from the ground level. Markers are also placed at the chair top to determine its elevation, and also on the ground to determine relative movement of the shoulder with respect to the ground frame of reference. The position coordinates of the shoulder joints of the candidates were then recorded during their movement from sitting to standing position. 10 different trials for a single candidate were taken so as to obtain precise position coordinates. The transfer trajectories were then obtained from the graphs plotted for the respective position coordinates followed by a mean trajectory. Figure 2 shows the graph of 10 mean trajectories of 10 different candidates. All dimensions are in mm. This graph depicts the similar nature of sit-to-stand trajectory for all the candidates. Figure 3 shows the mean trajectories of 3 candidates falling in the category of 5th, 50th and 95th percentile.

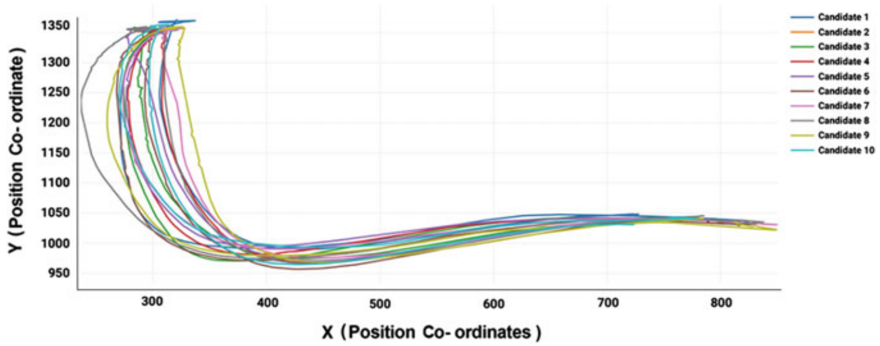

Fig. 2 Graph depicting ten mean STS trajectories of ten different candidates

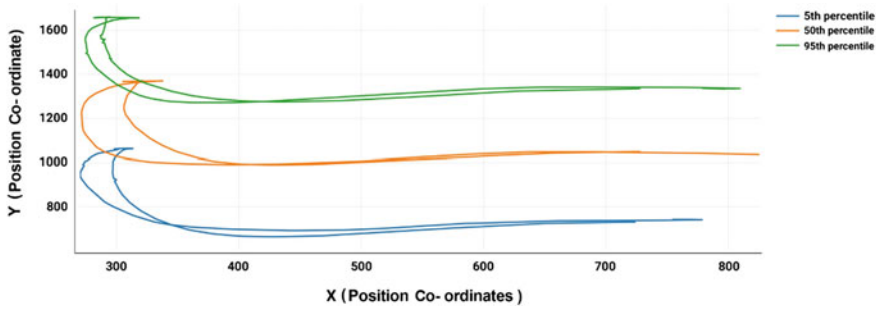

Fig. 3 Mean STS trajectories of 03 different persons each of 5th (*blue*), 50th (*orange*) and 95th (*green*) percentile

Analytical model of the pantograph mechanism
A four bar pantograph mechanism [9] is devised to follow the scaled down mean trajectory so as to trace the actual sit-to-stand natural transfer trajectory. Figure 4 shows the line diagram of the devised pantograph. The link lengths of the governing mechanism can be mathematically expressed as,

$$a, b = f(\theta_{min}, \theta_{max}, m) \tag{1}$$

where, $(m' x)^2 + (m' y)^2 + (2ab\, cos\theta min - a^2 - b^2) + 2\, m'y \sqrt{(2abcos\theta_{min} - a^2 - b^2)} = 2abcos\theta_{\max} - a^2 - b^2$, $OA = a$, $AB = b$, $OA' = a(m)$, $A'B' = b(m)$, m is the magnification factor and $m' = \frac{1}{m}$.

Here, θ_{min} and θ_{max} are the angles made by the link length OA during the initial and final position respectively while tracing the scaled down trajectory.

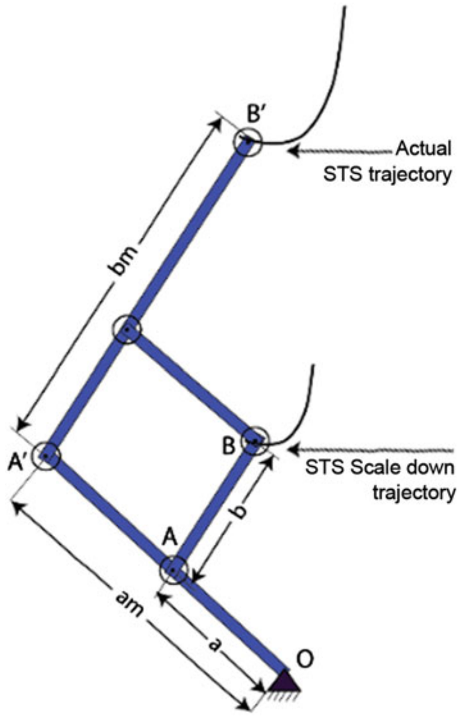

Fig. 4 Line diagram of the pantograph mechanism employed in the device

2.2 Design for Support Structures

Figure 1 depicts the complete structural framework of the proposed mobility assistive device. A set of electro-hydraulic actuator driving the pantograph (four bar) lifting mechanism which follows the scaled down natural sit-to-stand transfer trajectory consecutively along two parallel planes on each side. The actuator end R (shown in Fig. 1) is placed at one-fourth of the distance of the link OA’ from the end A’ [10]. Two shoulder supports connected with arm rests inside the frame are incorporated on each side to provide support and balance to the trunk portion of the user’s body during the lift. The stability of the device, while in use, is ensured by minimizing the toppling effect by completely accommodating the structural bearing loads inside the framework. The provision of straps, attached to the device, defines the sitting posture of the user and prevents sudden fall (not shown in Fig. 1). The flexibility of changing the height of the mechanism from the ground level and changing the link lengths of the lifting mechanism makes it accessible to an extended group of people ranging from 5th to 95th percentile.

2.3 Design for Mobility Assistance

The proposed device not only contributes for automated lifting but it also acts as a mobility assistive device. Figure 1 shows the inclusion of caster wheels at the base of the structural framework. These wheels, provided with brakes, aid in mobility once a person is lifted. The device provides a hassle free assistance in mobility with just a little application of force. Certain modifications in the base structure of the frame can be made to make the device compact and portable while not in use.

3 Implementation

The proposed design of the mobility assistive device is implemented in CATIA V6 modeling environment, a commercial CAD software. This software enables the users to create three-dimensional models in a Graphical User Interface (GUI). The Indian anthropometric standards of the 5th, 50th and 95th percentile have been taken into consideration based on the boundary mannequin approach [8], [11]. The scaled down STS trajectory and the structure of pantograph have been analyzed graphically to determine the position of the lifting mechanism mounted on the structural frame. The dimensional parameters required to completely design the novel mobility assistive device are shown in Table 1. Figure 5a shows the 3D virtual model of the automated lifting and mobility assistive device in the CAD environment. Figure 5b shows the 3D prototype (not in true scale) of the device developed using Rapid Prototyping technique and wooden frames for functional and visual verification.

4 Rapid Upper Limb Assessment

The 3D virtual model of the automated lifting cum mobility assistive device generated in CAD environment is exported to the ergonomic simulation module of CATIA V6. The shoulder and hand supports of the device along with the supporting straps helps the body of any person to lift from sitting to standing position while driving the lifting mechanism through a set of electro-hydraulic actuators provided at the base of the frame. The simulation from sit-to stand position in the device is evaluated for Rapid Upper Limb Assessment (RULA) to predict posture comfort. A 50th percentile mannequin has been considered for the present ergonomic evaluation. The range of movements for each body part is divided into sections; each of the positions of various body parts are assigned scores and corresponding color code (as shown in Table 2) according to the RULA Employee Assessment Worksheet [12] in order to investigate the acceptable or uncomfortable postures. Color code green and yellow with scores 1 and 2 respectively being the

Table 1 Dimensional parameters for the design of proposed mobility assistive device

Sl. No.	Parameters	Dimensions (mm)
1.	L_1 (length of the base of framework)	982.47
2.	L_2 (width of the base of framework)	798.57
3.	L_3 (length of the end point of the scaled down STS trajectory from the base)	784
4.	L_4 (height of the extension link of the mechanism)	304.80
5.	L_5 (heights of the actuator base points O' from the base of the frame)	124.17
6.	L_6 (length of the initial point of the scaled down STS trajectory from the base)	553.06
7.	L_7 (distance of the end point of the scaled-down STS trajectory from the extreme front end of the base)	218.22
8.	L_8 (distance between the hand and the shoulder support)	320
9.	L_9 (height of the shoulder support)	154.03
10.	L_{10} (height of the hand support)	150
11.	L_{11} (heights of the mechanism base points O from the base of the frame)	233.71
12.	L_{12} (distance between two pantograph mechanisms on each side)	818.64
13.	L_{13} (distance between the hand supports)	300
14.	L_{14} (distance between the shoulder supports)	400
15.	L_a (full length of the actuator)	521.39
12.	a (link length of the pantograph)	297.46
13.	b (link length of the pantograph)	297.46
14.	m (magnification factor for the pantograph)	2
15.	m' (reciprocal of m)	0.5

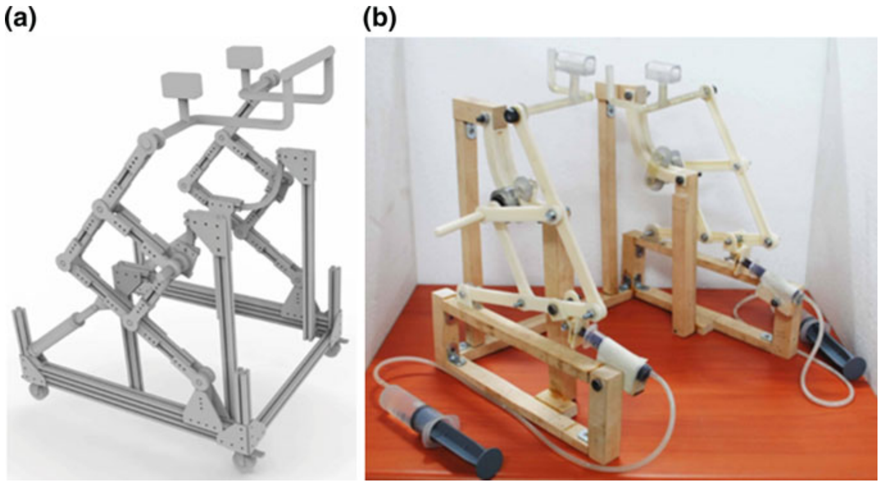

Fig. 5 Automated lifting and mobility assistive device **a** 3D Virtual model **b** 3D Prototype

Table 2 Color codes for rapid upper limb assessment scores

Sl. No	RULA score	Color code
1.	1	Green
2.	2	Yellow
3.	3	Orange
4.	4	Red

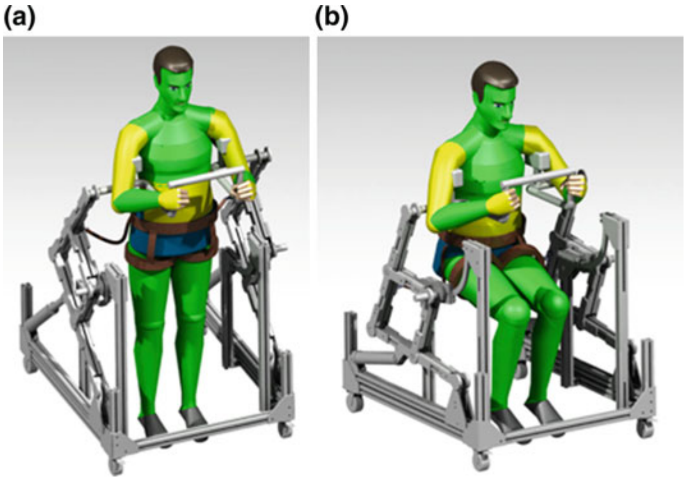

Fig. 6 RULA analysis considering **a** Standing posture **b** Sitting posture

acceptable posture and orange and red with scores 3 and 4 respectively being the uncomfortable postures. Figures 6a, b shows the two instantaneous positions of the mannequin during the lifting simulation. Color code variations from green to yellow over various body parts as shown in these figures during the simulation at two instantaneous positions shows the acceptance of the postures.

5 Conclusion

A user-centric product design approach is followed to conceptualize and develop a new automated lifting cum mobility assistive device. New product ideation, conceptualization, detailed design and implementation through prototype development followed by ergonomic evaluation is precisely shown for the development of a novel rehabilitation device. The concept of applying pantograph mechanism replicating the sit-to-stand trajectory to ensure the provision of the proper lift is properly ideated. This novel device helps the patient to attain a physiotherapeutic balance during the lift and also assists in walking by acting as a mobility assistive device. The device is functional for the population ranging from 5th to 95th percentile. Necessary attachments required to elevate the mechanism are designed properly and has the provision for changing the link lengths required to accommodate persons with variations in height. Here, the sliding surfaces used in this device are assumed to be frictionless. Proper bearings and roller channels can be incorporated in the design before manufacturing the actual working device to minimize friction. The ergonomic analysis was performed to assess the body angles at different postures during the lift. The Finite Element Analysis of the 3D model of the device needs to be performed in the future to analyze the strength and sturdiness of the device. The device may find an extensive application in providing rehabilitation and monitoring early ambulation during post-operative care.

The existing devices in the market are generally the gait belts, wheelchairs, crutches of various kinds and various patient lifts that require heavy support machinery to control and operate. Most of the devices requires an external help or care giver. In the proposed concept, the user can operate the device independently from sitting to standing to walking postures with great ease. Major advantage is the adoption of natural trajectory of sit-to-stand posture during the lift. This device can also be utilized by the elderly as a walking assistive device for their day-to-day activities where they face problems while sitting and standing. Further the device can also be used be as a physiotherapeutic device where proper harnesses can be attached to it that can help in providing rehabilitation to the victims of lower body fractures and injuries.

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Physiological Effects of Backpack Packing, Wearing and Carrying on School Going Children

Ishant Gupta, Parveen Kalra and Rauf Iqbal

Abstract Thirty male school children from primary school, aged 12 years, were selected to carry backpacks of 10% body weight where 0% body weight was used as a baseline. Heart rate and blood pressure tests were conducted on the subjects. Subjects had walked on a treadmill for 20 min at each load condition at 1.1 m/s. This was done in both cases when subjects followed the normal pattern of packing and wearing and when they followed the American Occupational Therapy Association (AOTA) recommendations. Heart rate was recorded before, during and 5 min after walking on treadmill whereas blood pressures were measured before and immediately after trial, and at 3 and 5 min after every trial. The results showed a significant difference in heart rate, blood pressure and its recovery for 10% body weight load conditions before and after recommendations. The packing, carrying, wearing of backpack should be done as per the AOTA guidelines.

Keywords School children · Heavy backpack · Physiological parameters · Packing strategies · AOTA

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1 Introduction

The most common form of load carriage used in the world since ages is backpacks, especially used by school going students. The education system prevailing in the country lays lot of emphasis on textbook based learning. In view of inability of teachers to specify the subject textbook to be used in a particular period and, the practice of giving homework to students and at times the children are usually forced to carry a number of books and notebooks between school and home resulting in heavy backpacks. According to the data released by Ministry of Human Resource Development in 2014 approximately 223 million students in India need a backpack to take away items to and from school every day [1]. The ideal load carrying system would be one that does not disturb the body's natural posture, balance and movements. The load must be dispersed onto the skeletal structure in a balanced way and should not put strain on the body in any direction.

School going children are the building blocks for their nation. Hence there has been a growing concern among health parents, practitioners, and educators to reduce the increasing load of school backpack that may cause serious effect on the growth of the students [2]. In US alone there were 12,688 acute injuries associated with backpacks [3]. As per the findings of the researchers around the world weight carried by the school going children should limits to 10% of the body weight [2, 4, 5]. According to the study conducted in Bengaluru, school going children carried backpacks of more than 25% of their body weights load conditions, which were two and a half times more than the recommended weight limit (10% of body weight) for backpacks carried by school children [6]. Another study conducted in India, by Malhotra and Sen Gupta which investigated the physiological variations due to backpack carriage of 2.6 kg on six school boys aged 7–11 years in different positions. The findings of this research showed that, double strap style rucksacks, resulted in the least energy expenditure as compared to backpack carried on the lower portion of back single shoulder and hand [7]. According to the study conducted by Voll and Klimt in Germany regarding the distance between home and school for the school children and weight of backpacks of class I to class IV. The weight of backpacks varied from 11.5 to 14.5% of body weight load conditions, and the averaged time taken by school children between school and home was 29 min. the findings of this study was suggested school bags weight should not exceed the optimum weigh limit of about 10% of the body weight, and the upper limit of the weight for the school backpacks should be 13% of the body weight [8]. Several health practitioners and ergonomist recommended that 10% of body weight should be the carrying weight of backpacks for school going children [2, 4, 5]. The research conducted by Pascoe determined the impact of backpack weight on human gait parameters and posture of school going children aged between 11 and 13 years, in four different cases i.e. without bag, single strap backpack, single strap athletic bag and double strap backpack [9]. The backpack weight carried by the subject were loaded with 18% of their body weight. With the help of video filming analysis, it revealed that single strap backpack caused shoulder elevation and lateral spinal bending, whereas the angular motion of trunk and head was also greater in case of single strap athletics bag as compared to the double strap backpack. Forward lean of the head and trunk was more in case of carrying the backpack as compared to carrying the athletics bag or for children without a bag. As per the results of the study, heavy backpack carriage caused increase in stride frequency but stride length was decreased. Wong and Hong conducted the study on the walking pattern of school going children while carrying different backpack loads. This study comprised of 10 school going boys aged 12 years having similar BMI walked on a treadmill for 15 min under four different conditions at a speed of 1.1 m/s. The load conditions carried by subjects in the form of backpacks were 0% (without backpack), 10, 15 and 20% of body weight [10]. The load carriage induced a steady state heart rate, which was approximately 50 ± 60% of the individual maximal heart rate. The study of above researchers proved that carrying heavier weight would increase the physiological strain especially in basic vitals like heart rate and blood pressure. The continuously increase of these physiological factors may causes the occupational burnout of school children due to school backpacks and they may also not recover from this strain due to daily carrying of backpack load. The above findings justify the need for creation of prevention programs and various interventions to reduce the risk of back pain and postural changes in schoolchildren because of improper utilization of school backpacks. In view of this American Occupational Therapy Association (AOTA) recommended the 1, 2, 3's of basic backpack wearing, carrying and packing guidelines which can helps to prevent back pain and postural changes in children and adolescents which helps to reduce the postural deformities of school children. AOTA guidelines includes three basic points of packing, carrying and wearing whereas Figs. 1, 2 and 3 shows these key points of school backpack [9, 11].

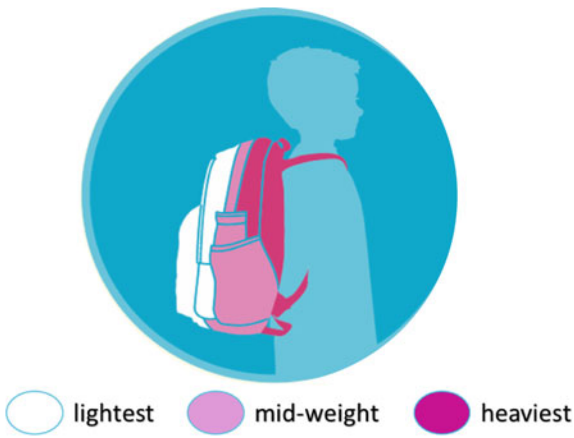

Fig. 1 Distribution of books and other items in the backpack

Fig. 2 Wearing of backpack in an appropriate manner

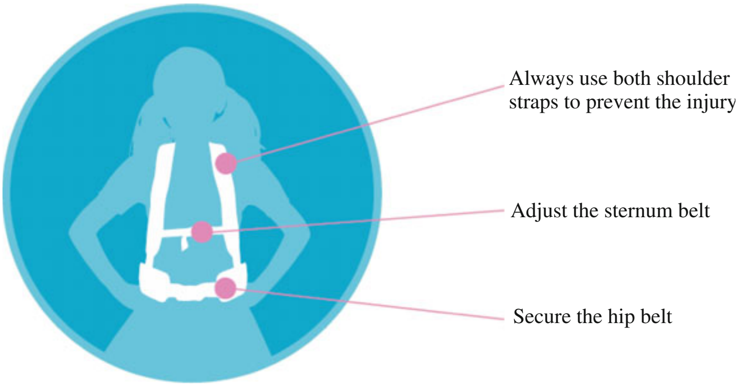

Fig. 3 Proper adjustment and carriage of backpack

1.1 Pack It Well

- Backpack weight for school going children should not be more than 10% of your child's weight whereas heavy backpacks can cause spinal damage and falls.
- School going children should utilize different pockets and compartments for place their study material to distribute weight.
- Students should place heavier items closest to the back and lighter items should be place in the front of the backpack.

1.2 Put It on in an Appropriate Manner

- Teach your child to pick up the backpack by using the squat posture (bending and lifting at the knees) instead of using the stoop posture (waist) to prevent back injury.

- Backpack should be carried on both shoulders for distribution of weight evenly. Wearing a pack slung over one shoulder can cause a child to lean to one side, curve the spine and cause pain or discomfort.
- Backpacks should be design in such a manner, it comprises of shoulder straps adjustment feature so that the pack fits snugly on the child's back. A pack that hangs loosely from the back can pull the child backwards and strain muscles.

1.3 Adjust and Carry

- The way backpacks are worn affects your health. The height of the backpack should extend from approximately 2 in. below the shoulder blades to waist level or slightly above the waist.
- Backpack always wear on both shoulders so the weight is evenly distributed.

The purpose of this paper was to differentiate the physiological effects of proper packing and wearing of backpack carrying backpack load of 10% of subject's body weight before and after intervention followed by the school children. It was hoped that the findings of this paper would help to guide the parents, schools and educators to promote the AOTA guidelines on proper packing and wearing of school backpacks.

2 Methodology

A case study was conducted in the schools located in Chandigarh with one month follow up. Thirty male subjects without any orthopedic, neuromuscular or cognitive disorder and with most representative Body Mass Index (BMI) of 22–24 were selected in this study from three different schools. Permission was sought from Principal of each school and voluntary consent form was signed by each of the students and their parent/local guardian prior to the study. Detailed procedure about the study was explained to them. The study had approval from the Institutional Human Ethical Committee, Department of Industrial and Product Engineering, PEC University of Technology, Chandigarh, India. None of them had practiced any physical activity for more than 12 h per week. The average age, height and the weight of students was 11.77 ($\pm$0.52) years; 1.44($\pm$0.12) m; 37.97 ($\pm$8.51) kg respectively.

Presentation was prepared on three basic steps of wearing, packing and carrying of backpack as discussed in introduction and it was explained to all the subjects so that they got to know about the basics of packing & wearing it helps them to pack and carry their backpacks accordingly as per the guidelines. After inclusion in the study, the school children were submitted to pre- and post-intervention evaluations which consisted of taking heart rate and blood pressures when they carried 10% of their body weight on treadmill. The treadmill was used as an experimental apparatus in this study. Trials for post-interventions readings were recorded after a week of pre-interventions. Presentation on interventions was given in between the recordings. To ensure that, variability/test order effects due to interventions regarding packing and wearing are taken care of. The subjects wore their school uniform dress with socks and sporting shoes and using the same backpack in order to minimize the variability effects. The Loads were put inside the backpack. Each subject participated in three trials: walking on a treadmill without load (0% body weight); walking on a treadmill before packing and wearing intervention with 10% body weight; and walking on a treadmill after packing and wearing intervention with 10% body weight after a week. Subjects were warmed up for 3 min at 1 m/s and then subjects were asked to walk on a treadmill for 20 min at a speed of 1.1 m/s, a comfortable speed of walking for children, with school backpack carried. Heart rate was continuously monitored by using polar heart rate sensor and recorded automatically throughout and until 5 min after the walking tests with the load carriage. The heart rate recorded when subjects did not carried any load were taken as a baseline. Subjects then began the walking trial and all measurements were continuously monitored and averaged every 20 s at every 3-min interval of the 20 min walking period and 3 and 5 min after walking were used for analysis. Blood pressure was measured by using UA-767 V monitor (A and D Instruments) before walking, immediately after the trails and at 3 and 5 min after walking trails and they still carried the load at that time. Three sessions (without load; with load before intervention; and with load after intervention) were recorded by using heart rate sensor and blood pressure device for each subject. To reduce possible order effects due to a repeated-measure aspect of the experimental design, the presentation order of the experimental conditions to the subjects was randomized to minimize learning effects. Each session were carried out on subject after seventh day from the previous session on the same subject.

Statistical Package for the Social Sciences (**SPSS**) was used for statistical analysis of all the measurements and this was followed by paired sample t test to test for significance effect of packing and wearing intervention as recommended by AOTA. The 95% level of confidence was used for all tests as the criterion value when determining the presence or absence of statistically significant results.

3 Results

The minimum and maximum heart rate for the subjects in this study were 70 and 125 bpm respectively. The mean and standard deviation of the heart rate and blood pressure before and after the packing and wearing intervention as recommended by AOTA are listed in Tables 1 and 2.

The effect of packing, carrying and wearing intervention on heart rate for 20 min walking and heart rate for 5 min after walking is also calculated as shown in Table 1. Paired sample t-test showed the significant effect of AOTA intervention on

Table 1 Comparison of mean and standard deviation of heart rate before and after packing and wearing interventions

Variables	Time (mins)	Relative backpack weight load (%)		
		0 (baseline reading)	10 (B.I.)	10 (A.I.)
Heart rate (bpm)	0	79.44 (7.72)	84.62 (7.92)	83.94 (6.94)
	5	91.38 (7.23)	96.46 (5.49)	95.63 (6.67)
	10	96.59 (6.34)	101.47 (8.82)	99.78 (7.91)
	15	101 (6.37)	109.08 (6.33)	106.64 (7.43)
	20	106.63 (7.72)	113.32 (6.66)	110.49 (8.82)
	23*	95.47 (6.59)	99.42 (6.09)	98.62 (7.13)
	25#	84.62 (6.14)	92.46 (7.34)	91.12 (7.11)

B.I. Before Proper Packing and Wearing Intervention; *3 min recovery time
A.I. After Proper Packing and Wearing Intervention; #5 min recovery time

Table 2 Comparison of mean and standard deviation of blood pressure before and after interventions

Variables	Time (mins)	Relative backpack weight load (%)		
		0 (baseline reading)	10 (B.I.)	10 (A.I.)
Systolic pressure (mmHg)	0	100.04 (6.27)	101.32 (8.55)	100.97 (7.13)
	20	112.38 (7.34)	114.51 (7.21)	113.48 (8.72)
	23*	104.62 (8.31)	106.91 (9.38)	104.76 (9.17)
	25#	100.15 (7.62)	102.05 (6.71)	100.46 (8.58)
Diastolic pressure (mmHg)	0	69.30 (6.15)	69.90 (5.41)	69.75 (6.29)
	20	74.17 (7.70)	76.24 (6.69)	74.76 (5.36)
	23*	71.09 (6.81)	72.11 (4.47)	71.89 (5.06)
	25#	69.45 (6.13)	70.02 (6.81)	69.87 (5.41)

B.I. Before Proper Packing and Wearing Intervention; *3 min recovery time
A.I. After Proper Packing and Wearing Intervention; #5 min recovery time

heart rate. The average heart rate calculated after every 5 min of subjects before and after an intervention were significantly different and results obtained from the statistical test are given in Table 3. The heart rate increased significantly in the first 5 min of walking ($p < 0.05$), and then gradually increased over time during walking. After 3 min of recovery, heart rate steadily fell to achieve the normal state.

The minimum and maximum blood pressures for the subjects were 95/62 and 116/94 respectively. The effect of interventions on systolic and diastolic blood pressures is shown in Table 2. Paired sample t-test showed the significant effect of intervention on blood pressures. The results obtained from the statistical data are given in Table 3.

Paired-sample T test shows that there is a significant effect of packing and wearing interventions on heart rate, systolic and diastolic blood pressures. The measured physiological parameters of school children before and after ergonomic

Table 3 Paired sample T test to check the signify cant effect of interventions on the heart rate and blood pressures

Physiological parameters_(A. I-B.I) at any point of time	Paired differences					t	dof	Sig. (2-tailed)
	Average of mean diff.	Std. deviation	Std. error mean	95% confidence interval of the difference				
				Lower (%)	Upper (%)			
Heart rate	−0.66	0.913	0.118	−0.430	−0.902	−5.64	29	0.004
Systolic Pressure	−2.40	4.52	0.583	−3.57	−1.23	−4.11	29	0.002
Diastolic Pressure	−4.89	3.96	0.511	−5.914	−3.86	−9.56	29	0.001

intervention were significantly different and the results obtained from the statistical test are given in Table 3. The values given in the column of mean difference for heart rate and blood pressures demonstrates that average of mean difference of physiological parameters before and after intervention at any point of time were decreased after the intervention.

4 Discussions

The present study evaluated the guidelines suggested by AOTA on packing, wearing and carrying of school backpacks. The study set to measures the strain, children receive from carry heavy loads for after an extended period of time. In this investigation physiological variables have been used such as heart rate and blood pressures. Although the previous reported studies focuses were on the effects of backpack either on physiological or biomechanical parameters when students carried it on their backs. But this study is unique because of considering the effects of packing, wearing and carrying of backpacks on the school children. The main findings of this study were that, walking for 20 min with backpack load of 10% body weight before intervention induced longer recovery periods for heart rate and blood pressures than the same load carried by the subjects after intervention. However the mean heart rate at any point of time decreased by 0.66 bpm for 10% carrying load after the intervention. Although measurements of blood pressure also shows significant effect for intervention, mean systolic blood pressure decreased by 2.40 mm-Hg at any point of time after intervention whereas mean diastolic blood pressure decreased by 4.89 mm-Hg. When subjects walked for 5 min there was significant increase in heart rate and blood pressure and afterwards both were gradually increased. These findings shows very similar results with the findings of Malhotra and Sen Gupta, Wong and Hong studies on load carriage by school children. The paired sample T test also showed the significant effect of AOTA interventions on the physiological parameters for load 10% of bodyweight. This paper enlighten the benefits of AOTA guidelines on packing, wearing and carrying techniques, but still there are certain ill effects of backpacks which pushes the physiological, biomechanical and psychological strains [12]. There is an urgent need of modified design of backpack in order to equally distribute the load carry by school children.

This study has some limitations such as it was done in laboratory; subjects performed dynamic activities on a treadmill instead of normal walking on the ground; only male subjects were selected because of non-availability of female physician for the placement of sensors; the study was conducted on a single backpack thus the results cannot be carried over to all backpacks and it must be tested on each kind of backpacks to make valid conclusions; the study also not conducted on higher backloads loads so interventions are not valid for these loads.

Awareness regarding packing, wearing and carrying of backpacks as per the guidelines should be created among healthcare professionals, teachers and parents. The backpack load should be restricted to 10–12% of bodyweight as per the investigation reported by the previous researchers. [2, 9, 11]. From the above evidence it seems clear that, the present study has demonstrated that when subjects do not carry school backpack with proper interventions as per AOTA guidelines there is more chances of physiological strain in terms of heart rate, blood pressure.

5 Conclusions

It is hypothesized that carrying load with AOTA guidelines (interventions regarding packing, wearing and carrying of backpacks would help to reduce the physiological strain in school going children. For the participants in this study, carrying a load of up to 10% of bodyweight while walking on the treadmill before and after the interventions resulted in the increase of heart rate and blood pressures. It was hoped that the findings of this paper would enlighten the scope of the issue on backpack packing, carrying and wearing. It also help health practitioners, parents and teachers to give guidelines on the proper packing, wearing and carrying of school bags.

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Methodical Product Development in Medical Engineering—A Case Study on Radiography Systems

Sebastian Schweigert, Udo Lindemann, Vera Seitz and Erich Wintermantel

Abstract To create unique selling points in the competitive market of medical radiography systems, systematic approaches for the development are required. In a case study, standard procedures from academia were adapted to the situation of the industry partner. Starting from a requirements list, a relation-oriented function modelling was built to develop concepts with morphological boxes, which were evaluated by a weighted average method. This lead to the elaboration of CAD-based drafts in order to enable more detailed ratings. The methodical approach results in the identification of redundant bearing parts in the floor attachment, the removal of which does not cause any violation of the safety regulations of medical products. A verification with finite element software proved the applicability of the concepts. This example demonstrates that in a situation of highly developed predecessors and a limited design space, a methodical approach can identify improvement possibilities, which leads to innovations and cost advantages.

Keywords Medical systems · Methodical product development · Case study

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1 Introduction

The market for medical radiography systems is highly competitive as it includes many suppliers with similar products [1]. To succeed in this environment and distinguish newly developed systems from existing solutions while meeting cost requirements, a systematic approach for the product development is required.

Radiography is the most frequently used imaging diagnostic technique in Germany [2]. It is a subarea of radiology that applies electromagnetic radiation and mechanical waves for diagnostic, therapeutic, and scientific purposes [3]. There is a continuous increase in market volume and expenses towards X-ray diagnostics (see Fig. 1 [4]). It is expected that this trend will go on as imaging is more frequently used also during operations [5, 6]. This leads so far that due to the high number of diagnostic applications, diagnostic X-rays have become the largest man-made source of radiation exposure [7]. Because of the competition in the radiography market, a high demand for cost-efficient radiography systems can be observed especially in developing and emerging economies [8], which lead to the project of this case study.

The main components of a typical floor mounted radiography system are depicted in Fig. 2 and can be summarized to lift table, floor profile, carriage with track rollers, and pillar with support arm and X-ray source. Not visible in the sketch are the track rollers that support the pillar horizontally in former products. As the results in Sect. 3 show, these are redundant bearing parts that can be omitted.

The focus of this paper is the development of floor profile and carriage, which are not connected to the lift table. The work behind it results in finished CAD drafts of floor profile and carriage and does not cover support arm, lift table or the production process of the developed parts. In comparison to standard medical device design processes as of Medina et al. [9] or Alexander and Clarkson [10], this paper focuses on early stages of the design process and does not include testing and validation.

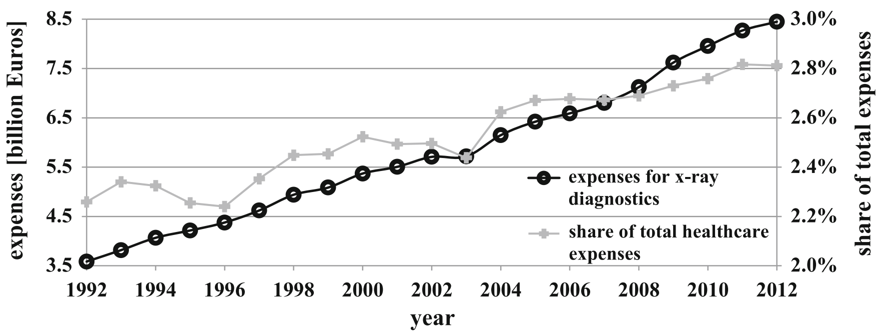

Fig. 1 Healthcare expenses for X-ray diagnostics in Germany (data from [4])

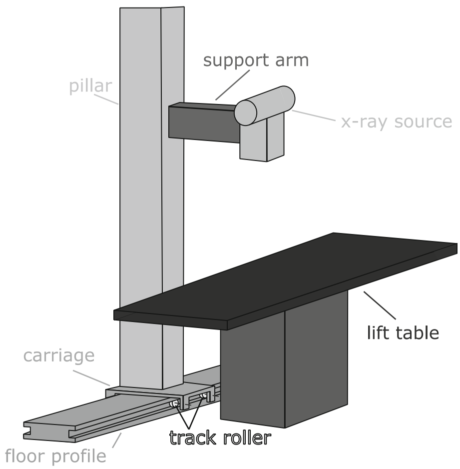

Fig. 2 Schematic diagram of an X-ray system with its essential components and lift table

2 Methods

To develop a corresponding system, standard product development procedures referring to Lindemann et al. [11, 12] and the VDI guideline 2221 [13] were used. Figures 3 and 4 show the corresponding development process in detail.

Figure 3 describes the process from first concept studies up to the final concept design and Fig. 4 represents the construction process in CAD. At one point, the standard process was altered to cope with unclear results after the first weighted average method. This alteration in the transition to preliminary designs before a finished concept selection is highlighted using a circle in Fig. 3.

The concept development included a relation oriented function modeling according to [11], morphological boxes with sub-functions and partial solutions, and a weighted average method with the corresponding graphical representation in diagrams. The following procedure describes how solution elements for the thus selected concepts were generated.

After the requirement list was completed, the problem was structured by a relation-oriented functional modelling. If a standard solution for a function from former projects or supplier catalogues was available, a direct input for the conceptualization was at hand. If there was no standard solution, a solution search followed using a morphological box. After a preselection, all solutions were evaluated against a selection of KO criteria. Solution elements that did not meet these mandatory KO criteria were excluded for the further process and documented in a negative list for future projects. Out of all other solution elements, concepts were built and prepared for evaluation by a weighted average method. The weighted average method oriented on a cost–utility analysis as each concept was evaluated in regard of thirteen criteria by values of zero to four that were then multiplied with the different weights of the criteria. The weights of the criteria were

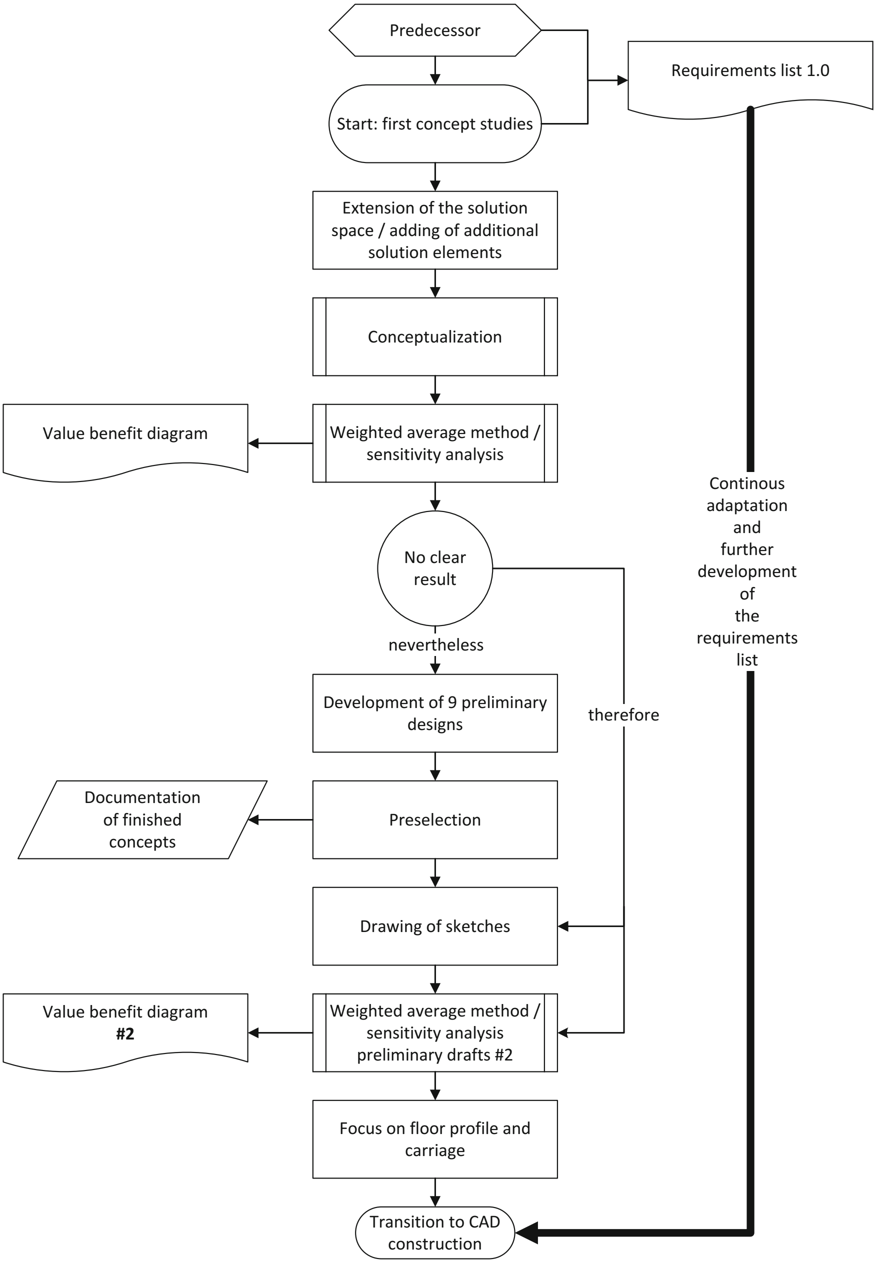

Fig. 3 Flowchart of the development process—part 1

Fig. 4 Flow chart of the development process—part 2

derived by a coupled comparison that had been conducted in collaboration with the customer.

A following sensitivity analysis was carried out to check the robustness of the method. This means that it was tested whether there is a significant change in the overall results when the values of the weighted average method are altered by plus/minus five percent. If so, the results were not clear enough to make a decision and multiple possible solutions were considered in the following process steps. After that, a plausibility analysis by interviews with experts ensured the meaningfulness and applicability of the developed concepts.

When the concept design was finished, the transition to CAD was the next step. During the design in CAD, many standard parts were used to avoid the effort of designing new parts. To verify the drafts from CAD and to make sure that the embodiment design results in useful parts, both analytical and numerical calculations were used. The results of these calculations had a great influence within this systematic approach (see Fig. 4).

3 Results

To focus on the most relevant results, just a few aspects of the concept design phase and the resulting floor profile are shown here. Besides of that the carriage was also designed in detail in the case study.

3.1 Concept Design

A central element of the concept design is the function modelling of the two basic parts, floor profile and carriage. Figure 5 shows the relation oriented modelling according to [11] of the floor profile and the carriage. Useful functions are depicted as a simple rectangle and harmful functions are symbolized by a rectangle with a black triangle in the upper right corner. There are three different relations between the functions: “causes”, “is necessary for”, and “has been introduced to avoid” (see legend in Fig. 5).

3.2 Floor Profile Design

After the concept design was finished, the relevant parts could be designed in CAD. The resulting parts of the floor profile are presented here while the carriage cannot be included here due to the scope of this paper.

The methodical approach described in the previous section enables the identification of redundant bearing parts in the floor attachment. Thus, the design differs

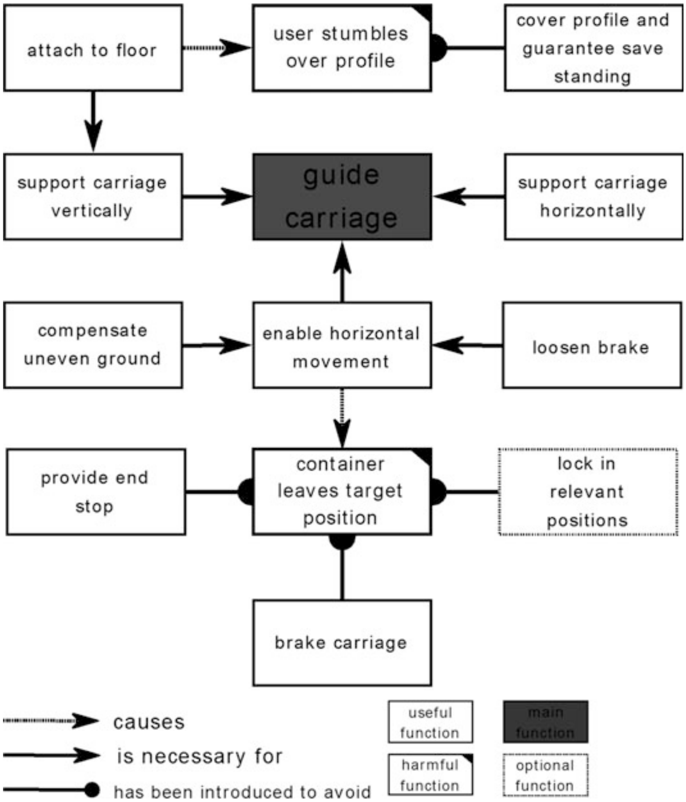

Fig. 5 Relation-oriented function modelling of the floor profile

from predecessors in the number of these bearing parts. While this can lead to a reduction in costs (cf. Sect. 4), the fulfilment of all requirements still has to be guaranteed with the new design. Therefore, the design proposal was tested with finite element (FEM) software, with the purpose to prove that the yield strength of the floor profile is not violated at any point even if a worst-case scenario load is applied.

The load for that worst-case scenario results from pillar, support arm, and X-ray source that are positioned in the middle of the floor profile, while two care persons that hold the patient stand on it. The weight of each person is assumed as 100 kg in this worst-case scenario. Figure 6 shows the resulting pressures on the contact surfaces.

The variables in Fig. 6 are declared as follows: a_g represents gravity, u is the vector of displacement, p_P is the pressure that results from care persons and patient while p_R symbolizes the pressure caused by pillar, support arm, and X-ray source and is transferred to the floor profile by the roller bearing of the carriage. All

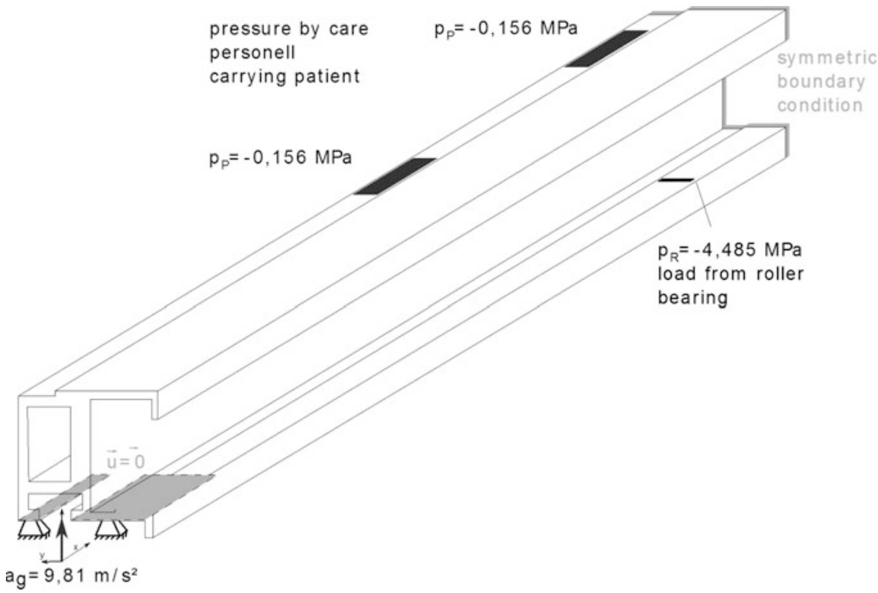

Fig. 6 Boundary conditions for the FEM-simulation of the floor profile

Table 1 Meshing parameters for the floor profile

Object	Element type	Meshing	Element size [mm]
Bearing surfaces	SHELL181	free	0.25
Surface roller bearing	SHELL181	free	0.4
Standing surface	SHELL181	free	4.0
Rolling surface	SHELL181	structured	0.4
Profile body	SOLID186	free	6.0

pressures are in negative z-direction. The meshing is described in Table 1. A linear-elastic material model was used.

To ensure the reduction of the number of floor attachments, it has to be proved that the stress does not exceed the permitted maximum at any point. The part exposed to the highest loads is the bearing surface of the floor profile. The FEM simulation confirms that the stress on the entire floor profile does not exceed the material's yield strength of 180 MPa at any position (Fig. 7).

In addition, the occurring bending of the floor profile is negligibly low at all positions. Figure 8 shows a side view of the floor profile with the bending in z-direction in grey scale and scaled by one hundred to make the effect visible. The maximum bending is 1.3558 mm. A low bending is important, as a high tilt of the whole system will lead to inaccurate diagnostic images. The optimal distance

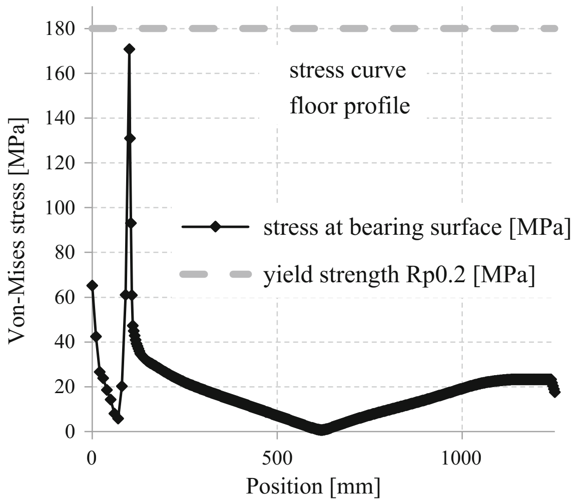

Fig. 7 Stress curve of floor profile

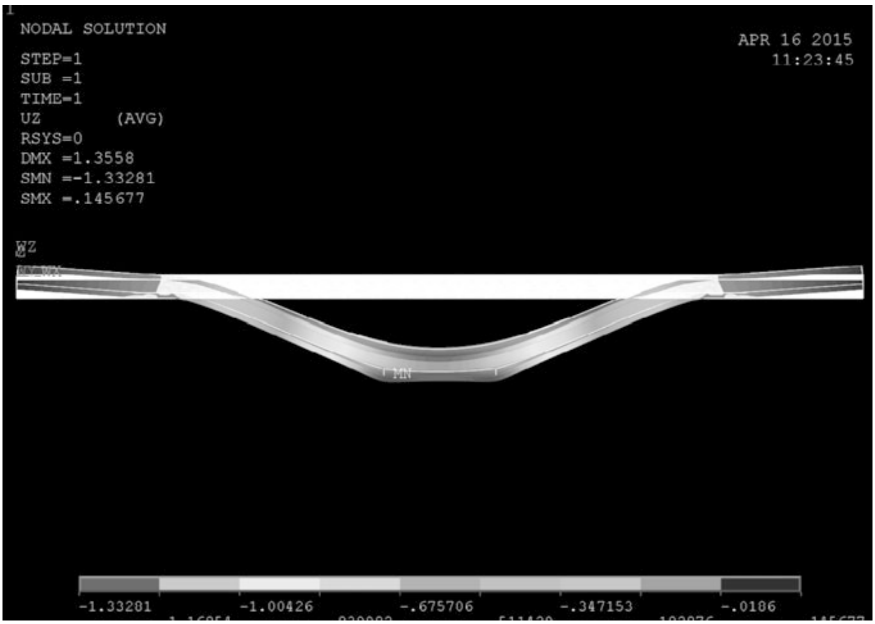

Fig. 8 Bending of the floor profile with optimal floor attachment positioning [mm]

between the floor attachments was determined from the results of the FEM simulations and as a result reduces the bending with a load in the middle by half in comparison to a floor attachment at the edges.

4 Discussion

The verification via FEM proved the applicability of the developed concepts within the given requirements. Therefore, the methodical approach results in the identification of redundant bearing parts. For both, floor attachment and roller bearing, the number of parts can be reduced. The removal of these parts does not cause any violation of the high safety regulations for medical products as proven by the finite element simulations.

These numerical results were double-checked with simplified analytical calculations of beam bending that resulted in similar results. Hence, this ensures that also the values for local stresses form the FEM simulations can be trusted.

Thus, the necessary effort for assembly is reduced, especially due to the reduction of floor attachments. This leads to a cost reduction as shown by cost estimations that also took the possible development of raw material prices into account. Consequently, the final product is able to remain competitive.

This example demonstrates that even in a situation of highly developed predecessors and a limited design space, a methodical approach can help to identify potential for optimization. This ultimately leads to innovative solutions and cost advantages in comparison to the state of the art.

5 Conclusion and Outlook

The case study shows how the use of a systematic design approach can help to identify redundancies and possibilities for design improvement. The modification in the design of the X-ray radiography system reduces costs and can potentially improve its innovative capacity. As this case study focused on the floor profile and surrounding parts, some of the results must be challenged when other parts of the radiography system like pillar and support arm are fully developed. Where the design of these parts differs significantly from the assumptions made for this case study e.g. in respect of weights and dimensions, alterations in the design of the floor profile may be necessary.

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Structural Optimisation of Wind Turbine Gearbox Deployed in Non-conventional Energy Generation

Sourabh Mandol, Debraj Bhattacharjee and Pranab K. Dan

Abstract The use of windmill has revolutionized renewable energy generation for people in communities, residing in remote areas that are not connected to the power grid. The gearbox, comprising planetary gear assembly, in the wind turbine, is a critical component in the structure and hence due care is to be taken in determining the design safety factor. This paper explores different optimisation techniques for analysing computer aided simulation data for obtaining the highest Safety Factor based on failure analysis, using experimental data of multiple design variables. Several design optimisation methodologies are used, namely, Taguchi Robust Design, Response Surface Methodology and Soft Computing Techniques etc. amongst others. It has been observed that optimality values differ, sometimes significantly, with the optimisation approach. An accurate comparison would provide the information regarding suitability of using a particular optimisation technique.

Keywords Planetary gears · Design optimisation · Safety factor · Failure analysis

1 Introduction

With the rise of the damage caused by the greenhouse gases, wind power energy generation has been the breakthrough in power generation technologies that promises pollution free solution to communities that are outside the smart grid and also satisfy the power requirements in the congested smart grid areas. There has been a substantial rise of wind power energy generation with more than 63 GW of power capacity installation worldwide in 2015, in which India accounts for 25,088 MW of installed capacity [1]. Wind turbine utilizes the kinetic energy from the wind, which is a free source of energy and convert it into electrical energy my means of a generator. It is an attractive source of power since wind energy is a renewable form

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of energy, being abundantly available and doesn't contribute towards air pollution when compared to the conventional power generation method by burning fossil fuels. Over the last decade there has been a tremendous development work to suitably capture the wind energy and convert it into electrical energy with the possible highest efficiency. Desirable concepts such as light-weight construction, high load reliability and power density led to the commencement of research and development activities by various organizations to develop efficient wind power energy equipment's. A quantitative comparison in-between different optimization techniques, containing same set of input data will provide valuable insight for obtaining feasible design solutions as per the needs of the end user. Thus, this paper compares the results from Taguchi Orthogonal Array results with Genetic Algorithm and Adeline based optimization approaches to seek the best design model.

1.1 Wind Turbine Gearbox

The wind turbine gearbox is a vital component in the entire machinery. A study conducted by National Renewable Energy Laboratory, a national laboratory of the US department of Energy, emphasised that the maximum failure of the windmill machinery occurs within the drivetrain, thus making it an important aspect to implement strategies for reducing failure chances [2]. Drive train is composed of several components (such as shafts, bearing assembly and couplings) amongst which the gearbox is the main element which is of the highest mechanical complexity in the drive train, due to the fact, that the gearbox must operate efficiently under different loading and environmental condition where it operates [3]. The main intention is to increase the rpm output from rotor and transmit it to the generator for power generation.

The requirements of failure reduction strategies are an important aspect for designing wind turbine gearboxes which is characterized by the integration of multiple disciplines. In order to ensure that the drivetrain transmits mechanical power efficiently to the generator, its structural design must endure the large moments and forces of the turbine rotor. The importance for identification of parameters for design and analysis of the gearbox is required to optimisation with the aim to improve the reliability, enabling the system to resist deforming forces that comes into play during operation, within the system. The application Taguchi method for design optimisation of planetary gear set's has provided important reliability based information [4]. Amongst the various testing methodologies, structural optimisation has been attempted with a CAD (Computer Aided Design) model developed in Solidworks. The Gearbox Assembly, taken into consideration, consists of one planetary gear stage and two helical stage (Fig. 1), the assembly was created in the Solidworks software package. Three design optimization approaches has been utilised to infer the best results with a feasible comparative study.

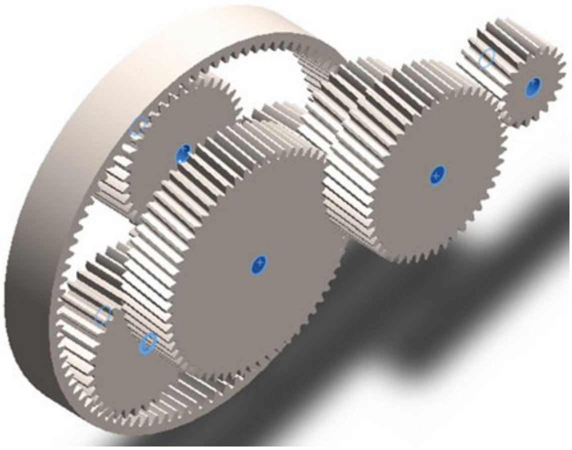


Fig. 1 CAD model of the windmill gearbox assembly

2 Details of Experimentation

A CAE (Computer Aided Engineering) structural analysis was carried out utilising a CAD assembly model, in which the most critically loaded component, the planetary gear stage, was selected for experimentation, as it is the first one to interact with the power transmitted from the rotor (Fig. 1). The rotary power is directly transmitted to the planetary stage which reduces the torque and an increase of rotational speed is observed. Further, the speed is increased sequentially by the helical gear stages. Thus, a structural optimisation approach for the planetary gear stage would improve the endurance of the overall assembly and contribute the same if other equipment's within the gearbox are analysed in the same manner [5]. Thus, an approach has been identified. A CAD generated model of the planetary staging was utilised for experimentation. In this paper the data is analyse in two steps using genetic algorithm based optimization the best feasible solution point is determined then the point is used as input weight for a supervised learning hybrid network for better solution point out of the Taguchi orthogonal table.

2.1 CAD Design and ANSYS Simulation

The creation of the planetary gear stage was developed in Solidworks software package utilising the design toolbox. ISO standard was chosen for obtaining the gear models. The pressure angle was selected as 20° and the numbers of teeth of the planet, ring and sun gears are 36, 91 and 20 respectively. Different modules were used according to the OA table treatment condition to obtain the response. The static structural module has been used for analysing the planetary stage developed in solidworks. The material was kept at default settings (i.e. structural steel) for

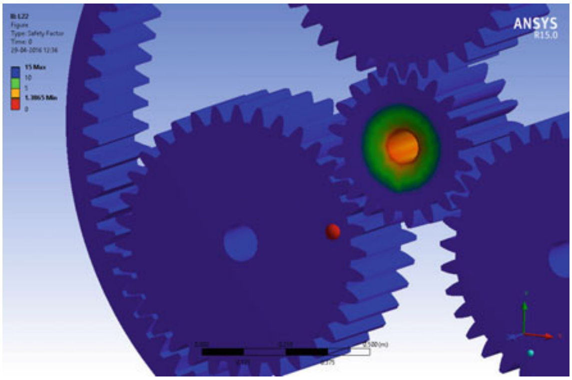


Fig. 2 ANSYS simulation screenshot

obtaining the Fatigue Safety Factor (SF) value. The SF was calculated utilising the Soderberg equation [6].

$$\left(\sigma_m/\sigma_y\right) + \left(\sigma_v/\sigma_e\right) = 1 \tag{1}$$

where, σ_m = Mean Stress; σ_v = Variable Stress; σ_Y = Yield Stress and σ_e = Endurance Limit. ANSYS simulation was carried out utilising the OA table treatment condition settings with different module, moment and temperature values to obtain Fatigue safety factor values. All other factors were kept constant. Figure 2 demonstrates the screenshot of the safety factor value as displayed in ANSYS Workbench user interface.

2.2 Taguchi Design

The Taguchi's Robust Design is a statistical method aimed to emphasize the significance of control parameters on a response variable of interest to find optimal solution leading to desirable performance characteristics. The Orthogonal Array (OA) Table generation was carried out in Minitab software package with the following values of process control factors: the gear Module in compliance with ISO Standard (with values of 12, 14, 16, 18 and 20); moment based on experimentation (with values of 120, 140, 160, 180 and 200 Nm) and temperature based on experimentation (with values of 30, 40, 50, 60 and 70 °C).

The resulting OA Table with three factors at 5 levels is L25 (The letter L stands for Latin Square) with 25 treatment conditions [7]. The module of the gear teeth emphasises the size of teeth and its geometry. And, the moment and temperature process control was utilised in ANSYS for loading purpose to obtain the required responses as per the OA Table (Table 1). The Signal to Noise ratio characteristics has been selected as larger the better with the following formula [4]:

Table 1 L25 orthogonal array table with response data

Serial no.	Gear module	Moment (Nm)	Temperature (°C)	Fatigue safety factor
01	12	120	30	1.36
02	12	140	40	0.60
03	12	160	50	0.39
04	12	180	60	0.29
05	12	200	70	0.23
06	14	120	40	0.59
07	14	140	50	0.38
08	14	160	60	0.21
09	14	180	70	0.22
10	14	200	30	1.32
11	16	120	50	0.38
12	16	140	60	0.28
13	16	160	70	0.22
14	16	180	30	1.33
15	16	200	40	0.59
16	18	120	60	0.29
17	18	140	70	0.23
18	18	160	30	1.35
19	18	180	40	0.60
20	18	200	50	0.39
21	20	120	70	0.23
22	20	140	30	1.39
23	20	160	40	0.62
24	20	180	50	0.40
25	20	200	60	0.29

$$SNR = -10\ \log_{10}\left(\sum \frac{1}{Y^2}\right)/n \tag{2}$$

where, y = response in the OA table; n = number of treatment condition; SNR = Signal to Noise Ratio.

The highest value gives the best design settings. A linear regression analysis was made on Minitab from the data above which revealed the following equation:

$$\begin{aligned} \mathit{Fatigue\ Safety\ Factor} = 1.831 + 0.0024\ \mathit{Gear\ Module} - 0.00010\ \mathit{Moment}\ (\mathrm{Nm}) \\ - 0.02574\ \mathit{Temperature}\ (^{\circ}\mathrm{C}) \end{aligned} \tag{3}$$

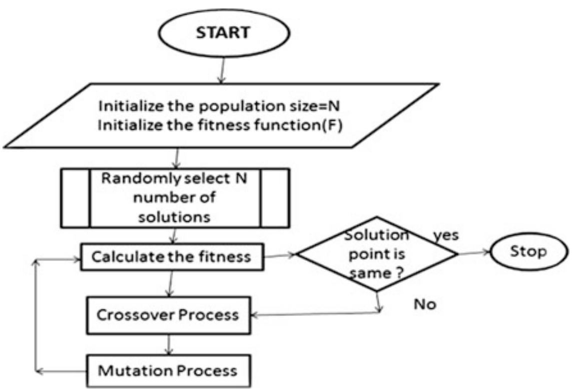
2.3 Genetic Algorithm Based Optimization

In design optimization with the traditional mathematical optimization techniques nonconventional technique like genetic algorithm is used by modern designers to get improved results [8]. Thus, improving the accuracy of results tend to facilitate the optimal criteria to satisfy the goal. Baumal used genetic algorithm to optimize design of vehicle suspension another example of design optimization can be found in Wloch's paper [9]. Genetic algorithm based optimization is an optimization tool, which is inspired by the evolutionary theory of nature. The best chromosome or the best solution point is selected based on the fitness of the chromosomes. At the start GA creates a randomly generated population of solutions. The fitness of each solution (chromosome) is determined by calculating fitness against an objective function. Then mimicking the crossover process the solutions (chromosomes) share the information to each other. In the next step mutation or significant random change occurs in the child chromosomes (solutions) and at last again the child solutions are evaluated to get the best or fittest chromosome or solution. This cycle goes on until the solution result is same or can be terminated by pre-initialization of number of iteration. A flow chart is given below (Fig. 3) to show the steps of GA based optimization. In this paper the Genetic algorithm is used to find out the optimal design point.

2.4 Hybrid Supervised Learning Adeline

Inspired from Adeline, a supervised learning a new technique for determining better feasible solution point is given here. The use of modified weight approach can be found in the paper of Pajares [10]. The neural network can be used for finding better output [11]. The output from the genetic algorithm and a desired safety-factor are feed to the network as input (initial weight and target value). Base on this input the

Fig. 3 The flow diagram of the genetic algorithm



network modified itself in each iteration to minimize the Square error between output and target value. Thus it reaches near to the target value and gives a weight vector which is the solution point for desired target. The mathematical model of Adeline inspired hybrid model is given below.

$$y_{in} = \sum w_i x_i \tag{4}$$

$$\Delta w_i = \alpha(t - y_{in})x_i \tag{5}$$

$$E = (t - y_{in})^2 \tag{6}$$

$$w_{ni} = w_{oi} + \Delta w_i \tag{7}$$

where, Δw_i = weight change, α = Learning rate, t = Target, E = Mean square error, Y_{in} = Net input to output input, w_{ni} = New weight, w_{oi} = Old weight.

In this model bias is fixed to remove the complexity. The main idea used in this paper of keeping the inputs fixed and according to the target value, the network will change itself to minimise the mean square error E. The Adeline uses the activation function as

$$\mathrm{Y} = \begin{cases} 1 & \text{if} \quad \text{yin} \geq 0 \\ -1 & \text{if} \quad \text{yin} < 0 \end{cases}$$

From the regression analysis the relation of Fatigue safety factor with Gear Module, Moment and Temperature is determined and the relationship is given below:

$$\begin{aligned} \textit{Fatigue Safety Factor} = 1.831 + 0.0024\ \textit{Gear Module} - 0.00010\ \textit{Moment} \\ - 0.02574\ \textit{Temperature} \end{aligned}$$

So we can write the optimization problem as below:

$$Max\{1.831 + 0.0024X_1 - 0.00010\,X_2 - 0.02574\,X_3\} \tag{8}$$

Such that.

$$\begin{aligned} &12 \leq X_1 \leq 20 \\ &120 \leq X_2 \leq 200 \\ &30 \leq X_3 \leq 70 \end{aligned}$$

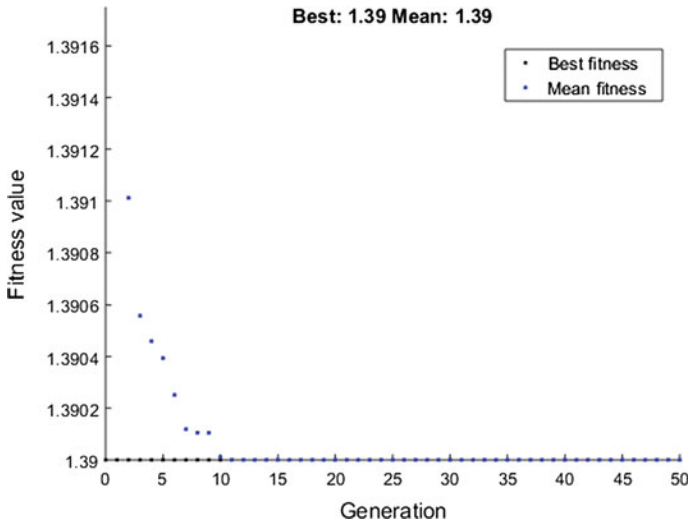


Fig. 4 GA fitness curve

where, Fatigue Safety Factor = Y, Gear Module = X_1, Moment = X_2, Temperature = X_3. Some initialization was made before solving the optimization problem. Population size N = 30; Mutation probability is takes as 0.01. The Solution design point from the genetic algorithm is X_1 = 20, X_2 = 120 and X_3 = 30. The fitness curve is given below (Fig. 4). The fitness curve is showing the fitness of best solution point in each iteration. In Fig. 4 the observed best fitness value is 1.39 and which is the mean fitness value.

2.5 Neural Network

To create the model, regression is done in a different way. First the Gear module, Moment and Temperature is scale downed. The reason behind this weight scale down is to bring the values under 1. The maximum value for weight can be 1 but all the values of independent variables are over 1. So gear module and temperature is multiplied with 0.01 and moment with 0.001 to scale down the values. The values are given in the Table 2.

The Regression Analysis of SF versus X_1, X_2 and X_3 are as follows:

Table 2 Scaled down values of the OA table

X1	X2	X3	SF
0.12	0.120	0.30	1.36
0.12	0.140	0.40	0.60
0.12	0.160	0.50	0.39
0.12	0.180	0.60	0.29
0.12	0.200	0.70	0.23
0.14	0.120	0.40	0.59
0.14	0.140	0.50	0.38
0.14	0.160	0.60	0.21
0.14	0.180	0.70	0.22
0.14	0.200	0.30	1.32
0.16	0.120	0.50	0.38
0.16	0.140	0.60	0.28
0.16	0.160	0.70	0.22
0.16	0.180	0.30	1.33
0.16	0.200	0.40	0.59
0.18	0.120	0.60	0.29
0.18	0.140	0.70	0.23
0.18	0.160	0.30	1.35
0.18	0.180	0.40	0.60
0.18	0.200	0.50	0.39
0.20	0.120	0.70	0.23
0.20	0.140	0.30	1.39
0.20	0.160	0.40	0.61
0.20	0.180	0.50	0.40
0.20	0.200	0.60	0.29

Analysis of Variance:

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	3.31409	1.10470	24.64	0.000
X1	1	0.00115	0.00115	0.03	0.874
X2	1	0.00020	0.00020	0.00	0.947
X3	1	3.31274	3.31274	73.89	0.000
Error	21	0.94145	0.04483		
Total	24	4.25554			

Model Summary:

S	R-sq	R-sq (adj)	R-sq (pred)
0.211734	77.88%	74.72%	67.31%

Coefficients:

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1.831	0.373	4.91	0.000	
X1	0.24	1.50	0.16	0.874	1.00
X2	-0.10	1.50	-0.07	0.947	1.00
X3	-2.574	0.299	-8.60	0.000	1.00

Regression Equation:

$$\mathrm{SF} = 1.831 + 0.24\,X_1 - 0.10\,X_2 - 2.574\,X_3 \tag{9}$$

To design the net first the coefficients are taken as input and the variables are as input weight. After designing the net the bias is fixed to 1.831 and the bias weight is fixed to 1. The model of the net is given in Fig. 5.

After designing the model, the target is set as 1.4 because in the GA the calculated safety factor was 1.39 so to improve that we give a slight better target to achieve. In this analysis the learning rate (α) is 0.1. After running the model, the following results are observed and the result is given in the Table 3. The change of

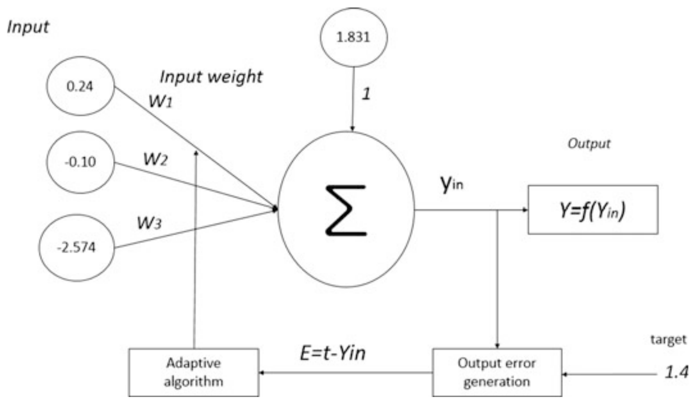


Fig. 5 Self supervised network diagram

Table 3 Weight values with iteration and square error E

Iteration/epoch	w_{o1i}	w_{o2i}	w_{o3i}	w_{n3i}	w_{n2i}	w_{n3i}	Square error $E = (t - y_{in})^2$
1	0.20	0.120	0.30	0.2079	0.1173	0.2214	0.0929
2	0.2079	0.1173	0.2214	0.2105	0.1164	0.1957	0.0099
3	0.2105	0.1164	0.1957	0.2114	0.1161	0.187	0.0011
4	0.2114	0.1161	0.187	0.2116	0.116	0.1845	1.13E−04
5	0.2116	0.116	0.1845	0.2117	0.1159	0.1836	1.21E−05
6	0.2117	0.1159	0.1836	0.2118	0.1159	0.1833	1.29E−06
7	0.2118	0.1159	0.1833	0.2118	0.1159	0.1832	1.38E−07
8	0.2118	0.1159	0.1832	0.2118	0.1159	0.1832	1.47E−08
9	0.2118	0.1159	0.1832	0.2118	0.1159	0.1832	0.00E+00
10	0.2118	0.1159	0.1832	0.2118	0.1159	0.1832	0.00E+00
11	0.2118	0.1159	0.1836	0.2118	0.1159	0.1832	0.00E+00
12	0.2118	0.1159	0.1833	0.2118	0.1159	0.1832	0.00E+00
13	0.2118	0.1159	0.1832	0.2118	0.1159	0.1832	0.00E+00
14	0.2118	0.1159	0.1832	0.2118	0.1159	0.1832	0.00E+00
15	0.2118	0.1159	0.1832	0.2118	0.1159	0.1832	0.00E+00
16	0.2118	0.1159	0.1836	0.2118	0.1159	0.1832	0.00E+00
17	0.2118	0.1159	0.1833	0.2118	0.1159	0.1832	0.00E+00
18	0.2118	0.1159	0.1832	0.2118	0.1159	0.1832	0.00E+00
19	0.2118	0.1159	0.1832	0.2118	0.1159	0.1832	0.00E+00
20	0.2118	0.1159	0.1832	0.2118	0.1159	0.1832	0.00E+00

weight and change of square error E. In Fig. 6 the change of weight values are given and the change of E value can be visualised in Fig. 7. The final result from the network is w1 = 0.2118, w2 = 0.1159 and w3 = 0.1832. Now if the values are scale upped then the feasible solution point is 21.18, 115.9, and 18.32. To validate the result, the approximation values are taken as 22, 116, and 18.32. After designing and testing the simulation we got the result for both GA and Hybrid neural net that is given in Table 3. In the following table 'w_{o1i}' old weight and 'w_{n1i}' is new weight and E is the measure of square error. The value is decreasing with each epoch and the value is ultimately becomes '0' at ninth epoch. From ninth epoch to seventeenth epoch there is no significant change in the square error value. So it is fully trained. The change of $w_{1,}$ w_2 and w_3 can be observed in Fig. 5 also. The change of w1 is denoted with '*', w2 '+' and w3 '−'. The change of square error is shown in Fig. 7.

All the analysis is done in Matlab, Minitab, ANSYS Workbench and the system specification is 5th generation INTEL i5 processer, 4 GB RAM.

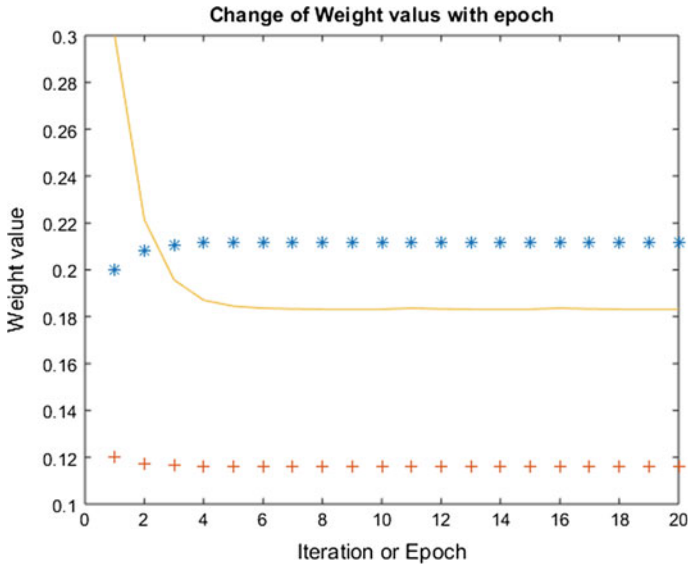


Fig. 6 Change of weights with epoch, w1 is ‘*’, w2 is ‘+’ and w3 is ‘−’

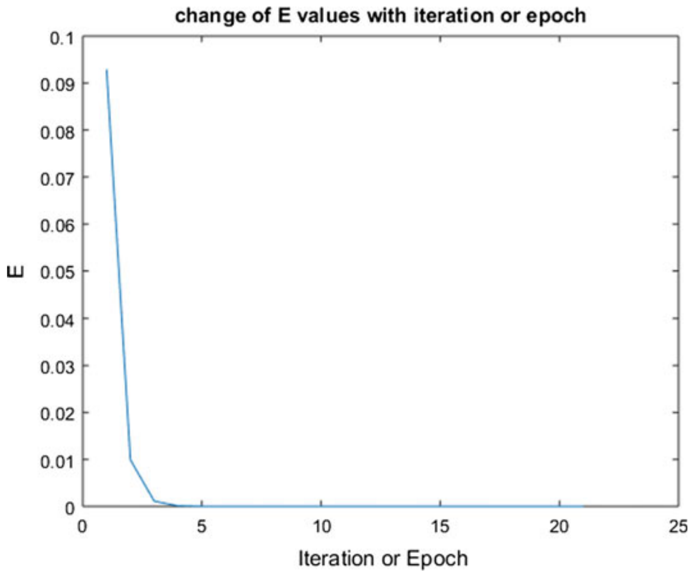


Fig. 7 Change of square error with each iteration

Table 4 Comparative Optimal Results

Serial No.	Method	Gear module	Moment	Temperature	Safety factor fatigue
01	Taguchi SNR	20	140	30	1.39
02	GA	20	120	30	1.39
03	Hybrid net	22	116	18.32	3.12

3 Result and Discussion

The results were analysed by three methods, namely Taguchi Signal to Noise Ratio (SNR), Genetic Algorithm and Hybrid Adaline. The optimised settings taken from each of the methods (i.e. optimised values of gear module, moment and temperature) were simulated in ANSYS to obtain the respective safety factor value. It has been found that the results (Table 4) yielded by both two methods, i.e. Taguchi and GA, gave similar results, whereas, the hybrid Network gave a larger value thus is the most preferred amongst the three method, sufficing the goal efficiently. Thus, from this observation it can be concluded that the hybrid network method is more suitable for obtaining the best design as compared to the other two methodologies.

The regression equation obtained from the OA table results, provided a relationship in-between module, moment and temperature to the fatigue safety factor. A safety factor value greater than one is preferred, this is due to the fact, that a safety factor value less than one indicates failure before the design life is reached. This relationship can be utilised by designers even though from the ANOVA (Analysis of Variance) data, we see that, the moment and module are insignificant. The two insignificant factors (namely, module and moment) is a vital design parameter for designing gear members within the gearbox as the module reflects the geometrical shape of the gear teeth and the moment is an effect that comes into play as torque is applied on the gearbox. Thus, these two parameters were used even though the test results showcased that they are insignificant. The results in Table 4 proves that the regression model is useful even though two factors out of three factors are statistically insignificant because ANSYS simulation with the optimal settings reveal higher values of safety factor, thus improving the results [5]. This methodology for analysing failure criterion will enable the end user to identify design constraint within a system and provide feasible solutions to reduce those constraints, enhancing the power transmission capabilities of the gearbox.

4 Conclusion

The comparative study amongst the three optimisation methods provides outcome for selecting the best approach for designing and developing a windmill turbine gearbox. The increase in safety factor value reveals that the system can withstand the specified loading conditions and to improve the result in respect of safety factor, based on a CAE Simulation experiment has been carried out that demonstrates an increase in accuracy and precision. Thus, the findings demonstrate the potential for multi-disciplinary design optimisation concepts, for design and development of systems which can perform efficiently under desired loading condition.

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Driver Distraction: Methodological Review

Indresh Kumar Verma and Sougata Karmakar

Abstract Driver distraction is the main cause of crashes and near-crash incidences all over the world. For conducting research on driver distraction various methodologies have been adopted by researchers as found in the literature. These methods follow driving performance metrics to assess the level of driver distraction. In the present paper, popularly used driver distraction assessment techniques (viz. 'naturalistic driving study', 'driving simulator study', 'visual behaviour', 'visual occlusion'', 'lane change task', and 'peripheral detection task') have been reviewed with the main focus of demonstrating their effectiveness (accuracy), ease of use, efficiency (time required), advantages and disadvantages. It is expected that information presented in this review would be helpful for designers, engineers, and researchers to understand the superiority of one technique above another and would motivate them to perform empirical studies in this regard. The present review would also be beneficial for researchers to decide feasible and right technique or combination of techniques for their intended study on driver distraction.

Keywords Driver distraction · Driver-vehicle interaction · Lane changing task · Visual occlusion · Peripheral detection · Driving simulator

1 Introduction

Driver distraction has intensified to a new level, with the introduction of mobile phones, satellite navigation, e-mail and internet facilities and many others information and entertainment (infotainment) systems in the modern vehicle. These systems have provided more convenience but at the same time have increased the occurrence of distraction and cognitive workload upon the driver. Distraction while

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driving has been reported as the main cause of accidents across the world. Driving is visual-manual task and requires a great deal of attention. A significant proportion of ergonomics research pertaining to driver distraction is being carried out by researchers to understand physical and mental demand of the driver. Literature in English language from different electronic databases (science direct, scopus, pub-med, google scholar etc.) was searched using a combination of keywords relating to the scope of paper. Research work mainly related to methodologies for measuring driver distraction were segregated and studied at least by abstract. Available hard copy journals, articles and books were also taken into account. Information regarding various techniques has been summarized and critically analysed to achieve the goal of present paper. Though there are many methods reported in the literature; in the present paper commonly used methods of driver distraction measurement (viz. 'naturalistic driving study', 'driving simulator study', 'visual behaviour', 'visual occlusion', 'lane change task', and 'peripheral detection task') have been discussed. Each method has its own benefits and limitation. The selection of measurement technique(s) depends upon the objective of the research and availability of resources. Meagre consensus is found among researchers as to which method is better for distraction measurement. The present review on commonly used methods in distraction research, will give an idea about the benefits and limitations of each method to the budding researchers. Driving performance metrics which are the basic variables to be measured in any of the driver distraction measuring method involving secondary task performance are also being discussed in brief in the current review. Before we know the different distraction measurement techniques, first let us know about driver distraction and its sources.

1.1 Driver Distraction and Its Causes

The following definition of distraction was adopted at the 1st International Conference of distracted driving [1].

> Distraction involves a diversion of attention from driving because the driver is temporarily focusing on an object, person, task, or event not related to driving, which reduces the driver's awareness, decision-making, and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes.

Driver distraction may happen due to stimuli sources occurring either inside or outside the vehicle. The US National Highway and Traffic Safety Administration (NHTSA) has identified several activities that cause distraction during driving. These include eating/drinking, looking roadside advertisements/pedestrians, adjusting radio/cassette/CD, talking to passengers, talking/texting on mobile phones, using in-vehicle devices, adjusting climate control, smoking-related etc. [2].The extent of distraction due any one cause has not been quantified yet. However, researchers have shown that drivers should not be distracted for more than 2s from driving task to maintain safety [3]. Several researches have been done to relate behavioural indicators (mean speed, time headway etc.) of distraction to traffic safety, but no clear standard cut-off values for safe or unsafe driving is being obtained [4].

2 Various Driving Performance Measures

The extent of distraction due to performing secondary task(s) while driving can be comprehended by some variables/measures of driving performance. Compatibility with the distraction measurement technique(s) is a critical aspect in choosing these variables. Commonly used variables/measures in distraction research are presented here. *Longitudinal control* includes speed and following distance (headway). *Speed* is generally used in road safety and driver distraction research. These variables include maximum, mean, 85th percentile and variability of speed. Both on-road and driving simulator research have shown drivers display greater variability of speed while performing secondary task during driving [5]. *Vehicle following (headway)* indicates the safety margin which the driver keeps from the front vehicle. This measure is commonly employed in driver distraction research which include mean, minimum and standard deviation of headway [5]. *Lateral control* variable employed in the distraction research comprises of lane keeping and steering measures. *Lane keeping (lateral position)* is the position of the vehicle on the road with reference to the centre of the lane in which vehicle is moving. Secondary task load affects the lateral position control. Mean lane position, standard deviation of lane position, and number of lane exceedances (LANEX) are the generally used matrices in distraction research [6]. *Steering wheel metrics* include steering wheel angle, standard deviation of steering wheel angle, steering wheel reversal rate, high-frequency component (HFC), steering wheel action rate, and steering entropy. Drivers will make less steering movement when not performing secondary task as compared to when engaging in visual-manual task during driving. *Event detection and reaction time* metrics reported in literature comprise of number of missed/detected events, number of incorrect responses made, response time and distance (the distance of event when detected). On-road as well as driving simulator studies have shown that drivers' ability to identify and react to external events and objects when performing the secondary task gets compromised [5]. *Gap acceptance* [7] measure includes, "number of collisions initiated" and the size of gap accepted. Researches have shown that while using in-vehicle instruments, the driver tends to take shorter gaps and initiate a greater number of collisions as compared to when not. *Subjective mental workload* metric allows the participants to rate their workload just after completion of the secondary task. The major scales used for this purpose in the driving distraction research include NASA Task Load Index (NASA-TLX) [8]. DALI—Driver activity load index [9], is a specially designed technique for assessing the drivers' workload while operating the in-vehicle instruments. Assessment of driver distraction using these measures is of low cost, quick, easy, and nonintrusive.

3 Driver Distraction Measurement Techniques

3.1 On-Road and Test-Track Studies (Naturalistic Studies)

Naturalistic driving studies are being conducted to measure/evaluate the distracting activities which the driver get involved while driving in a real scenario. Instrumented cars fitted with video cameras and data loggers are being used to monitor the activities of the driver in the car/vehicle during driving [10]. The drivers drive their car without any instruction and data collection is very discrete as possible. Sensors are used to assess longitudinal, lateral control and headway from lead vehicle. These kind of studies are generally take long period of time and generate a large volume of data to be analysed. Trained coders are required to quantify drivers' exposure to variety of distracting tasks including drinking and eating, adjusting in-vehicle instruments, mobile phone usage, reading and personal grooming. In a study conducted by Carney et al. [11] naturalistic driving data was collected through event triggered (in–vehicle event recorder) IVERs technology. Data was not continuously recorded rather the video, audio, and accelerometer data was event triggered. Apart from data loggers other sophisticated devices can also be used. For example, eye-tracker [10, 12] can be used for recording drivers' visual behaviour.

3.2 Driving Simulator Studies

Simulator studies make use of driving simulators in a controlled laboratory environment. A wide variety of driving performance data can be collected. Driving simulator studies are relatively realistic and safe. However, the output of the study is affected by fidelity (or realism) and validity. Driving simulators are subdivided as low, middle [6], and high fidelity driving simulator [5]. A high - fidelity simulator provides a realistic driving environment, 360° field of view, advanced graphics, sophisticated motion base, realistic layout, and components. Middle fidelity has realistic vehicle, projector screen, and simple motion base. Low fidelity simulator has less realistic driving environment generally with PC or workstation and simple driving controls. There are several advantages of simulator study over on—road and test track studies. They provide a safe environment in which research can be conducted, which otherwise might be hazardous in reality. Distracting effect of in—vehicle system/activities can be easily evaluated in a multi—vehicle scenario. As compared to on-road/test track studies, simulator studies have greater experimental control as the type and difficulty of driving task can be specified easily. Moreover, a variety of test conditions (e.g. day/night, different weather and road environment) can be instigated with relative ease that are hazardous/difficult in real driving conditions. In spite of the above mentioned benefits, the demerits of using driving simulator includes learning effect of using the simulator and in some cases the effect of direct monitoring from the experimenter. High-fidelity simulators are expensive to install and require expertise for operating peripheral equipment (e.g. eye-tracker) [10]. Simulator discomfort is also a common problem among old drivers and female suggesting a greater drop out in comparison to male drivers. The drivers can allocate their cognitive resources to primary and secondary task differently, than in real world scenario, as they would consider their safety not being compromised.

3.3 Visual Behavior for Distraction Measurement

Driving is primarily a visual-manual task, requiring the driver to keep eyes on the road. In such cases, glancing away for a long period can have accidental consequences. Hence, metrics related to visual behaviour such as total glance duration, glance frequency, mean single-glance duration, and total task time, area of interest, saccades, and blinks are of prime importance for driver distraction measurement research [13]. These metrics compute the extent of time spent looking on and off the road. Researchers have reported eye-movement matrices as high performing and sensitive to visual and auditory demands while driving (HASTE project [14]). The drawback of this technique is that it is difficult and time consuming, also it requires expensive setup (eye-tracking instrument and analysis software) [15]. Research work in the recent past has developed more robust, reliable and easy to analyse eye movement behaviour. Percent road centre (PRC) as the percentage of time within 1 min that the gaze falls within a road centre area of 8° radius from road centre (the lane ahead). However, more work need to be done to make automated eye movement measurement easy, robust, and inexpensive. Metz and Krueger [16] used head movement analysis as an alternative to eye movement metrics for distraction measurement.

3.4 Visual Occlusion Technique

When the driver is looking at roadways then it is expected that attention is being set to the primary task of driving. However, if he is looking at the in-vehicle device, it is questionable that he is paying attention on road. As more features are being added into the in-vehicle devices (entertainment, information and communication), more chances are there for the driver to be distracted. Eye glance behaviour are imperious, but are difficult to collect and time-consuming to analyse. Visual occlusion method can be used to measure visual demand of IVIS (In-vehicle information system) in the preliminary product design cycle. Visual occlusion has been used by many researchers as driver distraction measurement technique in several different ways. The basis of this technique is that driving is a visual-manual task [17].This technique measures the visual demand of a task performed concomitantly with driving and was initially proposed by Senders et al. [18]. It can be used on both

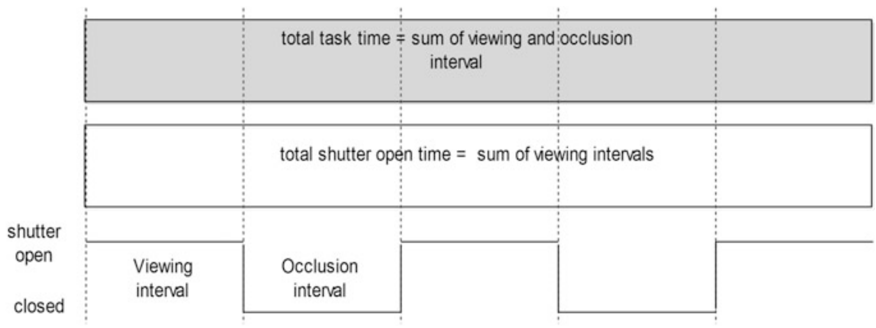

Fig. 1 Illustration of occlusion and timing measures. *Source* Adapted from [17]

simulators and on-road/naturalistic driving studies. Visual occlusion is "physical obstruction of vision for a fixed period of time" [19]. This method comprises of systematically obscuring the driver's vision and then removing obscuration shown in Fig. 1. The parameters of visual occlusion technique as mentioned in ISO standard 16673 [20] are: Total shutter open time (TSOT) *(total time during which vision is un-occluded),* TTTUnoccl *(total task time for a task completed without occlusion)*, Resumability ratio (R) *(ratio of mean TSOT to the mean TTTUnoccl).* This method measures the performance of the participants while performing a secondary task, both when there is no occlusion (total task time un-occluded, TTTUnoccl) and when periodically occluded (total task time occluded, TTTOccl). The task duration is measured from the end of instruction to the participant says 'done'. A shutter open time (SOT) of 1.5s is acceptable for standardised occlusion procedure. Visual occlusion method has also been proposed to assess in-vehicle information and communication system [19, 21, 22]. Research work for improving upon the standard visual occlusion technique in terms of its sensitivity was carried out by Gelau et al. [23]. More recently in-vehicle information system have been evaluated for safety and usability by using visual occlusion method [24]. Empirical work of Domeyer et al. [25] using occlusion technique shows, age and work profile (employee of NHTSA and general public), affect distraction. Occlusion method has also been used for visual workload while driving [26].

3.5 Lane Change Test (LCT) Technique

LCT is a dual task approach for measuring the effect of distraction on the primary task of driving due to secondary task performed parallelly. It is a simple, cost-effective, reliable and valid tool to measure the demand of an IVIS [27]. LCT was originally established by the research project 'Advanced Driver Attention Metrics' (ADAM), jointly done by BMW AG and Daimler Chrysler AG. It combines the features of driving simulators and reaction time paradigms. LCT can be effectively used to evaluate the interaction with in-vehicle information system, controls (manual, visual, haptic, vocal/auditory) and its combinations. In LCT, the participants have to drive on a straight, three-lane road at a system controlled speed of 60 km/h. A pair of sign appears on the side of road indicating on which lane to drive. The track length is 3000 m and approximately takes 3 min at aforesaid speed. Six possible lane changes (from left to the middle, left to right etc.) are performed equally. Every sign contains two "X" and downward arrow, indicating the correct lane to travel. Participants are instructed to change the lane as proficiently and promptly as they see the lane change sign. This lane change has to be performed before passing the sign. The LCT is standardized in ISO 26022. It has been successfully used to explore the effect of additional in-vehicle tasks while driving [28]. Harbluk et al. used LCT as an efficient and effective way to assess distraction when operating a navigation system [29, 30].

3.6 Peripheral Detection Task (PDT) Studies

Peripheral detection task (PDT) is a kind of artificial signal detection method recently being employed in the driver distraction research. A number of modifications of PDT are employed, namely visual detection task (VDT) (use of visual LED lights), tactile detection task (TDT) (use of tactile vibrators) [31], and signal detection task (SDT). The PDT was first developed by van Winsum et al. [32]. The main idea behind this method is that the response time to the stimuli increases as a function of driving task demand. The stimuli are presented on the visual field with temporal and spatial differences. PDT and its variants can be easily implemented in both on-road and simulator studies. In a simulator study by Merat and Jamson [33] used auditory stimuli, presented by loudspeakers inside the simulator, which is called as auditory detection task (ADT). The variants of PDT principally differ in the way stimuli are presented, however, the response are more or less the same (typically micro switch attached to index figure of steering wheel) [34]. In TDT stimulus is a vibration to the body (wrist and neck). In PDT related studies a with-in group experimentation is performed, firstly, while performing a secondary task (driving with secondary task and detection task), and then without (driving with detection task). The performance of PDT is measured in response time (RT) or hit rate (total number of hits divided by total number of stimulus).

4 Advantages and Limitations of Various Studies

The present paper discusses six different driver distraction measuring techniques. Each method has its own merits and demerits. Naturalistic driving study and visual behaviour study (requires eye-tracking) are quite expensive, cumbersome, and require a high level of skill for analysis and coding. Recently developed methods

Table 1 Advantages and disadvantages of various studies

Study type	Advantages	Disadvantages	Parameters measured
Naturalistic driving study	exposure to many distracting activities quantified in natural driving condition	the cost is high with various logistic issues, less experimental control	All the parameters (speed, headway, steering wheel metrics) in real driving [10]
Driving simulator study	Safe environment, multi-vehicle scenario can be safely evaluated, great experimental control	Participants' response may differ as there is no fear of errors or accidents	All the parameters (speed, lateral control, gap acceptance, reaction time) in simulated condition [5]
Visual behaviour study	Accurate, reliable and gives complete understanding; simulator and on-road test possible	Expensive setup, time consuming, high skill for analysis	area of interest, saccades total glance duration, blinks, glance frequency, total task time [13]
Visual occlusion	Easier and less costly than eye glance measurement, applied in early stages of system prototype	Short < 1s, dynamic moving element task are out of scope	TTT, OCCLT, TSCT INSPT, TSOT [21]
Lane change test	Simple, cost-efficient, reliable, sophisticate and expensive equipment not required	Learning effect of driving simulator may happen	MDEV, LCI, task duration [29]
Peripheral detection task	Reliable, sensitive to variety of secondary task, low cost and easy setup, simulator as well as on-road test possible	Affect visual behaviour when simultaneously performed	Hit rate, reaction time [32]

TTT Total task time, *OCCLT* Occlusion time, *INSPT* Inspection time, *TSOT* Total shutter open time, *TSCT* Total shutter closed time, *MDEV* Mean deviation, *LCI* Lane change initiation

such as lane change test, visual occlusion, and peripheral detection task are relatively simple, cost-efficient, and have an easy setup. Simulator studies provide a safe and high degree of experimental control, but there is also a growing concern that the drivers may be less worried when performing a secondary task while driving as their safety is not compromised. A brief summary of the benefits and drawbacks of various methods have been presented in the Table 1.

5 Conclusion

Although there are many popular methodologies, none of the methods is fully capable of drawing the complete picture of the driver distraction under varying circumstances. Hence, a combination of different methods based on the research objectives and resources would be highly useful to researchers for conducting empirical study on driver distraction. As driving is mainly a visual-manual task, it is recommended to conduct visual behaviour studies, in a simulated environment and if possible, in a natural driving environment, so as to draw a consensus between the two methods. Understanding of the advantages and disadvantages of various driver distraction techniques would help the researchers in selecting the most appropriate method based on their research needs. Future studies need to be conducted on-road as well as in driving simulator for listing various behavioural markers of distraction during driving. Collaborative research on 'driver distraction' involving researchers from all over the world is needed to be executed aiming at an international standard towards allowable limits for a combination of behavioural indicators to ensure driving-safety. The present review concerning benefits and limitations of various methods would help budding researchers to choose the right strategy for their intended research on driver distraction.

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Weight Reduction of FSAE Vehicle Using TRIZ Principle

Ankit Jinturkar, Rohan Channa, Roohshad Mistry and Bhagyesh Deshmukh

Abstract Weight is a major limitation for the performance of an automobile. Increased weight results in poor acceleration, poor dynamics and reduced efficiency. Weight can be reduced by extensive use of composites which is expensive and requires a complete redesign of the vehicle. This paper aims to provide a systematic analysis by applying TRIZ to reduce the weight of Formula SAE (FSAE) Student Competition Vehicle. TRIZ ideas and analysis tool such as contradiction matrix are applied in order to discover some feasible and elegant solutions for reduction in weight. Study revealed that the problems of high weight are due to the poor design layout of the vehicle, redundancy in function and lack of systems approach. The main factors that lead to increase in weight are solved by applying contradiction matrix, and inventive changes such as dynamization, segmentation, parameter change are recommended. The study resulted 10% weight reduction in the overall weight of the vehicle.

Keywords FSAE · Automobile · Vehicle dynamics · Systematic analysis · TRIZ · Contradiction matrix

1 Introduction

Today many automobile manufacturers are concerned to low down the production costs. In design optimization weight reduction is an indicator of sustainability design [1]. A large part of vehicle performance depends on the drive train, suspension and chassis of the vehicle. The total weight of the vehicle including the driver weight has significant impact on dynamic performance of the car. Weight makes a key impetus on the performance of the vehicle powered by the small engine, so a perfect design needs to be developed that can make out a perfect

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compromise between the strength and weight of the vehicle. Thus the chassis design becomes very important in the vehicle performance. Frame is one of the basic components of vehicle. The frame should be developed with minimum possible weight. It should stand sound during *frontal impact, rollover of chassis, side impact, torsional and bending forces.* Developing such a kind of solutions is a bit difficult and requires a perfect blend of research and innovation.

Many organizations use TRIZ as a systematic approach to overcome complex design problems. This paper showcases the systematic implementation of TRIZ to design a frame which would assist in the significant weight reduction of the car.

2 TRIZ Method and Review

Teoriya Resheniya Izobretatelskikh Zadatch (TRIZ), (*in Russian*) as 'Theory of Inventive Problem Solving' (*in English*), is a framework for developing conceptual designs for the existing functional contradictions [2]. It was developed by Genrich Altshuller and his colleagues in the former USSR in the late 1940s and 1950s.

2.1 TRIZ Framework

Problem solving in TRIZ is based on logic and database, which leads to more creative solutions. Algorithmic approach of TRIZ provides repeatability, predictability and reliability [3]. TRIZ believes that there are universal principles of creativity; and if those are identified and codified, they could be harnessed to teach the people to think in creative ways. The research in TRIZ over last six decades has passed through several stages, which had unveiled the following findings that:

- There is a repetition of problems and solutions across the industries. The proper classification of contradictions existing in each problem can be used to foresee the creative solutions possible on it.
- There is a repetition in the patterns of technical evolution across the industries.
- Many innovations have found applications of it in the different field, from where they were developed.

Figure 1 explains the general problem solving process by TRIZ method as conceptualized by Gao [4].

2.2 Contradiction Analysis

Altshuller discovered that the majority of patented solutions to problems were developed using just 40 inventive principles and that all functions can be described under 39 basic parameters; Contradiction analysis is the primary TRIZ tool based

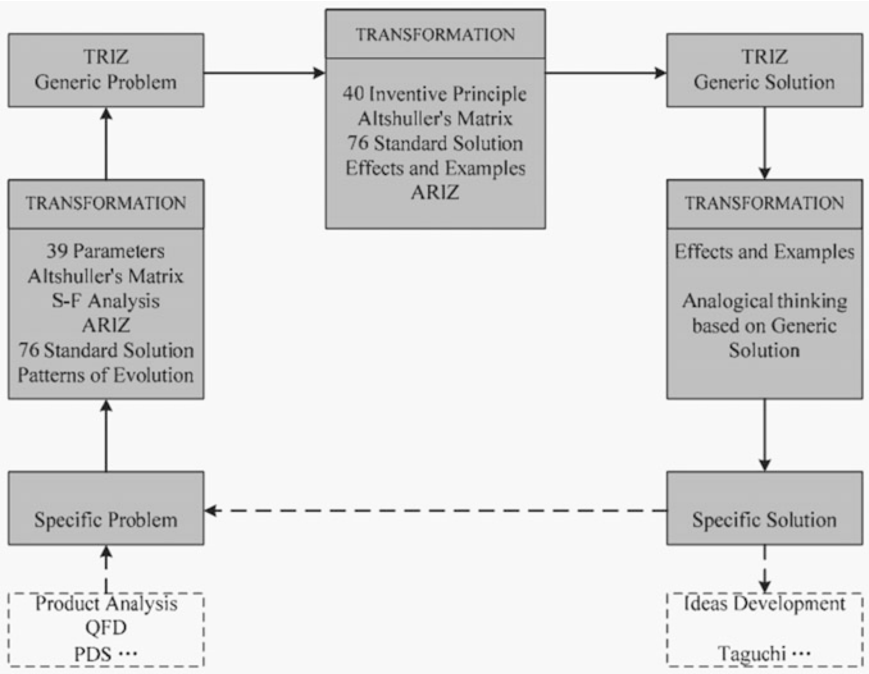


Fig. 1 General problem solving process by TRIZ

on Altshuller's discovery [5]. Altshuller found the major issues when creating solutions for the engineering problems is that the functional requirement is often in conflict. Conflict is caused due to technical contradictions where enhancement of one functional parameter is detrimental to another, e.g. a blacksmith requires that a metal piece is hot enough to work but is cool enough to hold.

Ideality is another key concept that supports the identification and treatment of technical contradictions. This says that all engineering systems should alleviate its degree of ideality and the problem solver should conceptualize an Ideal Final Result (IFR) [6]. The ideal system is visualized as a pure function that delivers benefit without any detrimental effect on the occupied space, weight and requires no additional energy or maintenance [7]. Every real system is less than the ideal because it generates both, the desirable functional requirements and simultaneously the undesirable by-products, e.g. the generation of heat and noise as a byproduct of the combustion process in an engine. The objective of the design is to maximize the functionality and minimize the harmful effects. The effectiveness of the solutions can be assessed by using the following equation:

$$IFR = \frac{Sum\ of\ useful\ functions}{Cost + Sum\ of\ all\ harmfull\ functions} \tag{1}$$

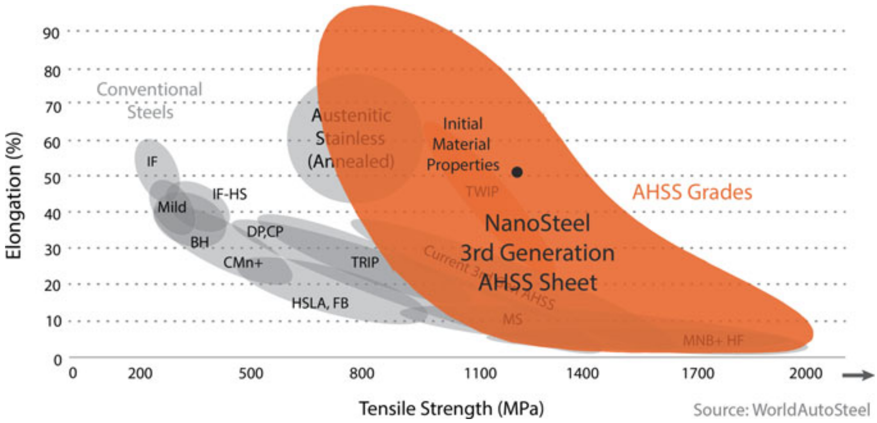


Fig. 2 Stress strain curve for steels (*source* Website-Nanosteel)

2.3 Review

Vallurupalli et al. shows that there is a high demand for the light weight chassis frame that improves fuel efficiency and reduces cost of the vehicle [8]. It talks about the process of weight optimization in chassis frame without affecting current durability performance. Optimization parameters for the study were sheet metal gauges and the lightening holes. The optimization in design was limited to the chassis unique parts. The verification of the optimized design was done for the detailed load case and life target. Approximately 5% reduction in weight was obtained implementing this process.

However above research never focused on material optimization, which is covered by Sohmshetty et al. [9]. It deals with the implementation of AHSS such as DP590 for the chassis structures. Hot rolled steel grades in the yield strength range of 220–250 MPa are typically used to build frames [10]. Instead hot rolled AHSS such as HR DP 590 can be an option to enable the weight reduction and the strength enhancement of these structures (Fig. 2).

Though above mentioned are some approaches to weight reduction, many more inventive approaches are untapped, which would be systematically unveiled in this paper using TRIZ.

3 Design Methodology for Frame

Figure 3 shows a generic illustration of the major steps involved in the design optimization process of the frame of FSAE car.

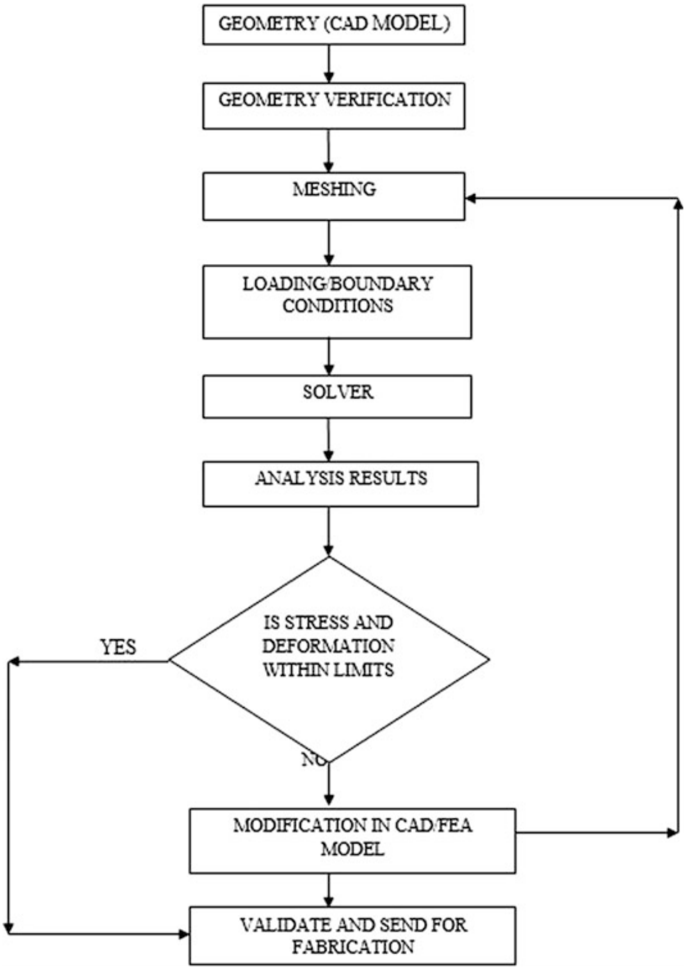


Fig. 3 Flow chart for generic design process

4 Weight Reduction Problem Analysis Using TRIZ

The existing frame focused on safety so major emphasis was on increasing the body strength. Strong frame members add strength to the structure. The strength is proportional to the volume of the materials. As the volume of the material increases, the strength of the structure also increases. The strength is calculated by the various analyses on the frame in Solidworks. Here we target to build a light weight frame, by implementing TRIZ to sort out the technical contradictions.

In general, new product design is started with the concept design which composed of several parts; task analysis, product function analysis, life cycle analysis and value analysis which is described by Baxter [11]. Concept design lays the foundation for developing the design principles for the new product. These design principles should satiate the consumer needs and should assist to produce an outstanding product.

4.1 Design Objective and Ideal Final Result(IFR)

Design Objective—*"To enhance the performance of the vehicle by reducing its weight without compromising its safety".*
IFR—*"The new modified frame reduces weight maintaining the strength, simplicity and ergonomic constraints constant".*

4.2 Multi Objective Optimization Using TRIZ

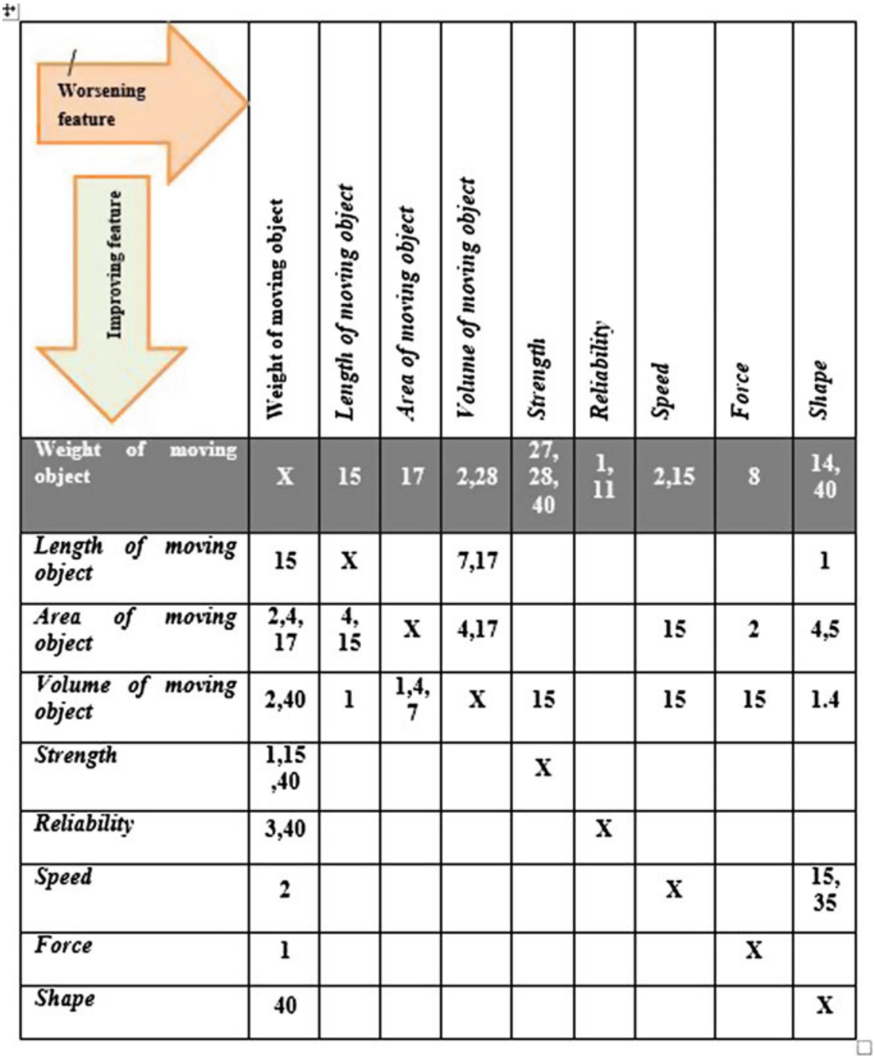
The design objective focuses on reducing the weight subjected to the constraints of strength requirements and safety of the vehicle. Ideality principle directs to choose the chassis that improvises weight thereby minimizing the complexity and maintaining the driver's ergonomics.

For analyzing these contradictions systematically the contradiction matrix is formed using the *39 Basic Parameters* of Altshuller and the solutions are derived using *40 Inventive Principles of TRIZ.* These *40 inventive principles of TRIZ* check for every possible optimization for the *39 Basic Parameters* of Altshuller, which cover almost all the possible optimizations that ultimately lead to the *multi objective optimization* of the frame.

Figure 4 shows the contradiction matrix with the possible solutions to cope up the problem. The major contradictions concerned with our problem statement are highlighted and their solutions are explained clearly in Table 1.

5 Results and Discussion

The purpose of this paper was to demonstrate the generation of design solutions for the frame of the car using TRIZ. The Concepts of Separation in time and separation in space are used to accomplish this. The separation of space is obtained by the modification in the design of frame by eliminating unnecessary members (*Taking*



Worsening feature / Improving feature	Weight of moving object	Length of moving object	Area of moving object	Volume of moving object	Strength	Reliability	Speed	Force	Shape
Weight of moving object	X	15	17	2,28	27, 28, 40	1, 11	2,15	8	14, 40
Length of moving object	15	X		7,17					1
Area of moving object	2,4, 17	4, 15	X	4,17			15	2	4,5
Volume of moving object	2,40	1	1,4, 7	X	15		15	15	1.4
Strength	1,15 ,40				X				
Reliability	3,40					X			
Speed	2						X		15, 35
Force	1							X	
Shape	40								X

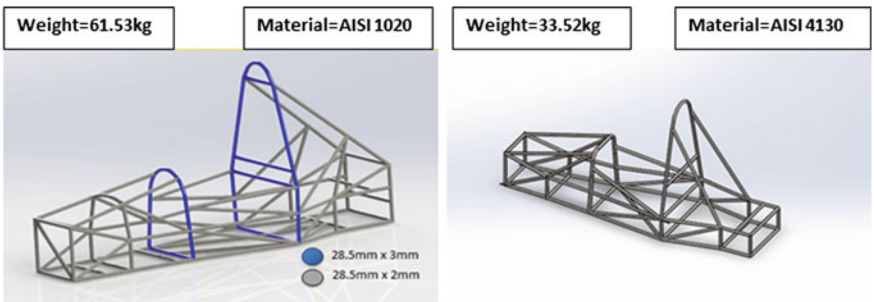
Fig. 4 Contradiction matrix

out) of the it, which is possible due to change of the material (*i.e. Composite*) used to build it Fig. 5. The FE analysis was carried out to check the strength of the frame under various conditions Table 2.

The weight of the frame got reduced from 61.53 to 33.52 kg, which is about 45% reduction in weight of the frame and it contributes about approximately 10% reduction in the overall weight of the car (*i.e. about* 265 kg).

Table 1 TRIZ based solutions

Contradiction	TRIZ design principle	Solution
Weight versus Length	15-Dynamics	Reduce the weight of the car such that it has an optimum length for maintaining the dynamics of the vehicle
Weight versus Area	17-Another Dimension	While reducing the weight of the car, the required functional area should be maintained by using another dimension in its construction
Weight versus Volume	2-Taking out 28-Mechanical substitution	Take out the redundant parts without compromising on the required volume
Weight versus Strength	27- Cheap short living objects 28-Mechanical substitution 40-Composite material	To compensate on strength while reducing weight we can use cheap replaceable components, or instead of mechanical devices can implement light weight and reliable electronic equipment or we can go for a change in the material of construction of the structure e.g. Composites
Weight versus Reliability	1-Segmentation 11-Beforehand cushioning	Segmentation of the system into various subsystems can help to improvise the reliability of the system Prepare a back-up for the relatively low reliable components to cope up with the failures during emergencies
Weight versus Speed	2-Taking out 15-Dynamics	Take out the redundant weight to improvise the speed and the dynamics of the car
Weight versus Force	8-Antiweight	Implementation of aerodynamics on the car can reduce the amount of traction force required by it
Weight versus Shape	14-Spheroidality-curvature 40-Composite material	By using composites we can retain the shape of the car simultaneously reducing its weight



(a) Earlier (b) Improved

Fig. 5 Frame

Table 2 FE analysis of frame

	M	W(kg)	Front impact			Side impact			Rollover		
			D (mm)	BS (MPa)	FOS	D (mm)	BS (MPa)	FOS	D (mm)	BS (MPa)	FOS
Earlier	72	61.53	9	270	1.3	3.2	262	1.34	2.3	219	1.6
Improved	54	33.52	5.6	275	1.28	2.72	247	1.9	0.67	96.1	4.79

Where, *D* Deformation; *BS* Bending Stress; *FOS* Factor of safety

As per the FSAE rules the permitted life of the frame is only for the two consecutive events, so the concept of separation in time could be adopted to construct the frame with the optimum reliability.

6 Conclusion

This paper provides an insight on generating the concept solution ideas for an optimized frame of the car. The freedom to generate the concept designs without any consideration for practicality at the initial stages could lead to generate an innovative hybrid solution consequently in the further stages of development.

It demonstrates that the tools like TRIZ, which have the algorithmic approach to generate the concept solutions are worth to address the design problems.

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Design of Quick Jack and Push Bar Using TRIZ Principle

Ankit Jinturkar, Shubham Shah, Roohshad Mistry and Bhagyesh Deshmukh

Abstract Formula SAE (FSAE) student competition vehicle requires *Quick Jack* for lifting the vehicle for maintenance and repair. It also requires push bar for pushing vehicle into inspection bay and repair bay. Both quick jack and push bar have opposite functions. Function of Jack is to prevent vehicle motion where as the function of the push bar is to put the vehicle in motion. The aim was to combine the two functions into one product. This presents a contradiction of functions and separation in space. The paper shows application of TRIZ ideas such as separation in time, separation in space etc. and analysis tools such as function analysis, cause and effect chain analysis and contraction matrix to deliver functional and effective design to combine quick jack and push bar into one product. The result is elegant and simple toggle and lock mechanism which allows to quick jack and push bar into single product which meets both function.

Keywords FSAE · Automobile · Vehicle dynamics · A systematic analysis · TRIZ · Contradiction matrix

1 Introduction

Formula SAE (FSAE) student competition vehicle requires *Quick Jack* for lifting the vehicle for maintenance and repair. It also requires push bar for pushing vehicle into inspection bay and repair bay. Teams participating FSAE use simple push bars and quick jack of various designs. But we have combined the function of quick jack and push bar into one product. As per the rules of FSAE we have to carry quick jack and push bar while going to inspection bay and repair bay, but due to combination of these two equipments we have eliminated the problem of carrying two different equipments. To resolve engineering issue many of engineers use the "Add" or

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"Substitute" process. This system of introducing addition elements to work out a problem comprise "Add" components to have more functions. Many also might utilize "Substitute" by substituting a issue regarding element with a new design to give solution to a problem. The paper gives a theoretical base and systematic way of utilizing the concept of "Combining" 2 products with 2 different functions into single product providing both functions. This method is called "Merging" in the context of TRIZ (Theory of Inventive Problem Solving) methodology. TRIZ is the (Russian) acronym for the "Theory of innovative issue solving" is an international way of creativity that is based on the study of the way of problems and solutions, not on the spontaneous and intuitive creativity of individuals or groups. Six TRIZ principles are used in this design.

2 Literature Review

The three aspects are applied to enhance products, services, and systems in the application of TRIZ method. These aspects are studying by applying scientific effects, iterative patterns of problem solutions and using the common TRIZ patterns. Innovative design of an automatic car by Hesin-Sheng Lee and Long-Chang Hsieh (door opening way) [1]. Hassan [2] applied TRIZ method considering safety on both exploitation and design levels, highlights management contradictions constituting human, economic or technical aspects. The aim of this communication is to put forward element to pilot the exposure of new solutions regarding the persistence of contradictions allied to the safety integration by availing our "working state" model.

Quick lift jack used at pit stops and in the garage of F1 was a easy tool. In the course of the race pit stops have become a significant part of the performance of the team, where as the jack has utilized for improving levels of development. Teams depend on a massive pull from a mechanical jack to raise the car and gravity to lay down the car to the ground as powered jacks are not allowed. Enhancing this procedure has made most teams to adopt a same quick-release swivel jack. A complex looking kit, jack is still a manageable device when lessen to its component parts.

At pit stops, for lifting the front and rear of the car quick lift jacks is used by the teams. It is more complex as the front jack should be removed to move the car out of the pit. As the mechanism is almost same, this quick jack needs different mechanism for raising the vehicle which results in an increase in weight.

3 Triz

Teoriya Resheniya Izobretatelskikh Zadatch (TRIZ), is a basic structure for the visionary design of engineering solutions which provides functional contractions and is translated as 'Theory of Inventive Problem Solving' [3]. It is developed by Genrich Altshuller and his workmates in the bygone USSR in the late 1940s and 1950s. The TRIZ structure of knowledge-based tools was built out of an ample study of universal patent applications. Its conclusion resulted to a few number of design solutions which were truly laid the foundation of inventions and the other were bygone known ideas and concepts that were reused in a new way [4].

TRIZ presents a methodical approach for defining and understanding challenging issues: tough problems require an innovative solution, and TRIZ yields a range of strategies and tools that can be used to find these innovative solutions. One of the earliest discoveries of the tremendous research on which the theory is grounded is that the vast majority of difficulties that require innovative solutions typically reveal a need to prevail over a confusion or a tradeoff between two conflicting elements. The principle purpose of analysis based on TRIZ is to systematically put into practice the tools and strategies to find finest solutions that prevail over the need for a settlement or tradeoff between the two elements.

By the early 1970s the research of two decades covering thousands of patents had established Altshuller's earlier perceptions about the patterns of innovative solutions and one of the initial analytical tools was published in the form of 40 innovative principles. These principles could record for virtually all those patents that put forward truly innovative solutions. By following this way the "Conceptual solution" shown in the figure can be built by defining the conflicts which needs to be determined and systematically taking into account which of the 40 principles might be applicable to provide a peculiar solution that will prevail over the "contradiction" in the problem, allowing a solution that is close to the "ultimate ideal solution [5]".

The merging of all of these concepts—the analysis of contradiction, the tracking of an ideal solution and exploring one or more principles that will prevail the contradiction, are the major elements in a process that is designed to assist the inventor to perform the process with the intension and focus. The tools which evolved as an enhancement of 40 principles was the contradiction matrix (in this the contradictory elements were categorized as per the list of 39 factors that could affect on each other. A matrix is set out as a result of the union of each pairing of these 39 elements (for instance, the utilization of energy by a non stationary object, the weight of a still object, the effortlessness of repair). Rows and column are used to represent the 39 elements (as negatively affected element) and built the analysis and research of patents: anywhere precedent results have established which resolve the confusion across the two elements, the cells in the matrix usually hold a subset of 3 or 4 principles which have been used most repeatedly in innovative solutions that work out contradictions between the two elements. The main motive of the

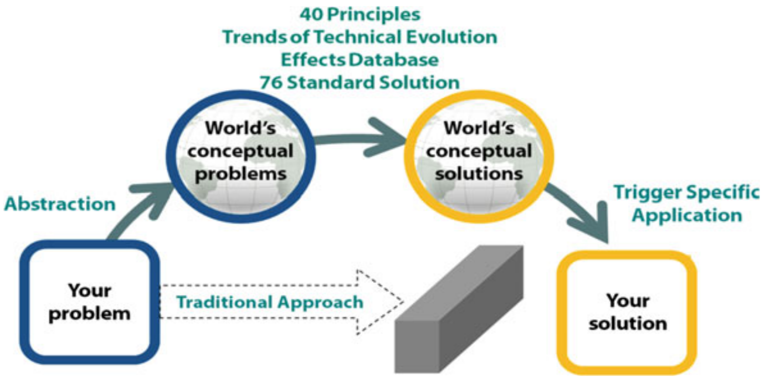


Fig. 1 Triz model of problem solving [5]

contradiction matrix was to ease the process of choosing the most suitable principle to resolve a particular contradiction (Fig. 1).

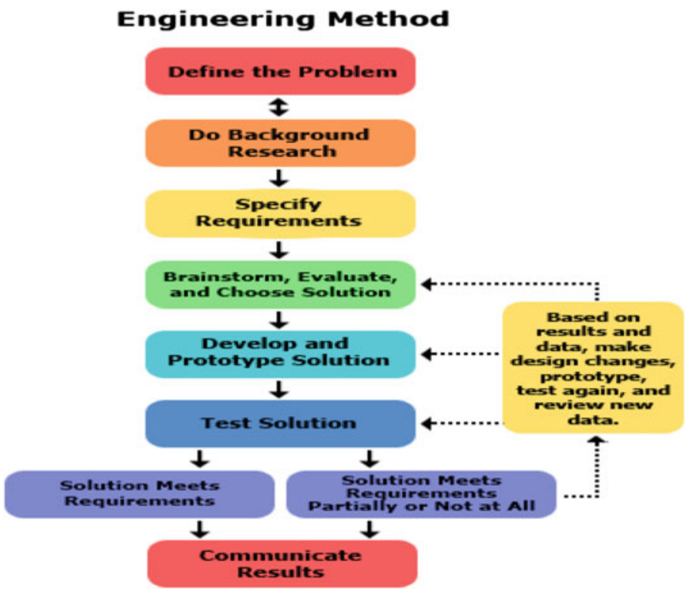


Fig. 2 General design procedure [6]

4 Design Methodology for Quick Jack and Push Bar

This methodology was used to analyze the Quick Jack and Push Bar of FSAE car. Figure 2 shows the process involved in the designing of the product.

FSAE vehicle needs a better way to lift and push it. As there are two different equipments for these two requirements, the task seems to be very tedious.

Hence the problem statement was identified and accordingly the existing solutions to similar problems were taken into consideration and the faults which were done before were not repeated.

Then considering the objective, function and design parameters such as weight, durability, strength, ease of use, cost, manufacturability, assimilability etc. multiple designs were established. The optimum solution was chosen and improvement of solution continues throughout the design process. CAD model was developed in Solidworks.

4.1 Design Objective

The objective of the work is to design a product which can perform tasks of quick jack and push bar where quick jack and push bar have opposite functions. It also eliminates the problem of carrying both the equipment as it is combined in a single product.

4.2 Ideal Final Result

The ideality theory proposes that Ideal Final Result (IFR) should always provide no interference, no added space and no add on weight to the product.

The new modified Quick Jack and Push Bar Combine to functions into one product which reduces the weight of the product.

5 Triz Principles and Contradiction Matrix

There are many application design methodologies which are practiced in the applications. For this project to be effectual and pertinent, the nature of the suggested TRIZ Design Methodology outcomes as a addition and not as a replacement for the current design processes. The methodology is to contribute the common design procedure. In this project new and advance design tools are established. The following TRIZ principles used for the design of the product:

1. Segmentation [1]: The degree of fragmentation or segmentation is increased by making the product multifunction i.e. jacking as well as moving vehicle.
2. Local Quality [3]: Jack is used to lift and push bar is used to move the vehicle hence each part of an product satisfies a unique task.
3. Merging [5]: Two different products are combined and used to perform multiple functions.
4. Universality [6]: A single product can perform a task of jack and push bar which shows universality.
5. Anti-Weight [8]: The total weight of individual parts is more as compared to our product as two different parts are combined eliminating unnecessary parts.
6. Dynamics [15]: The degree of free motion is increased as it can swivel so as to jack the car and also moves the car.
7. Another dimension [17]: The product is re-oriented so as to it give swivel motion.
8. Parameter Changes [35]: Alter the degree of workability to give both multi-function ability as in this case jacking and pushing the vehicle.
9. Composite Material [40]: Use of different materials depending upon the function of part.

Table 1 Contradiction matrix for quick jack and push bar

Worsening feature → / Improving feature ↓	Weight of moving object	length of moving object	Area of moving object	Volume of moving object	Waste of substance	Waste of energy	Reliability	Strength	Stability of the object	Convenience of use	Complexity of device
Weight of the moving object	X	15,8	17	40	3,5,35	6	1,3	40	1,15	3,8,35,40	
length of moving object	8,15	X	15,17	17,35		35		8	1,8,15	1,5,6,8,15	1,5
Area of moving object			X			15					
Volume of moving object				X							
Waste of substance	40,15				X						
Waste of energy						X					
Reliability	3,8,40				40		X				
Strength	15,40							X			
Stability of the object	40,8								X		
Convenience of use	40,8,5									X	
Complexity of device											X

Fig. 3 Quick jack

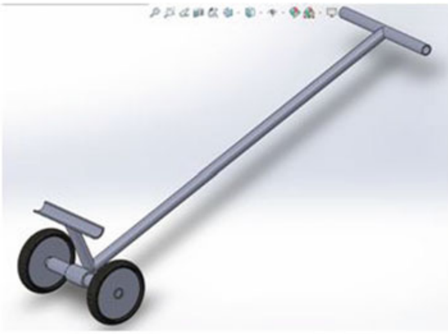
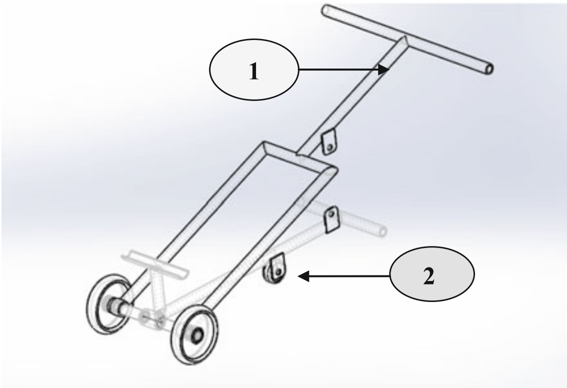


Fig. 4 Push bar

Fig. 5 Isometric view



With the help of the above listed TRIZ principles we have reduced the space, effort, total weight of the equipment, increased the product durability, increased the product service and designed the efficient and economical product. For analyzing the contradictions systematically the contradiction matrix is formed using the *39*

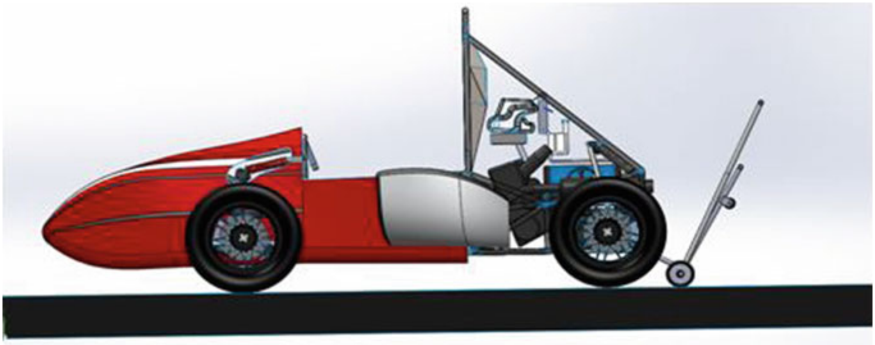


Fig. 6 Car in normal position

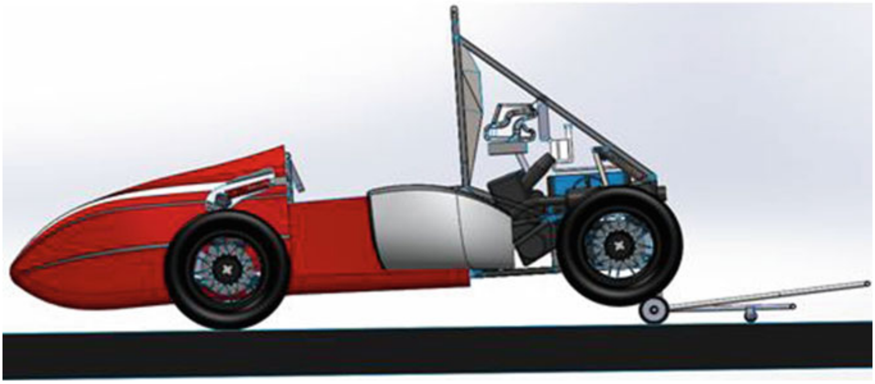


Fig. 7 Car in lifted position

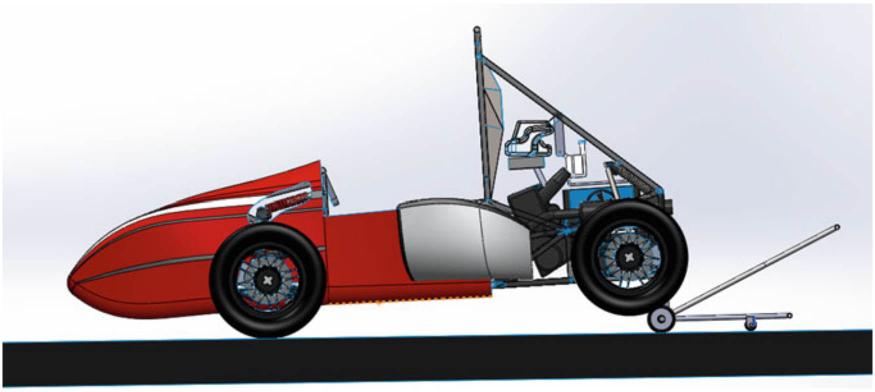


Fig. 8 Car in moving forward

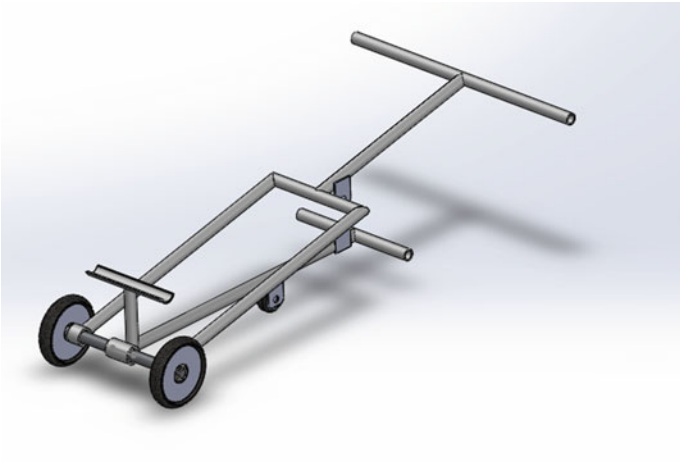


Fig. 9 CAD model of quick jack and push bar

Basic Parameters of Altshuller and the solutions are derived using *40 Inventive Principles of TRIZ.* The table shows the contradiction matrix with the possible solutions to cope up the problem. The major contradictions concerned with our problem statement are highlighted and their solutions are explained clearly in Table 1.

Figures 3 and 4 shows the Quick Jack and Push Bar respectively. Then by applying TRIZ principal using contradiction matrix, the design was optimized by combining the function of Quick Jack and Push Bar into one product. Figure 5 shows the optimized design of the Quick Jack and Push Bar (Fig. 6).

Figure 5 is an isometric view of the developed mechanism. Both the quick jack (2) and push bar (1) are combined into single product as shown in Fig. 9. The pivot point of push bar (1) and quick jack (2) is mounted on the axle. While using the jack, both the mechanisms push bar (1) as well as quick jack (2) have to be lowered as shown in Fig. 7 and while using the push bar (2), jack has to be lowered and push bar (2) is lifted upwards to push the vehicle as shown in Fig. 8.

6 Discussion

The basic idea of the equipment is ease of use and economy of manufacture. It is feasible, reliable, and durable mechanical equipment. This mechanism can be adoptable for all the FSAE vehicles. This ensures the modularity of design. The mechanism is satisfied with relative arrangement of components which caters the as per exact requirement.

7 Conclusion

TRIZ design methodology permits it to be incorporated into concept and product design processes. The functions of quick jack and push bar is successfully combined by using this product. Due this product the extra effort of carrying both the equipments differently is eliminated. The designed product is simple and efficient.

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Improving Aid Through Good Design: A Case Study in Rural Zambia

Clara Watkins, Gareth Loudon, Steve Gill and Judith Hall

Abstract This paper presents case study material relating to the application of a process of Human-Centred Design that draws upon Design Thinking for the development of medical products for rural Zambia. The underpinning method was developed in response to calls for the development of culturally and contextually appropriate medical product solutions as opposed to the current solution; directly imported products and methods from industrialised nations. The authors note the benefits and limitations of the approach taken, reflect on the resulting insights and provide recommendations for future studies.

Keywords Design thinking · Human-centred design · Disruptive innovation · Healthcare · Zambia

1 Introduction

This paper responds to the questions surrounding the suitability of applying design methodologies developed in the industrial context, to the context of low-income, developing regions, through applying a process which combines HCD [1] and Design Thinking [2] methodologies, to the design of medical products for rural Zambia. Specifically the design of a solution to treat victims of road traffic accidents (RTAs), a major issue in Zambia identified by the contextual review. The aim of

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this study was to gain insights into the most appropriate method of ensuring contextual appropriateness and adherence to the WHO's 4 As.

HCD and Design Thinking were chosen for this study due to their resonance with observations made by e.g. Papanek [3], Bonsiepe [4] and Donaldson [5]. All of them argued in favour of applying user-centric approaches to the design of products and solutions aimed at meeting the needs of the world's poor and disagree with methods relying on Western designers' 'stop-over visits'. All three argue in various ways that such an approach fails to account for 'sense of culture, language, norms and deep understanding of the problems people face' [5]. Donaldson and Bonsiepe also refer to these approaches variously as 'remote' or 'parachute' design. Donaldson also claims that 'remote design' (an approach where designers are 'remotely located' in the geographic sense to the target users) limits the ability to be truly user-centric due to the lack of 'comprehensive customer involvement and ready access to the environment.' Whichever term is used, all describe a tendency for people from industrialised nations to produce solutions for developing regions with little understanding of the context or culture of the item's intended environment. In this sense they design 'for' the developing world, as opposed to designing 'in' the developing world. All three argue that this failure to design in the developing world limits understanding and appropriateness.

2 Background

As aid agencies and governments unite to tackle the challenges of healthcare provisions in developing countries, the appropriateness of directly importing medical solutions from industrialised nations has come under scrutiny. This has resulted in calls for the development of culturally and contextually appropriate solutions, prompting the rise of a number of design development methods, including Participatory Design [6], Design Thinking [2] and Human-Centred Design (HCD) [1]. However, there has been criticism of the lack of scholarly evidence to support the suitability of such methodologies, and questions have been raised as to the appropriateness of applying design methodologies developed in and for industrialised countries to the developing world.

The challenge of designing in, for and with developing countries has been a long debated subject. The design community's attempts to meet the needs of the world's poor, has seen the emergence of methods including the Appropriate Technology Movement, the Design for Development movement, Design for the Other 90%, Jugaad Innovation, Disruptive Innovation methods, Gentle Action and Design for the Bottom of the Pyramid (BoP) to name but a few. Although these movements vary in their approach, their authors all agree that to meet the needs of the world's poor, products and solutions must be developed to be contextually appropriate. To achieve this, they argue in favour of ensuring that solutions meet the 'Critical 4' A's outlined by the World Health Organisation (WHO). The 'Critical 4 A's' are: Accessibility, Availability, Affordability and Appropriateness [7].

Despite recognising the ability of existing methodologies' to assist in the development of contextually appropriate technologies for the BoP, Diehl and Christiaans [8] identify weaknesses in their emergence from industrial markets and a need for greater understanding of their ability to be adapted to the developing country context. When considering what innovation means to the BoP Castillo et al. [9] identified a need for solutions for the BoP 'to go way beyond the market-pull strategies' used in industrial nations, and argued that to achieve this, people must apply evolutionary innovation strategies.

3 Project Design

The project design for this study follows Design Thinking's 'overlapping, non-linear spaces of innovation: inspiration, ideation, and implementation' [2], and the iterative HCD process 'hear, create and deliver'. It also sits within the framework of Design Thinking's three competing constraints; desirability, viability and feasibility (see Fig. 1). Due to identified similarities between Design Thinking and HCD, in this study these approaches are combined [a method also used by IDEO [1]]. The study was undertaken by an interdisciplinary team with medical, technical, design and commercial backgrounds.

For the purpose of this paper, the study has been broken down into three key stages: 1. Contextual study, 2. Ideation, Creation and User testing, 3. Reflections.

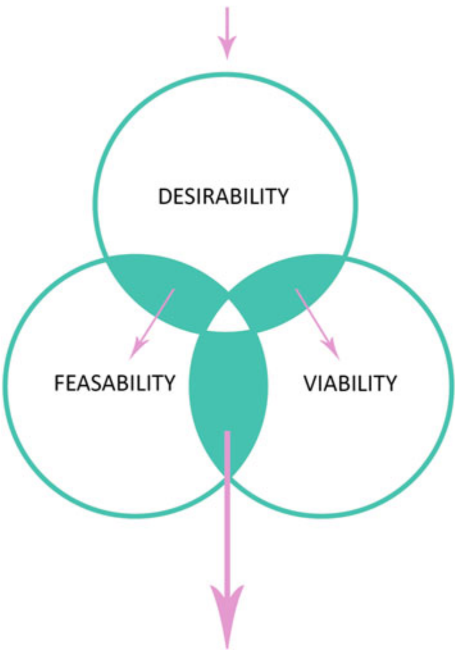

Fig. 1 HCD, Three intersecting constraints (*Source* Redrawn from IDEO, 2009)

The stages of ideation, creation, user testing and reflection were iterated until an appropriate solution was generated in accordance with the process of Design Thinking as outlined by Brown and Wyatt [10].

Stage 1. Contextual study: a 10-day field study in Lusaka Province Zambia. The aim of the contextual study was to gain insights into the users' beliefs, desires, work habits, cultural concerns, needs, aesthetic preferences and the contextual elements impacting on use, availability, accessibility and affordability of the solutions.

The method of 'hearing' employed for this study involved a process of rapid-ethnography [11]. Ethnographic research methods used included semi-structured interviews, dialogues with key people and local experts, group interviews, direct observations and story gathering [12]. Data was recorded using audio and video recorders, a camera and a note pad.

The findings from the study were synthesised in accordance with Design Thinking's three lenses: viability, feasibility and desirability. The findings were then used to compose a product brief.

Stage 2. Ideation: the findings from the contextual study were used to facilitate ideation. This was conducted in the UK by the interdisciplinary team. Creation: using Design Thinking's iterative approach, ideas were turned into concrete solutions in the form of low and high fidelity prototypes. Testing: to assess the solutions' suitability, function and usability, a series of user tests were conducted and feedback gathered from a range of typical expert and end users in the UK and Zambia.

Stage 3. Reflections: on completion of each round of user testing, the findings were analysed by the interdisciplinary team. This facilitated an iterative process of ideation, prototyping and user testing.

3.1 Participant Recruitment

In response to HCD and Design Thinking's need for the incorporation of users throughout the design process, typical Zambian end and expert users [13] were identified during the contextual review and included rural dwellers, police officers, fire fighters, drivers and hospital staff.

4 Findings

4.1 Contextual Study

An extensive contextual review identified a number of recurring themes surrounding the provision of healthcare services in Zambia. These included low levels of human resource, a lack of access to consumables and equipment, and major differences in access to services and amenities in regions only a short distance apart. This difference was particularly apparent between urban and rural locations and included access to a regular energy supply, availability of running water, education access (impacting e.g. literacy) and users' understanding of technology.

The study also identified challenges surrounding well-meant but inappropriate equipment donations, which e.g. required unattainable drug supplies or incorrect power requirements. Machines were thus respectively unusable from the start or quickly disabled by power surges. Other common issues included missing training manuals or guides, missing components and a lack of training, including training in maintenance and repairs [14] (Fig. 2).

Through the Design Thinking approach of identifying desirability, viability and feasibility, the study identified desire for low-cost, highly accessible solutions with high usability levels that reduce training needs and remove the reliance on existing supply chains or irregular supplies of donations. This approach also identified a need for a solution to the high fatality rates that result from RTAs. In 2010 Zambia recorded 1,348 reported road traffic deaths. RTAs are now Zambia's third biggest killer after Malaria and HIV/AIDS [15].

Many of these aspects were also identified as necessary to ensure the feasibility and viability of the solutions in conformance with Zambia's existing healthcare models and funding availability. Using these findings the interdisciplinary team composed a brief that responded to the constraints and which would drive the design process.

The Brief:

'The development of a First Responder pack composed of sustainable, locally sourced materials, which can be used by people with limited knowledge, understanding and education, to stabilise victims of road traffic accidents (RTAs)'.

Fig. 2 Medical equipment stored due to missing manuals, breakages and missing parts, Chongwe District Hospital, September 2012

4.2 Ideation, Creation and User Testing

A series of low-fidelity prototypes were developed during stages two and three of the study, in accordance with Design Thinking's process of ideation and HCD's process of create. These were tested with typical users in the UK and Zambia. This was done in order to detect gross design errors and provide confidence in the medical efficacy of the design before embarking on the more logistically complex and expensive user testing trials in Zambia.

Once the UK trials were completed and necessary design changes made, the prototypes were presented to the intended end and expert users during three rounds of user testing in Zambia. At this point a number of challenges were identified, as users presented dissatisfaction with the design solutions they tested. Their dissatisfaction emanated from a number of key factors, including a lack of comprehension of the design process and a failure to understand that the prototypes they were experiencing were developmental and thus lacked 'polish'. This combined with a pre-existing expectation amongst users as to what they thought solutions developed by western designers would look like.

When attempting to gather feedback from Zambian participants, minimal interest was displayed in the prototypes' functional capabilities, and the participants instead focused on aesthetic qualities which had a strongly negative effect on the usefulness of the trial.

For example: when testing a functionally sound ultra-low cost cardboard, box leg splint, designed for manufacture in Zambia, the nurse who worked in the village health post laughed in response to a request for his engagement in user testing. When asked what he found amusing, he dismissed the prototype, stating: '*But this is just a cardboard box!*' As a result, the team found it difficult to convince him to participate in the study. Despite the participant's reluctance and displeasure at taking part in the testing, he applied the solutions perfectly and when asked if he was happy with the support it provided he responded '*yes, but it's just cardboard*'. Attempts to explain that the end solutions would be of higher aesthetic quality failed to convince or reassure him and he just shrugged his shoulders in response. This type of response was typical of the team's experience with these initial field trials.

Having detected the problem, the team spent some time discussing these difficulties with a selection of Zambians, they explained their response: '*UK products do not look like this, they are attractive and high- tech, this is what people like [sic]*'. Interestingly and conversely, the response in the UK to the low-tech look of the pack was correspondingly positive. These findings highlighted a conflict between what the users defined as their desires during the Hearing stage of the HCD process and their actual desires. During the hearing stage, Zambians stated that their greatest desire was increased accessibility to medical solutions. However, on presentation of highly functional and accessible solutions, the Zambian participants expressed dissatisfaction, despite the fact that the solutions solved the key issues

Fig. 3 User testing 2013 and 2014

that they had identified (high levels of accessibility, affordability and appropriateness) (Fig. 3).

User testing in the context of Zambia had therefore uncovered hidden influences, unidentified during the contextual review, including the influences of Western culture on people's desires and expectations. The team concluded that these were a result of Western influence through the media, tourism, aid and colonialism, leading Zambians to expect and desire solutions developed by and available in industrialised nations and which reflect high levels of aesthetics, regardless of suitability to the environment. Put simply, the Zambians in the field trial had suspicions that a product that would not be considered fit for purpose in the West was being suggested for their use. Given that suspicion, they quite reasonably felt that was not right, and while the team knew this was not the case (one of the project's key goals was to develop solutions for deployment in the West having used the extreme constraints of the African cost and manufacturing environment to provoke creative approaches) they were nevertheless unable to convince many participants of the pack's value.

The participants in the Zambian study showed a strong desire to access similar services and products to those of people living in the West. People openly discussed their desire for products they had seen online, on the TV or being used by members of the team. American culture had a clear influence; for example the young men in one of the villages visited, commonly mimicked American rappers such as Jay-Z, 50 Cent and Dr. Dre.

This influence of Western technology was identified as posing a risk to creativity in considering the possibilities of solutions developed for and within Zambia. For example, when discussing the possibility of products designed specifically for the Zambian context during focus two groups with 20 clinical anaesthetist students, the students demonstrated a marked tendency to focus on a Western-centric notion of design values. This is pervasive, partly because in some cases Western goods have undercut locally made solutions on price, as demonstrated in the vast quantities of second-hand Western clothes around Zambia in market and street-side stalls. These have diminished the Zambian textile industry because Zambians would rather buy second hand 'fashionable' Western clothing for a lower cost than locally made garments new [15]. As a result of this influence, the study failed to gather insights on ideas Zambian people had for methods of improving the community, insights which Sirolli [16] argues is essential to progression.

The team also encountered difficulties gaining commitment and interest in the project. This was as a result of the previous experiences participants had of Western aid: Charities and organisations having previously visited, donated funds and equipment and then left, leaving villagers with minimal long-term benefits. The school was a prime example of this. Previous investments have included a now unused Playpump [17], a half-built school building, an almost derelict school building and a drop toilet. As a result, the team encountered a lack of willingness amongst people to invest themselves in something new, preferring simply to ask for donations.

4.3 Reflections

On completion of each round of user testing, the findings were analysed by the interdisciplinary team, facilitating an iterative process of ideation, prototyping and user testing. These reflections proved highly valuable in providing insights into how the solutions needed to evolve to achieve a level of acceptability in the Zambian context.

Whilst the contextual review provided insights into the need for increased levels of functionality and suitability, it was not until the presentation of three-dimensional prototypes that true understandings of participant's views were gained. When gathering feedback on the prototypes, the user's honesty and focus on aesthetic qualities highlighted pre-existing expectations and tendencies to compare the developed solutions with those previously donated from industrialised nations. The result had been the development of solutions that lacked acceptability in the local context, thereby ensuring that the approach lacked a characteristic identified by the WHO [4] as essential to ensure suitability. The team found that although the solutions met all of the requirements outlined in the contextual review, users presented disappointment and disinterest in the developed solutions.

In response to these reflections, efforts were made to develop the solutions to present increased aesthetic qualities while retaining the same levels of usability, manufacturability in context and cost. To assist in this process low-fidelity prototypes were replaced with high-fidelity prototypes.

5 Discussion

While there were benefits in applying Design Thinking's three competing constraints to product development in Zambia, this study's results suggest the addition of a fourth constraint—the constraint of expectations. Findings from the study recognise that people's expectations were highly influential in the success or failure of the solutions being developed. It has been recognised that 'desires' in developing countries such as Zambia go beyond people's wants and needs to elements that people may not be willing to share directly, such as an aspiration for Western lifestyles.

In response, despite Castillo's argument against 'market pull strategies' the authors suggest that the inclusion of *expectations* as a fourth constraint will provide a greater definition of what people want and expect from new products under development. This constraint goes beyond the cultural setting and considers external factors that may be influencing a person's expectations; for example, influences of Western industrialisation and consumerism.

This study's findings expand on those presented by Castillo et al. [6], in arguing that there are limitations in an approach to design for the Bottom of the Pyramid [a socio-economic group composed of the world's poorest 4 billion people who live on less than $2 a day [18]] that fails to account for sustainability [accounting for environmental, social and economic factors to ensure a continued a prosperous product life cycle]. Castillo et al. identified the need for a fourth 'cluster' (constraint) of sustainability, which bridges the gap between desirability, feasibility and viability. They argue that this element must be considered from the start of the project and can be achieved through the use of existing Design for Sustainability processes, such as those presented by Crul and Diehl [19]. They argue that this approach would ensure that the life cycle of the developed solution is accounted for in the social and environmental context (Fig. 4).

This study's findings point to the need to expand upon Castillo et al.'s proposal, removing sustainability from its placement as a bridging factor and placing it as an integral component that forms a building block upon which factors such as desirability, viability, feasibility and expectations are understood (see Fig. 5). It has been identified that the placement of sustainability as an integral factor, ensures solutions meet the needs of the world's poor, removing reliance on external sources and ensuring solutions can be made within the local context, thus enabling the attainment of accessibility and availability. This approach also ensures that solutions are suitable for the current economic and social structure in the country—guaranteeing appropriateness and affordability.

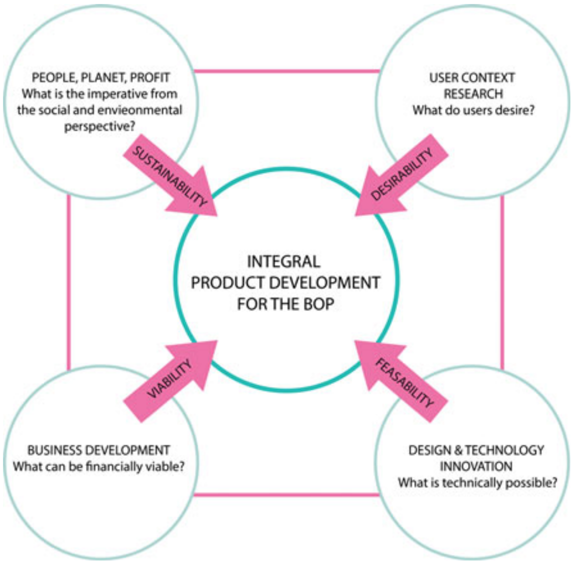

Fig. 4 Integral Product Development (*Source* Redrawn from Castillo et al. [9])

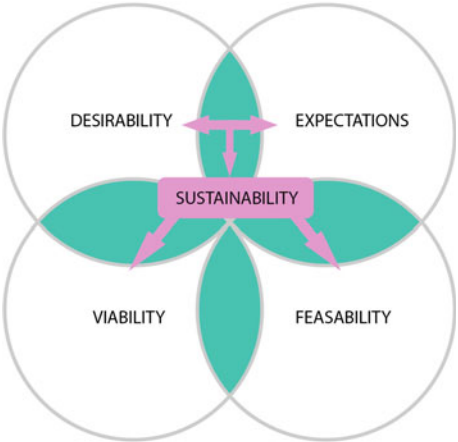

Fig. 5 Recommendation: four competing constraints built upon sustainability

This study's identification of the need for greater understanding of users' desires and expectations and the elements impacting on sustainability, in pursuit of the WHO's four A's (accessibility, availability, affordability and appropriateness), aligns with the argument presented by Donaldson [9], Bonsiepe [8] and Papanek's [7]. The study highlights the importance of Papanek, Fathers and Donaldson's calls to ensure that designers immerse themselves in the culture they wish to impact on and with the support of the four competing constraints built on a foundation of sustainability, identify an appropriate brief and a foundation of knowledge for the solutions to evolve from.

6 Study Limitations

Time restrictions were placed on the study in Zambia as a result of the study taking place alongside a charity expedition. Travel within Zambia was also limited as a result of poor road safety. In addition, language barriers placed limitations on the study (even though translators provided assistant) as only 1.7% of the Zambian population use English as their language of communication [20].

7 Conclusions

This study found a number of benefits that can be gained through the application of a Design Thinking methodology that draws upon HCD, but also identifies a number of limitations and difficulties with this approach. On reflection, the study highlighted the importance of conducting both a contextual review and in-context user testing with the combination being vital. This study recognises and agrees with the limitations of stop-over visits and failure to gain a deep understanding of the problems people face, their cultures and language as identified by Donaldson [9], Bonsiepe [8] and Papanek [7]. The authors found that although the three competing constraints highlighted as necessary by Design Thinking provided a good understanding of the main factors impacting on product use in the Zambian context, they fail to account for the impact of users' expectations of the acceptability of the developed solutions. This inhibited the solutions from meeting the WHO's four critical A's. In response to these findings the authors recommend that the three competing constraints be expanded to four with the inclusion of *expectations* to ensure a full understanding of user wants, which may alter levels of acceptance and desire, resulting in a hindered adoption of the solution.

In addition to expanding Design Thinking's competing constraints, this study also found common ground with Castillo et al.'s argument that the life cycle of a solution aimed at the BoP must account for the intended social and environmental context. However, the study identified a need for sustainability to be included not as an additional competing constraint alongside desirability, expectations, feasibility and viability but as a factor that forms the foundation of understanding each constraint.

8 Ethical Approval

Ethical approval for the project was sought from Cardiff Metropolitan University ethics board. In accordance with the University's ethical standards, all participants involved in the study were required to provide informed consent, and were informed that they were able to withdraw from the study at any point.

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Degree of Musculoskeletal Pain and Other Discomforts Experienced by School Children Using Different Type of Furniture During Class

Ajita Dsingh

Abstract Children spend long hours inside their classrooms which require them to continuously sit on the classroom furniture provided to them. 400 boys and girls school going children ranging in age from 4 to 14 years of government and private sponsored schools in Punjab were randomly selected for the study. A structured questionnaire was used for evaluating Musculoskeletal and other health problems of school children. The Faces Pain Scale—Revised and Visual analogue scale were used to measure pain intensity. The percentage of musculoskeletal pain and discomfort complained by subjects were Neck Pain 11%, Upper Back Pain 17.5%, Low Back Pain 14.75%, Upper Limb Pain 31%, Lower Limb Pain 33.25%, Sleep/dozy in classroom 14.25%, General Body Fatigue 35% and Any other discomfort 26%. Study concluded that classroom Furniture has significant impact on wellbeing of school children. This in order will help overcome the growing problems of poor posture found frequently among present day young generation.

Keywords School children · Musculoskeletal pain · Discomfort · School furniture · Punjab

1 Introduction

1.1 General Introduction

Children spend one-quarter of a day in school and out of this, 60–80% of time in classrooms. As they are at growing age and various factors like school environment, Classroom features, such as classroom furniture, sitting arrangement, blackboard distance and height influence their overall development [3, 4] (Jayaratne et al. 2009). Wrong sitting posture may develop backache and habitual poor posture in school children due to prolonged sitting hours during school on one seat

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(Zacharkow 1988). In India the school children use bench and desk in the classroom in general. However, in a large number of schools, especially in rural areas, school children use tat for sitting purposes in their classrooms to sit on the floor. The reason behind use of tat could be infrastructural limitations or to maintain the traditional Indian custom or could be both [5]. It is traditional custom in India to sit on the floor with folded knees. In addition the students also sit with stretched legs while sitting on floor [5].

1.2 Aim and Objectives

In the present study efforts have been made to evaluate the musculoskeletal pain and discomfort in school children while sitting in their classrooms.

1.3 Hypothesis

Based on the aims and objectives of the study, the following hypothesis was formulated for the present study:

1. (a) The ergonomics of children in educational environments is still novel in the region and there would be a high level of body anthropometric measurements mismatch with classroom furniture of its users.

(b) Mismatch between classroom furniture dimensions and anthropometric measurements of its user are one of the prominent causes of poor posture found in Indian school children.

1.4 Delimitations

1. The study was delimited to data obtained from four hundred Indian school children drawn from different schools in different places and the motivation level of the boy and girl subjects was not controlled at the time of testing.
2. The age group of subjects was selected between 4 and 14 year of age as posture evaluation of only children was taken into consideration while toddlers and adolescent group was excluded from this study.
3. Only two districts i.e. Patiala and Mansa district of Malwa region of Punjab were selected for research area.

1.5 Assumptions

It would be assumed that all boy and girl subjects who participated in this study were representative of a normal population and an equal distribution to validate the study. It was also assumed that all the boy and girl subjects participated in this study were at their very best level prior to performance.

1.6 Exclusion Criteria

The exclusion criteria were:

1. Respiratory conditions: any kind of acute or chronic illness.
2. Musculoskeletal Deformities.
3. Neurological conditions.
4. Amputation, Polio, Bone fractures etc.
5. Congenital anomalies.

1.7 Significance of the Study

The findings of present study would be used to:

1. To know factors affecting the body posture of growing individuals of age group 4–14 years.
2. This will add new dimensions to existing beliefs and strategies to promote development and maintenance of good body posture among children.

2 Materials and Methods

2.1 Study Design

The observational design of the present study is categorized as a cross-sectional study for the purpose of data collection.

2.2 Study Setting

Privately owned and Government sponsored Schools in Patiala and Mansa District of Malwa region of Punjab, India.

2.3 Study Location

Privately owned and Government sponsored Schools in Patiala and Mansa District of Malwa region of Punjab, India. Punjab is a state of India located between latitude 29°30′ N to 32°32′ N and longitude 73°55′ E to 76°50′ E and total area of 50,362 km^2 subdivided into Majha, Doaba and Malwa region. According to 2011 census of India, The total population of the Punjab is 24,289,296. The data for this study is collected from two districts of Punjab Patiala and Mansa of Malwa region. As Patiala is growing industrial region of Punjab, Mansa however forms the agricultural belt of Punjab and literacy rate is low in this region although the students of this town have excelled in medical/engineering areas.

2.4 Sampling

The techniques used for sampling was Stratified, incidental- volunteer sampling. The subjects, who volunteered for this study, were randomly selected from government sponsored (School 1, School 2) and privately owned (School 3) schools of Patiala and government sponsored (School 4, School 5) and privately owned (School 6) schools of Mansa District of Punjab, India. A total of 400 school children (both boys and girls in an equal ratio) have been taken for this study. The subjects were divided into five groups according to their decimal age i.e., 4–6.49, 6.5–8.49, 8.5–10.49, 10.5–12.49 and 12.5–14.49.

2.4.1 Inclusion Criteria

- Subjects studying in privately owned and government sponsored schools of Patiala and mansa district of Punjab, India
- 4–14 year age group.
- Subjects both boys and girls.

2.4.2 Exclusion Criteria

- Musculoskeletal disorders
- Any congenital anomalies
- Any medical or surgical condition
- Neurological conditions
- Previously diagnosed postural anomalies
- Recent Back or Neck injuries.

2.5 Methodology

2.5.1 Classroom Furniture Measurements

Bench, chair and desk length, width, height and standing clearance of classroom furniture was measured. Mismatch be-tween classroom furniture and anthropometric measurements were determined by the studies of Chakrabarti et al. (1997), Panero and Zelink [8], Pheasant [9].

2.5.2 Musculoskeletal Pain

A structured questionnaire was used for evaluating Musculoskeletal and other health problems of school children arising due to school environment such as classroom area, sitting arrangement and mismatch between class furniture and anthropometric dimensions of the students from Standardized Nordic questionnaire (SNQ) by Kourinka et al. [7].

2.5.3 The Faces Pain Scale

Revised [6] and visual analogue scale [12] were used to measure pain intensity in children between the age group of 4–14 years.

2.6 Statistical Treatment

All the variable values were expressed as their mean and standard deviation or frequency and percentage. The statistical tests were used in Statistical Package for Social Sciences (SPSS) 16.0 version to complete results.

3 Results and Discussions

Table 1 represents the tabulation of Frequency and percentage (in brackets) of total number of students using different kinds of furniture in their classrooms between the age group of 4–14 years belonging to different government sponsored and privately owned schools.

Out of total 400 students, 110 students belonging to government sponsored schools and were using Tat in their classrooms for sitting purposes. All other 268 students in privately owned schools and those belonging to government sponsored schools were using a bench and desk in their classrooms for sitting purposes. The 22 School children were from privately owned school and were using a chair and a table for sitting purposes in their classrooms. The students in their classrooms generally use a bench and desk for sitting purposes (Table 2).

Table 3 represents the Frequency and percentage (in brackets) of school children using correct and incorrect School Furniture matched with anthropometric measurements of its users N = 290.64% of total subjects of this study were using at least three or more matched classroom furniture dimensions with their anthropometric measurements while 36% were using less than 3 matched measurements of classroom furniture with their anthropometric measurements.

The furniture having more than 3 mismatched measurements with anthropometric measurements of subjects out of total 7 classroom furniture measurements were classified as incorrect bench-desk furniture while the furniture having at least 3 or more matched measurements with anthropometric measurements of subjects out of total 7 classroom furniture measurements were classified as correct bench-desk furniture. The classification was done as none of the subjects of this study were using classroom furniture with all measurements matched to their

Table 1 Tabulation of students using different kinds of furniture in their classrooms

Total number of students = 400	Tat	Bench-desk	Table-chair
Private school N = 200	–	178	22
Government schools N = 200	110	90	–

Table 2 Frequency and percentage (in brackets) of school children belonging to various age groups using different kinds of school furniture in government sponsored and privately owned schools (N = 400)

	N	Tat	Bench-desk	Chair-table
4–6 years	84	40(47.6)	22(26.2)	22(26.2)
6–8 years	82	34(41.5)	48(58.5)	–
8–10 years	76	23(30.2)	53(69.7)	–
10–12 years	79	13(16.5)	66(83.5)	–
12–14 years	79	–	79(100)	–

Table 3 Frequency and percentage (in brackets) of school children using correct and incorrect school furniture matched with anthropometric measurements of its users N = 290

	Correct furniture measurements	Incorrect furniture measurements	χ^2 value (p value)
Total N = 290	185(63.79)	110(37.93)	
Boys (N = 145)	95(65.5)	50(34.48)	13.97(0.000)
Girls (N = 145)	90(62.07)	55(37.93)	8.45(0.004)

anthropometric measurements. The results are in accordance with studies of Shivarti et al. [11], Asif et al. [1], Dhara et al. (2012).

Table 4 represent the comparison of Frequency and Percentage of school children experiencing musculoskeletal pain and other discomforts in sitting posture during class work by the School Children belonging to various age groups between 4–14 years. it was observed that a large percentage of School Children complained about the presence of musculoskeletal pain or other discomforts while doing class work in sitting posture in their classrooms. Occurrence of musculoskeletal pain and other discomforts was higher in the age group of 8–10 years in Boy subjects and 12–14 years in Girl subjects as compare to other age groups. Although as the age factor increased in both Boy and Girl subjects, there was no direct association of frequency of musculoskeletal pain and other discomforts with age however It was observed that lower age groups (4–6 years and 6–8 years) boy and girl subjects notified of lesser musculoskeletal pain and other discomforts while doing class works in their class-rooms as compare to upper age groups (10–12 years and 12–14 years). The results are in accordance with the studies of Olsen et al. (1992), Murphy et al. (2002), Daneshmandi et al. [3] and Jayaratne et al. (2009). Olsen et al. (1992) in his study had shown that ill fitted designs in classroom furniture had contributed to rise of musculoskeletal pain and discomfort among schoolchildren. Murphy et al. (2002) identified the extent of back pain experienced by 11–14 year old schoolchildren, and establish the possibility of physical risk factors association with musculoskeletal pains and discomfort reported by school children while sitting in their classrooms. The study found significant link between flexed postures and pain in low back region.

The intensity of musculoskeletal pain and other discomforts were assessed by Visual Ana-logue Scale and revised face pain scale measurements and is shown in Table 5.

Table 5 represents the comparison of Faces Pain Scale—Revised and Visual Analogue Scale measurements of various musculoskeletal pain and other discomforts experienced by the School Children belonging to various age groups in sitting posture during class work. The assessment of discomfort due to sitting in classrooms for longer duration was done using a 10 point visual analogue scale which is graded from no discomfort to maximum discomfort. The scores of the 10 point scale were divided into three categories of mild (1–4), moderate (>4–7) and severe (>7) [5].

Table 4 Frequency and percentage of musculoskeletal pain and other discomforts experienced by the school children in sitting posture during the class work

Musculoskeletal pain/other discomfort	Gender	Age groups					χ^2 value (p value)
		4–6 years N = 41, 43	6–8 years N = 41, 41	8–10 years N = 38, 38	10–12 years N = 40, 39	12–14 years N = 40, 39	
Neck pain 44(11)	Boy	01(2.4)	05(12.2)	05(13.2)	03(7.5)	03(7.5)	0.69(0.95)
	Girl	04(9.3)	03(7.3)	04(10.5)	09(23.1)	07(17.9)	1.71(0.79)
Upper back pain 70(17.5)	Boy	03(7.3)	05(12.2)	06(15.8)	06(15)	11(27.5)	0.27(0.99)
	Girl	04(9.3)	03(7.3)	07(18.4)	11(28.2)	14(35.9)	0.32(0.99)
Low back pain 59(14.75)	Boy	06(14.6)	05(12.2)	07(18.4)	05(12.5)	04(10)	0.44(0.98)
	Girl	02(4.7)	01(8.3)	03(7.9)	12(30.8)	14(35.9)	6.61(0.16)
Upper limb pain 124 (31)	Boy	14(34.1)	10(24.4)	12(31.6)	08(20)	10(25)	1.1(0.89)
	Girl	16(37.2)	08(19.5)	18(47.4)	12(30.8)	16(41)	3.67(0.45)
Lower limb pain 133 (33.25)	Boy	12(29.3)	12(29.3)	14(36.8)	10(25)	12(30)	0.91(0.92)
	Girl	20(46.5)	11(26.8)	18(47.4)	13(33.3)	11(28.2)	5.32(0.26)
Sleep/dozy in classroom 57 (14.3)	Boy	04(9.8)	03(7.3)	03(7.9)	04(10)	06(15)	0.17(1)
	Girl	09(20.9)	03(7.3)	05(13.2)	08(20.5)	12(30.8)	2(0.74)
General body fatigue 140 (35)	Boy	12(29.3)	12(29.3)	11(28.9)	15(37.5)	13(32.5)	0.47(0.98)
	Girl	17(39.5)	14(34.1)	14(36.8)	13(33.3)	19(48.7)	1.27(0.87)
Any other discomfort 104 (26)	Boy	04(9.8)	11(26.8)	16(42.1)	14(35)	09(22.5)	0.14(1)
	Girl	08(18.6)	05(12.2)	14(36.8)	16(41)	07(17.9)	0.65(0.96)

Table 5 Faces pain scale—revised and visual analogue scale measurements of various musculosketal pain and other discomforts

Musculoskeletal pain/Other discomfort	Gender	Age groups					p value
		4–6 years	6–8 years	8–10 years	10–12 years	12–14 years	
Neck pain	Boy	5.0 ± 0.0	4.4 ± 1.1	5.8 ± 0.96	4.3 ± 0.58	4.7 ± 0.58	0.342
	Girl	3.5 ± 1.0	4.3 ± 1.2	4.5 ± 1.0	3.8 ± 1.8	3.7 ± 1.1	0.341
Upper back pain	Boy	–	3.37 ± 1.16	4.37 ± 1.32	5.5 ± 1.6	4.3 ± 1.32	0.431
	Girl	2.56 ± 1.45	2.27 ± 1.03	2.18 ± 0.87	3.59 ± 1.48	3.38 ± 1.18	0.813
Low back pain	Boy	4.7 ± 0.82	3.6 ± 1.1	4.6 ± 0.79	5.4 ± 1.8	3.4 ± 0.89	0.745
	Girl	5.0 ± 0.0	6.0 ± 0.0	5.0 ± 0.0	3.6 ± 1.8	4.1 ± 1.1	0.000
Upper limb pain	Boy	4.60 ± 1.6	5.2 ± 1.4	4.75 ± 1.4	5.38 ± 0.92	5.56 ± 1.4	0.823
	Girl	4.87 ± 2.3	5.38 ± 3.0	5.61 ± 2.2	4.08 ± 1.6	3.92 ± 1.5	0.059
Lower limb pain	Boy	4.1 ± 0.67	5.2 ± 1.6	5.3 ± 2.5	5.2 ± 2.3	4.4 ± 1.6	0.58
	Girl	5.2 ± 1.6	5.5 ± 2.2	5.4 ± 2.9	4.3 ± 1.2	5.3 ± 0.89	0.127

For the school children below the age of 7 years The Faces Pain Scale—Revised was used to assess their pain and discomfort during sitting for long durations in classrooms [6]. The visual analogue scale was used in the age group of 7 years onwards [12].

4 Findings and Conclusions

The following findings and conclusions were drawn on the basis of analysis and interpretation of data.

The percentage of musculoskeletal pain and discomfort complained by subjects in the present study while sitting in their classrooms are Neck Pain 11%, Upper Back Pain 17.5%, Low Back Pain 14.75%, Upper Limb Pain 31%, Lower Limb Pain 33.25%, Sleep/dozy in classroom 14.25%, General Body Fatigue 35% and Any other discomfort 26%. The percentage of all musculoskeletal pain and discomfort was higher in subjects having poor posture than good posture subjects Neck Pain 14.23 and 5.8%, Upper Back Pain 13 and 3.25%, Low Back Pain 19.42 and 9.09%, Upper Limb Pain 35.37 and 25.32%, Lower Limb Pain 38.21 and 28.57%, Sleep/dozy in classroom 16.26 and 11.04%, General Body Fatigue 45.53 and 18.83% and Any other discomfort 3.25 and 4.55% respectively.

Ideal form of furniture provided in the classrooms to school children is a need of the hour. Use of correct furniture measurements is of utmost importance to school children because the habitual adaptation of bad sitting postures in order to accommodate on unmatched type of furniture are very difficult to change later in life and give arise to various musculoskeletal pains and discomfort [3, 4] (Jayaratne et al. 2009). Hence it is important that the school furniture provided to the students should be fit for requirements of its users and should be matched properly with anthropometric measurements of its users [1, 10].

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Machining Optimization of Nano-structured Hardfaced Tool Insert in WEDM Using MOORA Method

Abhijit Saha and Subhas Chandra Mondal

Abstract In recent years, nano-structured hardfacing alloy constituting fine carbides, borides and boro-carbides have become spearhead in cutting edge producing enterprises because of their prevalent properties like excellent hardness, toughness and wear resistance even at elevated temperatures. Nano-structured hardfacing alloy was produced using manual metal arc welding technique. This paper has focused on wire electrical discharge machining (WEDM) process identifies the influence of process parameters that affect the material removal rate, machining time and surface roughness while machining of nano-structured hardfacing alloy. The paramount process parameters have been employed during experiments such as discharge pulse time, discharge stop time, servo voltage, wire tension and wire feed rate. Experiments were designed using Taguchi's L25 orthogonal array. Multi-objective optimization was performed using MOORA (multi-objective optimization on the basis of ratio analysis) method coupled with PCA (principal component analysis) to identify optimal process parameters. The outcome demonstrates that discharge pulse time (0.5 μs), discharge stop time (8 μs), servo voltage (35 V), wire tension (800 g) and wire feed rate (7 m/min) are the optimal process parameters using brass wire and for zinc coated brass wire that corresponds to discharge pulse time (0.5 μs), discharge stop time (8 μs), servo voltage (41 V), wire tension (500 g) and wire feed rate (7 m/min) respectively.

Keywords Nano-structured · Hardfacing · WEDM · Taguchi · MOORA: PCA

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1 Introduction

Hardfacing is a standout amongst the most rising and cost-effective designing strategy to chop down the working costs on the support front and in the meantime to enhance execution and reliability of the apparatus. The achievement of the hardfacing technique relies on upon the determination of the hardfacing materials and its chemical composition for a specific application. The deposition of surfacing layers through various welding methods, such as manual metal arc welding (MMAW), submerged arc welding (SAW) and plasma arc welding (PAW) have been broadly connected economically in vast scale producing enterprises keeping in mind the end goal to enhance the wear and erosion resistance of the parts. It likewise gives anticorrosive performance of the deposited metal and reestablishes the span of damaged parts. Moreover, welding of the hardfacing materials may generate a substantially deposited layer with high deposition rate, and guarantees high bonding quality of the solidified layer [1]. Hardfacing materials are widely utilized in the assurance of grizzly bars, deplete fans, blender edges, sinter plant fans and screw transports.

The existence of nano-particles in hard facing materials significantly enhance surface territory to volume proportion, which brings about upgrading conductivity, durability, hardness, heat and wear safe properties even at lifted temperatures. Hardfacing materials commonly machined in traditional turning, milling, laser cutting and plasma arc machining, involves tool complexity, intricate and compound shapes and dimensional accuracy. Among non-traditional machining techniques, WEDM process is considered as the best option customary machining strategies. As of late, improvements of more current and more extraordinary materials should be a progressive test to the ability of the WEDM procedure in future assembling situation.

Although numerous optimization and modeling techniques have been applied for the analysis of quality characteristics of WEDM process considering various type of engineering materials [2–9]. To the best of the information of the authors, there is no data is accessible in previous papers for experimental investigation of material like hardfacing alloy which has bland modern application in WEDM. Hence, the choice of appropriate parametric mix of WEDM process for this material turns into a difficult job. In this study, MOORA method coupled with PCA was developed to recognize most favorable process parameters. With a specific end goal to streamline the different effecting qualities, MOORA was not connected straightforwardly. Since commitment of every execution trademark might not have a similar impact, all things considered arrangement. With a specific end goal to locate the relative impact of every execution parameter, PCA has been utilized to decide the weighting estimations of every effecting parameter. Consequently, MOORA strategy combined with PCA is utilized to optimize execution or performance parameters of WEDM process.

2 Experimentation

2.1 Experimental Setup

In this research work, tubular covered nano-composite based electrode (NanoCarb 110) has been utilized for hardfacing material. The proposed NanoCarb 110 has the trade name of the Larsen Toubro Limited, India. Figure 1 demonstrates the SEM-microstructure and optical micrograph of NanoCarb 110. It has remarkable elements, for example, high single layer hardness (>67 HRc), great strength due to firmly pressed nano structure, excellent wear factor (>110), and high temp applications up to 750 °C. The MMAW has been utilized for hardfacing (3 mm thickness layer) over the substrate material (low carbon steel) under direct current (145–160 A) and circular segment voltage (18–25 V).

Tests have been performed on 5-axis WT 355 CNC WEDM fabricated by Joemars (Taiwan) (Fig. 2a). A 0.25 mm diameter across brass wire and Zinc-covered brass wire has been favored as the tool electrode [10]. Deionized water has been utilized as the dielectric liquid as a part of this exploration. At every test, jobs has been measured to 12.7 mm × 12.7 mm × 4.76 mm from original job dimension 90 mm × 65 mm × 13 mm was made to cut by the WEDM procedure (Fig. 2b).

In this paper, the discharge pulse time, the discharge stop time, the servo voltage, the wire tension and the wire feed rate have been selected the input process parameters for the WEDM process and the range for each of input process parameters has been derived as shown in (Table 1). A L25 of Taguchi's orthogonal array has been used for the experimental design followed by conducting the experiments with fixed values of arc on time (A_{on} = 8 unit), arc off time (A_{off} = 10 unit), open voltage = 8 unit) and water flow rate (WA = 7 unit) [11].

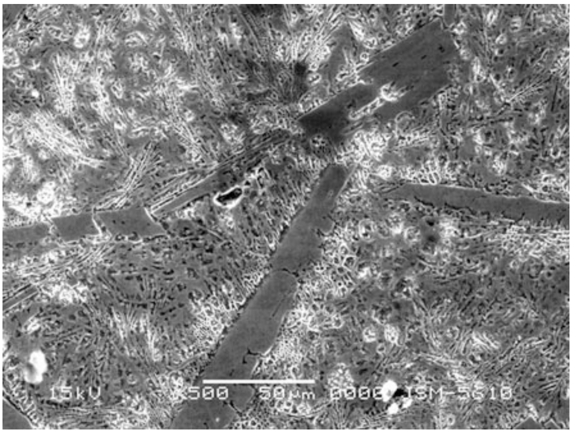

Fig. 1 SEM-microstructure of NanoCarb110

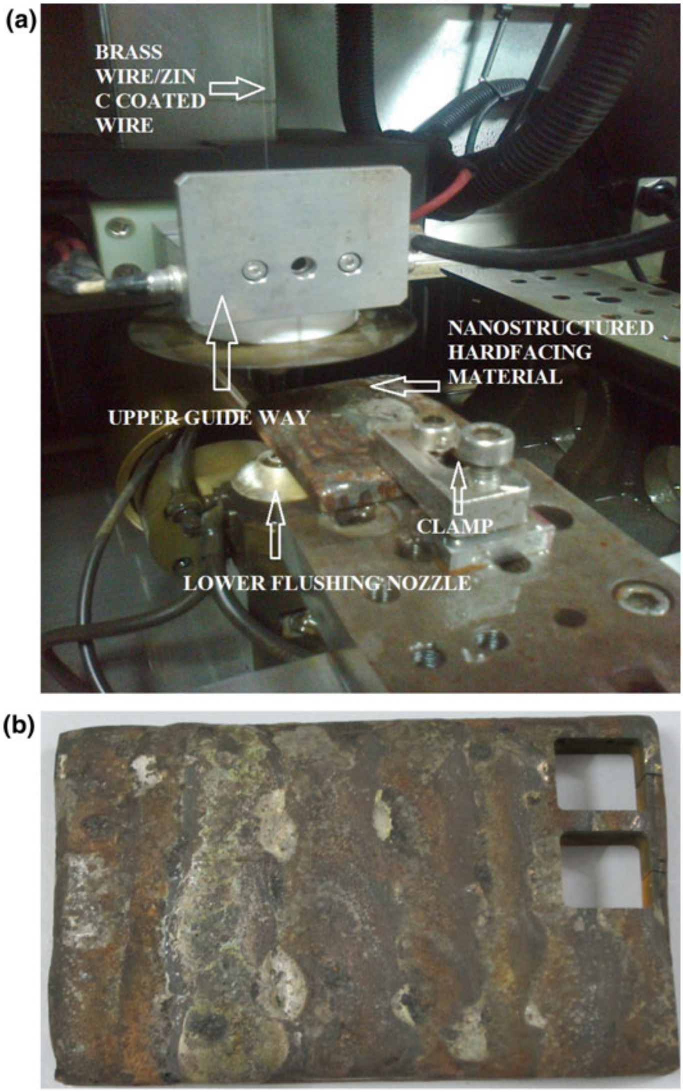

Fig. 2 **a** WEDM of nano-structured hardfacing material. **b** Job piece after WEDM

2.2 *Experimental Results*

During WEDM, the electrode (wire) diameter remains invariable and the discrepancy in the amount of width of cut is insignificant when contrasted with different parameters, for example, cutting speed (C_s) and material thickness (L). Average C_s was observed straightforwardly from the WEDM machine screen. Hence, the

Table 1 Machining parameters and their levels

Machining parameter	Factor	Unit	Level 1	Level 2	Level 3	Level 4	Level 5
T_{on}	A	μs	0.3	0.35	0.4	0.45	0.5
T_{off}	B	μs	8	9	10	11	12
SV	C	V	35	38	41	44	47
WT	D	g	500	600	700	800	900
WF	E	m/min	5	6	7	8	9

material removal rate (MRR) was evaluated via Eq. (1), which is demonstrated as follows:

$$\mathrm{MRR} = \mathrm{C_s L} \tag{1}$$

Taking after the DOE, the work-piece is machined using different process parameters and machining time is noted down. The arithmetic mean surface roughness (R_a) of the machined surface is measured by using Mitutoyo Surftest SJ-301 stylus type surface texture-measuring instrument. The trial task for five variable parameters with their levels by L25 Taguchi's orthogonal array and the mean estimation comes about for MRR, machining time and R_a are shown in Table 2.

3 Multi-response Optimization Using MOORA Method Coupled with Principal Component Analysis

In this research, a multi-criteria decision making model [12] combining with MOORA method and PCA has been utilized for the optimization of multiple responses. The approach comprises of various strides as takes after:

3.1 Multi-objective Optimization on the Basis of Ratio Analysis (MOORA)

Step 1: Specify the Problem

Initial step connected with to characterize the target and to distinguish every single alternatives and its attributes.

Step 2: Formation of Decision Matrix

After recognizing the goals and options the following stride for MOORA is readiness of choice lattice like other Multi Criterion Decision-Making process.

Table 2 L25 design matrix with the exp. value of MRR, machining time and R_a

Experiment No.	Levels of machining parameter settings										
	A	B	C	D	E	Brass wire			Zinc coated brass wire		
						MRR (mm^2/min)	Machining time (min.)	R_a (μm)	MRR (mm^2/min)	Machining time (min.)	R_a (μm)
1	1	1	1	1	1	39.434	2.56	3.06	39.321	2.57	2.83
2	1	2	2	2	2	31.628	3.53	3.20	36.322	3.15	2.74
3	1	3	3	3	3	30.407	4.00	2.69	36.635	3.35	3.00
4	1	4	4	4	4	27.008	4.50	2.21	33.204	3.56	2.61
5	1	5	5	5	5	24.174	5.18	2.59	27.683	4.30	2.70
6	2	1	2	3	4	32.911	3.34	2.70	36.549	3.10	3.17
7	2	2	3	4	5	35.724	3.28	2.65	42.238	2.42	3.49
8	2	3	4	5	1	30.808	4.20	2.19	35.541	4.05	2.73
9	2	4	5	1	2	28.241	4.31	2.39	37.908	3.50	2.45
10	2	5	1	2	3	29.933	3.51	2.62	33.075	3.20	2.68
11	3	1	3	5	2	41.943	3.01	2.79	45.044	3.00	2.59
12	3	2	4	1	3	39.045	3.07	2.09	41.118	2.40	2.73
13	3	3	5	2	4	35.708	4.57	2.67	41.533	2.20	2.60
14	3	4	1	3	5	36.217	3.45	2.72	36.016	3.12	2.55
15	3	5	2	4	1	37.821	3.2	2.80	36.352	3.10	2.90
16	4	1	4	2	5	32.676	3.37	2.47	42.803	2.49	3.34
17	4	2	5	3	1	41.171	3.00	2.93	46.563	3.34	3.10
18	4	3	1	4	2	48.768	2.29	2.78	52.125	3.00	3.25
19	4	4	2	5	3	43.911	2.44	2.80	50.970	2.05	2.73
20	4	5	3	1	4	36.239	3.36	2.88	43.862	2.35	2.86
21	5	1	5	4	3	50.388	2.28	2.80	52.360	2.01	2.86
22	5	2	1	5	4	47.162	2.50	3.18	43.237	2.44	2.58
23	5	3	2	1	5	39.999	3.08	2.68	61.055	1.45	2.87
24	5	4	3	2	1	48.536	2.38	3.57	52.469	1.51	2.47
25	5	5	4	3	2	45.841	2.27	6.45	49.369	2.15	2.74

$$A = \begin{bmatrix} a_{11} & a_{12} & \ldots & \ldots & a_{1n} \\ a_{21} & a_{22} & \ldots & \ldots & a_{2n} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ a_{m1} & a_{m2} & \ldots & \ldots & a_{mm} \end{bmatrix} \tag{2}$$

where, a_{ij} is the performance measure of the i-th alternative on j-th attribute, m is the number of alternatives, and n is the number of attributes.

Step 3: Normalized Performance Measures

In the third step decision matrix is normalized to make it dimensionless so that we can compare all its elements. It is important to mentioned that the criteria whether it is beneficial or non-beneficial does not effect in decision matrix normalization. This normalization procedure followed ratio system which is the square root of the sum of squares of each alternative per criterion. This ratio can be represented as below:

$$\mathrm{a}_{\mathrm{ij}}^{*} = \frac{\mathrm{a}_{\mathrm{ij}}}{\sqrt{\sum_{\mathrm{i}=1}^{\mathrm{m}} \mathrm{a}_{\mathrm{ij}}^{2}}} \tag{3}$$

where, a_{ij}^{*} represents the normalized value i-th alternative on j-th criterion which lies between 0 and 1.

Step 4: Evaluation of Overall Assessment Value

These normalized performance measures are then added together in case of Larger is better or beneficial criterion and subtracted in case of Lower is better or non-beneficial criterion. This helps in overall assessment of the performance measures as represented in the following equation:

$$y_i = \sum_{j=1}^{g} a_{ij}^{*} - \sum_{j=g+1}^{n} a_{ij}^{*} \tag{4}$$

Usually it is experienced that some of the characteristics are more influential than others. Therefore, in order to give more importance to an attribute, it could be multiplied with its corresponding weight. At this case Overall Assessment Value becomes:

$$y_i = \sum_{j=1}^{g} w_j a_{ij}^{*} - \sum_{j=g+1}^{n} w_j a_{ij}^{*} \tag{5}$$

where, w_j known as the weight of j-th criterion.

Step 5: Assign Ranking to Overall Assessment

At last we sorted the Overall Assessment value in descending order. The alternative having highest assessment value is the best alternative. The highest value of y_i represents the best alternative whereas lowest value of y_i represents the worst.

3.2 Principal Component Analysis (PCA)

PCA begins with multi-response array with n experiments and m attributes. In the current research, responses parameters are obtained after the calculation of normalized value y_i for computing the criteria weights. Thereafter, the computation of correlation coefficient uses the following expression:

$$R_{jl} = \left(\frac{\mathrm{cov}(x_i(j), x_i(l))}{\sigma x_i(j) * \sigma x_i(l)} \right) \tag{6}$$

where, x_i (j) is the normalized values of each response, cov(x_i (j), x_i (l)) is the covariance of response variables j and l, σx_i (j) and σx_i (l) are the standard deviation of response variables j and l.

Thereafter, eigenvalues and corresponding eigenvectors are

$$(\mathrm{R} - \lambda_\mathrm{x} \mathrm{I_m}) \mathrm{V_{ik}} = 0 \tag{7}$$

where λ_x eigenvalues, $\sum_{k=1}^{n} \lambda_k = n$, k=1, 2, …, n, and $V_{ik}\, [a_{k1}, a_{k2}, \ldots, a_{km}]^T$ are the Eigen vectors corresponding to eigenvalues λ_k.

Thus, the principal components are

$$Y_{mk} = \sum_{i=1}^{n} x_m(i)\, V_{ik} \tag{8}$$

where Y_{m1} is called the first principal component, Y_{m2} is called the second, and so on.

The principal components are aligned in descending order with respect to variance, and thereafter, the first principal component Y_{m1} accounts for the most variance in the data.

4 Results and Discussion

4.1 Multi-response Optimization: Hybrid Approach

The alternatives (machining parameters) considered in the present work are discharge pulse time, discharge stop time, servo voltage, wire tension and wire feed rate and attributes (quality characteristics) are material removal rate (C_1), machining time (C_2) and surface roughness (C_3) for both the wire. The major attention was to minimize (beneficial attribute) the machining time and surface roughness and to maximize (non-beneficial attribute) the material removal rate. While solving optimal combination of machining parameters in WEDM process selection problem using MOORA method, the data of the decision matrix, as shown in Table 3, is first transformed into dimensionless values using linear normalization procedure, so that all these criteria can be comparable. The normalized value of each performance measure has been calculated using Eq. (3) as shown in Table 4.

Table 3 Decision matrix for optimal cutting parameters selection problem

Experiment No.	Brass wire			Zinc coated wire		
	C_1	C_2	C_3	C_1	C_2	C_3
1	39.434	2.56	3.06	39.321	2.57	2.83
2	31.628	3.53	3.2	36.322	3.15	2.74
3	30.407	4	2.69	36.635	3.35	3
4	27.008	4.5	2.21	33.204	3.56	2.61
5	24.174	5.18	2.59	27.683	4.3	2.7
6	32.911	3.34	2.7	36.549	3.1	3.17
7	35.724	3.28	2.65	42.238	2.42	3.49
8	30.808	4.2	2.19	35.541	4.05	2.73
9	28.241	4.31	2.39	37.908	3.5	2.45
10	29.933	3.51	2.62	33.075	3.2	2.68
11	41.943	3.01	2.79	45.044	3	2.59
12	39.045	3.07	2.09	41.118	2.4	2.73
13	35.708	4.57	2.67	41.533	2.2	2.6
14	36.217	3.45	2.72	36.016	3.12	2.55
15	37.821	3.2	2.8	36.352	3.1	2.9
16	32.676	3.37	2.47	42.803	2.49	3.34
17	41.171	3	2.93	46.563	3.34	3.1
18	48.768	2.29	2.78	52.125	3	3.25
19	43.911	2.44	2.8	50.97	2.05	2.73
20	36.239	3.36	2.88	43.862	2.35	2.86
21	50.388	2.28	2.8	52.36	2.01	2.86
22	47.162	2.5	3.18	43.237	2.44	2.58
23	39.999	3.08	2.68	61.055	1.45	2.87
24	48.536	2.38	3.57	52.469	1.51	2.47
25	39.434	2.56	3.06	39.321	2.57	2.83

At that point in the following stride, using PCA method, the relative weights of every execution attributes was assessed (Tables 5 and 6) according to Eq. (7). The square estimation of the eigenvalues connotes the commitment of the related quality attributes to principal component analysis. The contributions of MRR, machining time and R_a are 0.392, 0.398, and 0.209 (for brass wire), for zinc coated brass wire, 0.496, 0.480 and 0.024 respectively. Likewise, variance contribution for the 1st principal component characterizing the three responses is as high as 74.1% (for brass wire) and 60.7% (for zinc coated brass wire). Accordingly, in the present work, the squares of its subsequent eigenvectors Y_{im} are preferred as weighing values of the associated responses, and coefficients of a^*_{ij}, i.e., W_1, W_2 and W_3 in Eq. (5) are thus put as for brass wire 0.392, 0.398, and 0.209 and for zinc coated brass wire, 0.496, 0.480 and 0.024, respectively.

Table 4 Normalized data matrix

Experiment No.	Brass wire			Zinc coated wire		
	C_1	C_2	C_3	C_1	C_2	C_3
1	0.207	0.151	0.205	0.184	0.178	0.200
2	0.166	0.208	0.214	0.170	0.219	0.193
3	0.160	0.235	0.180	0.171	0.233	0.212
4	0.142	0.265	0.148	0.155	0.247	0.184
5	0.127	0.305	0.174	0.129	0.299	0.190
6	0.173	0.197	0.181	0.171	0.215	0.224
7	0.188	0.193	0.178	0.197	0.168	0.246
8	0.162	0.247	0.147	0.166	0.281	0.193
9	0.148	0.254	0.160	0.177	0.243	0.173
10	0.157	0.207	0.176	0.155	0.222	0.189
11	0.220	0.177	0.187	0.210	0.208	0.183
12	0.205	0.181	0.140	0.192	0.167	0.193
13	0.187	0.269	0.179	0.194	0.153	0.183
14	0.190	0.203	0.182	0.168	0.217	0.180
15	0.199	0.188	0.188	0.170	0.215	0.205
16	0.172	0.198	0.166	0.200	0.173	0.236
17	0.216	0.177	0.196	0.218	0.232	0.219
18	0.256	0.135	0.186	0.244	0.208	0.229
19	0.230	0.144	0.188	0.238	0.142	0.193
20	0.190	0.198	0.193	0.205	0.163	0.202
21	0.264	0.134	0.188	0.245	0.140	0.202
22	0.248	0.147	0.213	0.202	0.169	0.182
23	0.210	0.181	0.180	0.285	0.101	0.202
24	0.255	0.140	0.239	0.245	0.105	0.174
25	0.241	0.134	0.432	0.231	0.149	0.193

Table 5 Eigenvalues and proportions of principal components

Principal component	Brass wire		Zinc coated wire	
	Eigen values	Proportion (%)	Eigen values	Proportion (%)
First	2.222	74.1	1.822	60.7
Second	0.677	22.6	0.988	33.0
Third	0.100	3.3	0.190	6.3

Finally overall assessment value (y_i) has been calculated using Eq. (5), and shown in Table 7. According to MOORA method, ranking has been assigned to each assessment value after arranging them in descending order. It was found that experiment no. 21(for brass wire) and 23 (zinc coated wire) has the highest y_i value.

Table 6 Eigenvectors for principal components and contribution

Quality Characteristics	Eigenvectors							
	Brass wire				Zinc coated wire			
	First principal component	Second principal component	Third principal component	Contribution	First principal component	Second principal component	Third principal component	Contribution
MRR	0.626	0.341	0.701	0.392	0.704	0.040	0.709	0.496
Machining time	−0.631	−0.305	0.713	0.398	−0.693	−0.178	0.698	0.480
R_a	0.457	−0.889	0.024	0.209	0.154	−0.983	−0.098	0.024

Table 7 Overall assessment value

Experiment No.	Brass wire		Zinc coated wire	
	y_i	Rank	y_i	Rank
1	−0.022	7	0.001	13
2	−0.062	19	−0.026	19
3	−0.069	21	−0.032	20
4	−0.081	24	−0.046	23
5	−0.108	25	−0.084	25
6	−0.048	16	−0.024	16
7	−0.040	12	0.011	10
8	−0.066	20	−0.057	24
9	−0.076	23	−0.033	21
10	−0.057	18	−0.035	22
11	−0.023	8	0.000	14
12	−0.021	6	0.011	11
13	−0.071	22	0.018	6
14	−0.044	13	−0.025	18
15	−0.036	11	−0.024	17
16	−0.046	15	0.010	12
17	−0.027	9	−0.009	15
18	0.008	2	0.015	8
19	−0.006	4	0.045	4
20	−0.045	14	0.018	7
21	0.011	1	0.049	3
22	−0.006	5	0.014	9
23	−0.027	10	0.088	1
24	−0.006	3	0.067	2
25	−0.049	17	0.038	5

Thus optimum combination of process parameters for the multiple quality characteristics should be selected as $A_5B_1C_1D_4E_3$ (brass wire) and $A_5B_1C_3D_1E_3$ (zinc coated wire) respectively.

5 Conclusions

The MOORA coupled with PCA strategy can be considered as a more helpful methodology than different other Multi Criteria Selection approaches because of its capacity to clarify process fluctuation. Based on the results of the present study, the following optimum combination of process parameters for the multiple quality characteristics should be selected as $A_5B_1C_1D_4E_3$ (brass wire) and $A_5B_1C_3D_1E_3$

(zinc coated wire) respectively. The proposed multi criteria decision making methodology can be applied to those industrial situations where a number of responses are to be optimized simultaneously.

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Insights from User Testing of *Jellow*: A Communication Aid for Children with Developmental Disabilities

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Abstract The current paper reports insights from user testing of a novel pictorial, free-of-cost, desktop-based communication aid, *Jellow*, developed at the Indian Institute of Technology Bombay to enhance communication in nonverbal to minimally verbal children with developmental disabilities. We asked 7 typically developing school-age children to use the *Jellow* application to convey specific messages based on test scenarios during a structured usability evaluation. We coded for task success, time to completion, number of errors made, and number of prompts required for completing each of the ten test tasks. We also collected qualitative data on children's satisfaction with various aspects of the application and their feedback on ways to improve the application. Quantitative and qualitative feedback from this study is currently being used to develop the next version of the application that will be tested with children with disabilities.

Keywords Alternative and augmentative communication (AAC) · Children · Disability · Communication aids · Technology

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1 Introduction

1.1 Alternative and Augmentative Communication (AAC) Systems: Types and Functions

Alternative and augmentative communication (AAC) systems are used to either supplement (i.e. augment) or replace (i.e. provide an alternative to) existing natural speech in children with developmental disabilities such as Cerebral Palsy, Down Syndrome, Autism Spectrum Disorder, and Intellectual Disability, who frequently have expressive speech impairments [1–3]. Children who are not able to communicate effectively face difficulties interacting with others, forming long-lasting friendships, and engaging in age-appropriate play with peers, thereby losing out on critical learning opportunities. Therefore, AAC systems have been used to enhance functional communication on a temporary or permanent basis in children with disabilities [3].

Typically, AAC systems are classified as unaided i.e. not requiring any external aids, or aided i.e. systems that use low-tech or high-tech external aids for expressive communication. Unaided systems that use gestures, facial expressions, eye contact, or manual signing for communication are portable, quick to produce, and have no limits in conveying novel content; however, only individuals familiar with sign/gestural communication can comprehend them [3, 4]. Moreover, sign languages require excellent fine motor and memory skills, making them challenging for children with motor and cognitive impairments [3]. In contrast, aided systems use aids such as graphic symbols, Picture Exchange Communication Systems (PECS), or computerized Speech-Generating Devices (SGDs), also known as Voice Output Communication Aids (VOCAs) to communicate messages [5, 6]. Although low-tech aided systems are easy to learn and can be easily comprehended by a larger audience, they require the user to carry bulky picture binders/boards everywhere with them [3, 5]. However, following recent advances in the fields of electronics and computer science, high-tech devices such as SGDs or VOCAs are being increasingly used as AAC systems; in fact such systems can be easily accessed as tablet- or smart phone-based applications [7, 8]. Moreover, given their speech generating potential, they can effectively attract listeners' attention and are easy to comprehend [2].

AAC systems can aid communication in children with minimal to no speech or unintelligible speech and also teach them language skills [2, 4, 9]. Contrary to previous concerns that AAC systems would impede natural speech development, there is considerable evidence that the early use of AAC systems in fact promotes speech development in children [10, 11]. Although different AAC modes seem to be equally effective in promoting communication, individuals with disabilities may prefer aided systems to unaided systems [5, 12]. Moreover, individuals show some preference for SGDs compared to other systems [9]. Given these user preferences for high-tech systems, the current project reports on insights from usability testing of a novel, pictorial, desktop-based software application called *Jellow*, developed at the Indian Institute of Technology Bombay (IIT-B) with the aim of assisting communication in individuals learning to speak or with difficulty in speech.

1.2 Current Trends in AAC Usage in India and Indigenous AAC Systems

There are currently over 1.9 million individuals with a speech disability in India [13]. Speech impairments are either evident at birth or before 9 years of age in around 37% individuals with a speech disability [14]. Overall, over 80% of individuals with speech disabilities completely lack speech, speak only in single words, or have unintelligible speech [14]. Therefore, there is a need for a variety of assistive technologies including AAC systems for individuals with speech impairments.

Our literature review on AAC applications suggests that there are several commercially available applications of Western origin and relatively fewer indigenously developed applications. Although a majority of the AAC apps developed in Western countries are quite comprehensive, they are not necessarily adapted to the Indian context. For instance, the types of foods consumed, the types of clothes worn, the kinds of games played, etc. are considerably different in Western countries compared to India. The content of the AAC app needs to be therefore designed bearing in mind the socio-cultural and linguistic context that children will experience in their daily life while using the app as their primary mode of communication. There are currently few indigenously developed AAC applications in India. "*Avaz*," one such customizable AAC application that can be used on iPADs and certain Android tablets, allows constant tracking of the child's speech, and also provides caregiver-training modules to facilitate easy use of the application (http://www.avazapp.com/). Similarly, *Vaneeshree*, a speech synthesizer for individuals with spasticity or vocal disability has around 56 commonly used sentences in its memory and uses a cordless connection between the device and a high-power amplifier to allow the user to communicate while freely moving around the house (http://www.iitk.ac.in/infocell/Archive/dirjuly1/vanee.html). In addition, local state-supported companies such as Webel Mediatronics have developed a few other communication aids for individuals with Cerebral Palsy (CP). For example, *Pictorial* is a software tool equipped with a library of icons and associated audio clips in vernacular languages such as Bengali, Hindi, English, and Nepali (http://www.webelmediatronics.in/SystemCerebralPalsy.htm). Similarly, *Kurakani* is a 16-key pictorial VOCA developed to aid communication in individuals with CP (http://www.webelmediatronics.in/16KeyVOCA-Brochure.pdf). Lastly, *Gupshup* is a simple pictorial VOCA that comes in 1/2/4 key configurations (http://www.webelmediatronics.in/SystemCerebralPalsy.htm).

1.3 Gaps in AAC Research in India and Background of the Current Project

As discussed above, a majority of the research on AAC systems is conducted in the Western world with limited research in the Indian context [15, 16]. Insights from a mixed-methods study in two metropolitan cities in southern India suggested that rehabilitation professionals consider technology to be a powerful tool to enhance communication in individuals with disabilities [15]. However, given that a majority of the commercially available AAC apps were designed considering the socioeconomic and cultural context of developed nations, there is a dire need for the native development of low-tech and high-tech AAC devices bearing in mind the unique cultural and linguistic considerations of India [15]. These findings highlight the need for extensive research on developing indigenous AAC solutions that are inexpensive, simple to use, and adapted to the Indian context.

The work reported in this paper aims to address these need gaps and develop a novel, free-of-cost, pictorial communication aid, *Jellow*, for children with developmental disabilities. *Jellow* has a unique interface consisting of central 'category' buttons and 'expressive' side-buttons designed to broaden the language repertoire of users (see Fig. 1); moreover, it has been developed keeping in mind the socio-cultural context of India. This paper reports results from usability testing of the desktop-based prototype of *Jellow*. *Jellow* has 6 'expressive' side-buttons—"like," "don't like," "yes/want," "no/don't want," "more," and "less"—and 5 central 'category' buttons—"learning," "eating," "play," "people," and "others". A button has to be clicked to activate it. Each category button has several sub-options that can

Fig. 1 Snapshot of *Jellow's* interface

be accessed by double-clicking on it. From the home screen, there are up to a maximum of 3 hierarchical nested levels within the information architecture of *Jellow*.

2 Methods

2.1 Participants

Seven typically developing children (5 girls, 2 boys) between 5 and 10 years (Mean (SD) = 7.68(1.13)) participated in the study. Children were recruited through convenience sampling from local schools and day care centers after obtaining written parental consent as approved by the Ethics committee at IIT-B. Children with significant additional hearing, visual, orthopedic, cardiovascular, neurological, or other medical comorbidities were excluded. Since the current version of *Jellow* is in English, we excluded children who did not understand English.

2.2 Study Procedure

Two sessions were conducted at each child's home by a pediatric physical therapist. In the first session, the therapist familiarized children with *Jellow* and allowed them to freely explore it for around 20 min. The second testing session, which was conducted about 1–2 days following the initial session, involved a structured assisted usability test [17] and a short discussion to obtain qualitative feedback from children. This session was videotaped for further behavioral coding. Children were given 10 test scenarios (2 scenarios per category—"learning", "eating", "play", "people", and "others") and asked to communicate specific messages using *Jellow*, as required by the scenario. The test tasks were representative of the types of scenarios children may face in the real world while using *Jellow* as a communication aid. Exemplar scenarios included indicating food preferences for breakfast, asking for specific toys, asking for help to get ready for school, etc.

Following the usability testing, we provided children a custom-developed, 7-item, pictorial feedback questionnaire to rate their satisfaction with *Jellow* on a 5-point Likert scale. Specifically, we assessed ease of use, comprehensibility of icons, visual appeal, intuitiveness of hierarchical structure, clarity of voice, level of enjoyment, and usefulness of the application. In addition, we asked children for suggestions to improve the existing version of *Jellow*.

2.3 Behavioral Coding

We coded for task success, time to completion, number of errors committed, and number of prompts required for each of the 10 test tasks. Task success was coded as *independent* (score of 0) i.e., when the child completed the task independently without assistance or *assisted* (score of 1) i.e., when the child required therapist assistance to complete the task. The therapist assisted the child when he/she made errors during the tasks. Since the testing was with young children, we ensured that all children successfully completed all the tasks, if required, with tester assistance. Time to completion was coded per task in seconds, starting from the end of the tester's instruction to when *Jellow* spoke the required message. Next, we coded rate of errors committed for each task. An error was defined as any incorrect option chosen within the application. Last, we coded the rates of therapist-provided verbal and manual prompts per task. Verbal prompts included cues such as "look carefully" or "try somewhere else" etc. and manual prompts included physical hand-on-hand assistance to complete the task. For all outcome measures, we report category-wise summed scores obtained by summing individual scores on each of the two test tasks within a category. A higher score indicates worse performance for all our outcome measures.

2.4 Qualitative Data Analysis

For the feedback survey data, we calculated a percentage of participants who gave specific ratings (1–5) for each of the evaluated criteria. A higher score suggested greater satisfaction with *Jellow*. In addition, we also received a wealth of qualitative suggestions for improvement of the software in terms of content, icons and accompanying text, and navigation. We will report salient insights obtained from children's feedback in the next section.

3 Results

3.1 Quantitative Data

Given our small sample size, we did not conduct formal statistical testing on our data. Instead, we report means and standard deviations on all outcome measures and also discuss individual data from participants. In terms of task success, 85.7% children required assistance for tasks belonging to the "learning" and "play" categories, 71.4% required assistance for tasks in the "eating" and "others" categories, whereas none of the children required any assistance for tasks involving the "people" category.

In terms of time to completion, children required least time to complete tasks belonging to the "play" and "people" categories (Table 1 and Fig. 2). In contrast, tasks that required children to navigate to options underlying the other three categories were relatively more time-consuming.

Further, a majority of the children committed multiple errors while completing tasks that involved accessing options under the "others," "play," and "learning" categories (see Table 1 and Fig. 3). The least error rates were seen for a majority of the children during tasks that involved the "people" and "eating" categories.

Lastly, in terms of the rates of verbal and/or manual prompts required, children needed the least number of prompts while completing tasks that required access to options under the "people" category. Tasks belonging to all other categories required a relatively higher number of prompts as suggested by Table 1 and Fig. 4.

Table 1 Summary of outcome measures from usability testing

Outcomes mean (SD)	Learning	Eating	Play	People	Others
Time to completion (seconds)	170.6 (86.9)	148.8 (63.6)	95.6 (16.2)	34.9 (9.5)	115.8 (52.7)
Error rates (per minute)	1.6(0.9)	0.8(0.8)	1.5(1.0)	0.5(0.9)	1.8(1.6)
Prompt rates (per minute)	1.3(0.7)	0.9(0.6)	1.4(1.0)	0.2(0.5)	1.1(0.9)

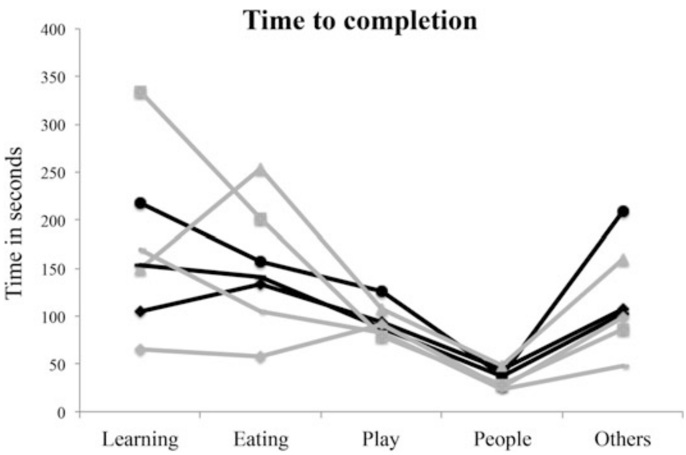

Fig. 2 Individual data on time to completion for different categories

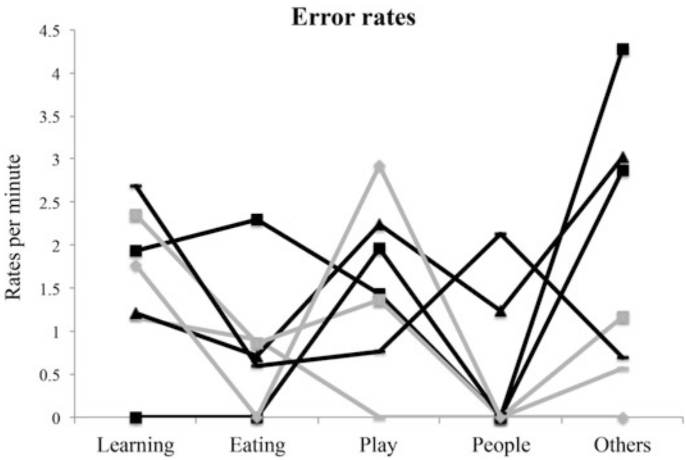

Fig. 3 Individual data on error rates for different categories

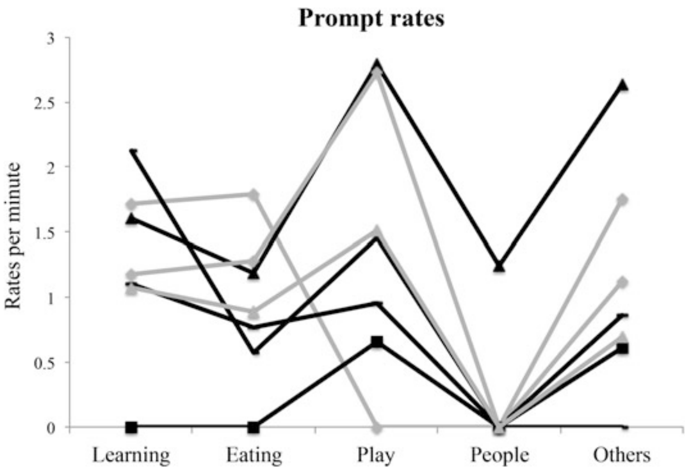

Fig. 4 Individual data on prompt rates for different categories

3.2 Qualitative Data

Our feedback survey data suggest that all children found *Jellow* very useful and enjoyable to use (see Fig. 5). They also found *Jellow's* voice clear and easy to understand. Over 80% of children found the software visually appealing and relatively easy to use. However, children had some difficulties understanding some of *Jellow's* icons and also had considerable trouble navigating through the application to reach their desired options.

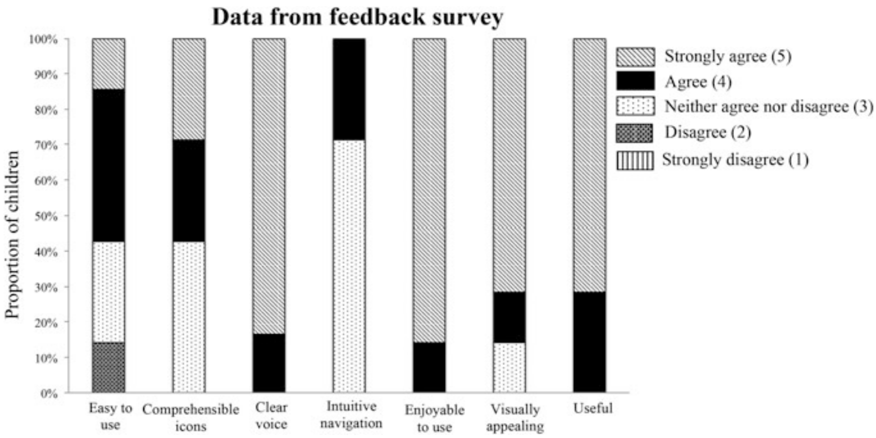

Fig. 5 Qualitative data on children's satisfaction with *Jellow*

Children also provided multiple suggestions to improve the existing version of *Jellow*. In terms of content, children recommended that we add some new categories to accommodate novel content, add new content within pre-existing categories, and simplify existing content to aid comprehension. For example, children suggested that we add a category on "greetings" to aid natural communicative exchanges. Similarly, they asked for the addition of multiple new food items within the "Eating" category, including, "idli," "dosa," "soups," "salads," and "desserts." Children suggested changing two labels, "beverages" to "drinks", and "hygiene" to "clean", to simplify comprehension of existing content. To aid use by children with varying abilities, *Jellow's* current language is very simple; moreover, the vocabulary associated with the expressive buttons remains constant irrespective of the accompanying category buttons chosen. For example, the same basic sentence structure is evident in "***I want*** lunch," "***I want*** books," or "***I want*** videogames." Children instead recommended that we develop a larger, category-wise customized verbal library involving a variety of action verbs, for example, "***I want to eat*** lunch," "***I want to read*** a book" or "***I want to play*** videogames." Currently, the "home" button takes the user to the home screen irrespective of where the user is (level 2 or level 3 of the hierarchy) within the software. To allow navigation to the preceding hierarchical level within the software children suggested that we add a "back" button. Lastly, children also had multiple suggestions to improve *Jellow's* visual appeal. For instance:

"Child 1: Doctor looks comical. (Doctor) should be totally white (wearing a white coat)"
"Child 2: The 'change footwear' picture looks more like socks, change this."
"Child 3: Change the "wafers" picture. I can't make out it is wafers. You should add a packet of wafers next to the plate with wafers."

"Child 4: The 'terrace' drawing is not clear. It looks like a slide."
"Child 5: The picture for medicine should have a medicine bottle. Medicines are always kept in a bottle, no?"

4 Discussion

4.1 Summary of Insights from Usability Testing

Our usability evaluation suggested that, on the whole, children found *Jellow* enjoyable to use. With regard to its existing content, tasks involving the "People" category were universally the easiest for children to complete, probably because this category included only a single underlying nested layer of options. Following this category, children found the "Play" category relatively easy to navigate given that it had fewer options compared to all other categories. Although the "Eating" category included several options and sub-options, children were familiar with the choices and seemed to know how they were categorized, for example, bread is a "breakfast" item versus rice is a "lunch" item, making it easier for them to find target options. In contrast, children found tasks involving the "Learning" and "Others" categories the most difficult, probably since they were unsure of the contents of these categories; therefore, they made more mistakes as they searched for desired options and took longer to find them.

Children also asked for the addition of new content within the software. Although this feedback is highly desirable in order to ensure that *Jellow* can assist children in communicating their intentions in a wide range of scenarios, it remains to be tested if a large verbal repertoire is indeed ideal for children with disabilities as they are learning to communicate. Perhaps it may be necessary to develop multiple versions of the software with incremental amounts of inbuilt speech capacity. Furthermore, multiple children recommended that we change the vocabulary of *Jellow* so that it becomes more suited to the context of usage. Lastly, our observations of the younger children in our sample suggested that they relied heavily on icons for identification of target content, given their lack of fluency in reading. Therefore, the software needs to have appealing icons that are easily comprehensible; similarly, the associated vocabulary should be as simple as possible.

4.2 Recommendations

Based on the above insights, we are currently working on improving several aspects of the existing version of the software. In terms of content, we will be adding significant novel content based on children's suggestions; however, given the grid layout of the interface that allows the display of only 9 options at a time on the screen, we will explore the option of adding a "More" button as the 9th option on the screen. When the child clicks on this option, he/she will be able to navigate to the next screen containing additional options. We also plan to incorporate an algorithm that will remember the child's most-preferred choices for any category and display them as the top options. Furthermore, to ease children's difficulties in remembering options underlying categories, we plan to incorporate a feature wherein, by hovering over a specific category icon, children will get a sneak peek at the underlying options. We will also provide a "back" button on the home screen to improve the exploration of content at different levels of *Jellow's* hierarchy. We are currently working on significantly improving the existing icons and their accompanying "word" labels to improve comprehensibility for children of different ages. We are also developing a richer verbal repertoire for the next prototype of *Jellow* to ensure that the vocabulary is adapted to the category chosen by the child.

We acknowledge that our study involved a relatively small sample size of children, thereby limiting the validity and widespread applicability of the findings; nevertheless this pilot usability study was meant to provide insights to further improve the software. We are currently working on developing an app-based version of *Jellow* that will be compatible with Android tablets and mobiles. We plan to conduct a more systematic and structured usability evaluation using a larger sample of children with developmental disabilities using this next app-based version of *Jellow* software.

5 Conclusions

The current report summarizes results of usability testing of the desktop-based prototype of *Jellow*. We are currently using insights from this study to improve the functionality and usability of *Jellow*. Following incorporation of these suggestions, we will conduct another round of usability tests with both typically developing children and children with different types of developmental disabilities to assess the ease of use of *Jellow* and its efficacy in aiding communication in children with moderate-to-severe expressive speech impairments.

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Part VII
Design Collaboration and Communication

Interactional Differences and Effects Between Collocated and Distributed Design

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Abstract Interactions (i.e. modes of operations through which product development knowledge is generated and externalized in the design process) play a vital role in knowledge processes of product development. Intentional or unintentional changes in interactions could have a significant impact on the design process (impacting e.g. idea generation, costly rework, and time delay). Although the literature has emphasized the importance of various types of interactions, defining and studying interactions from various perspectives are largely missed. In this study, interactions were studied with the following parameters to incorporate various perspective views: multimodal interactions (verbal, graphical, gesture, text and combination), variety of interactions (tools combinations), variation of interactions

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(frequency of interactions change), collaboration (individual and working together), and designers' movements and positions. Laboratory experiments in collocated and distributed set-ups were conducted using Smartboard^{TM} and Rhino^{TM} conceptual CAD software to study these parameters. This paper presents initial results from both original and redesign processes, and details follow-up research questions.

Keywords Interaction · Collaborative design · Distributed design · Sketches

1 Introduction

Globalization brings unique opportunities for organizations to group designers required for product development to work together from any parts of the world. Supporting collocated and distributed collaborations with appropriate tools are vital for design progression in a globalized environment. Currently, designers have to adapt themselves continuously to use frequently varying design tools used in collaborative environments. However, designer's adaption behaviors and their effect on design outcomes are not adequately studied and reported. Particularly multimodal interactions (i.e. verbal, graphical, gesture, text and combination) require for communicating complex design information need focused research.

The aim of this research is to understand designers' adaptation in different collocated and distributed design environments, focusing in particular, on interactions and knowledge capture (particularly sketches) behaviors. Laboratory experiments in collocated and distributed set-ups were conducted using Smartboard^{TM} and Rhino^{TM} conceptual CAD software to study this objective. Understanding transformation behavior of designers could lead to the development of new tools for designers' natural interaction patterns in different environments. The ultimate outcomes expected from these experimental protocol analyses are (i) to facilitate developing guidelines for designers to be better informed about possible interactional variations needed to adapt to collocated and distributed environments, and understanding the effects of distributedness on design outcomes; and (ii) to generate a list of requirements for developing advanced support mechanisms to aid collocated and distributed interactions for improving design outcomes and knowledge capture processes. This paper reports the initial results obtained from the analysis of six experiments each in collocated and distributed environments. Subsequent sections of this paper discuss current understanding of differences between collocated and distributed design, research questions and methodology, results from the twelve laboratory experiments, and conclusions and future work.

2 Understanding Differences Between Collocated and Distributed Design

This section reviews the literature on differences between collocated and distributed design. In the earliest, pioneering work, Bly [1] studied three design environments: face-to-face, geographically separated with an audio/video link, and a telephone-only connection. She observed that designers gesture less during distributed collaboration as they lose visual connectivity with remote parties, and draw and write more instead. But, the work mentioned only about the draw, write, and gesture actions, ignoring verbal segments in collocated and distributed settings. Bergström and Törlind [2] studied creative design sessions early in the product development process (one each in collocated and distributed sessions). The collaborative set-up for collocated design consisted of a big sheet of paper covering the entire table. Whereas in distributed setting, one group had a big back-projection surface as the primary display surface for video conferencing, a big sheet of paper on the floor and a video camera; while another group had a 30″ widescreen LCD computer for video conferencing, a tabletop microphone, and a portable whiteboard. Major findings from these experiments were the following: workflow in the collocated session was fluid and natural, but in the distributed session it was sometimes disturbed by limitations of the mediating technology. The authors argued that due to limitations of the technology, the communication mechanisms such as 'describe,' 'communicate' and 'build upon concepts' were seldom used in the distributed session.

Eris et al. [3] presented a comparative analysis of multimodal communication during conceptual design sketching in collocated and distributed environments. Design sessions in their study involved undergraduate students in two consecutive 30-min collocated and distributed sessions. The collocated group used a vertically mounted whiteboard, markers, and an eraser; whereas the distributed group used a digital camera and a vertically mounted glass plasma display at each site. The key findings from their analysis were: graphical communication was leveraged to compensate for gesture restriction in the distributed environment, communication structure used in collocated and distributed environments was different, and stressed the importance of cross-gesturing in shared understanding during distributed collaborative sketching. They observed that approximately 90% overlap occurred between participants' verbalization and gesturing, and verbalization was predominant in both set-ups (about $\sim$80% of the session). The limitations of this work are: the distributed set-up forced designers to work together all the time (i.e. camera image from one site fed as input display at the other site and vice versa). It diminishes the advantage of individual working in distributed environment, and subjects could hear each other due to lack of full insulation in the distributed environment. Gericke et al. [4] analyzed distributed whiteboard interactions and found that participants performed more deictic gestures (i.e. pointing gesture) towards the sketching surface in the audiovisual condition (by using Teleboard) than in the audio-only condition.

Tang et al. [5] studied design processes of designers in traditional and distributed digital sketching environments using Function-Behavior-Structure (FBS) ontology. Traditional collocated environment used large table space using pen and paper; and distributed environment used Wacom tablet, Ultra VNC software for sharing screens, and MSN video conferencing on LCD monitors. Ten groups of two industrial design students participated in two design tasks (i.e. one each on traditional and digital environment). The results showed that the types of segments (FBS) and their transitions were not statistically different across the two environments. Although average judges' score of traditional set-up outcomes was marginally higher than those in the distributed environment, these were not consistent across all groups. They argued that digital environment had a small influence on low-level activities (structure-related segments), and no influence on high-level cognitive activities. These results are interesting considering there are no influences of the medium on design content. The authors argued that a possible reason for this could be due to emulation of traditional sketching environment with Wacom Tablet and other supportive software and hardware, and the digital nativity of the participating students.

Among multimodal interactions, only verbal-based communication was seamless in distributed environments, whereas support tools for graphical and gestural communications are yet to become advanced. An analysis of the reported literature reveals that comparison of results from different studies is difficult due to the variation in collocated and distributed set-ups, usage of different software and hardware, different design tasks (i.e. varying levels of difficulty), and participants' background. Except for Tang et al. [5], all the other discussed work mentioned that collocated teams have richer mechanisms to develop the design in comparison to restrictions compromised many communication channels in distributed environment. No differences observed in Tang et al. express the need for further research to explore how designers adapt to given environments without influence design outcomes, and how different communication patterns influence design. More in-depth studies into multimodal communication are required. Particularly, influences of multimodal communications (i.e. verbal, text, graphical and gesture) on externalizing designers' internal thinking content and processes to enhance shared mental space in collocated and distributed design environments, with systematic, quantitative studies. All the reported studies focused on some of the design stages (particularly conceptual stage). Studies are required to cover all the design stages, so as to understand representation-medium differences in collocated and distributed environments. This research aims to extend understanding of multimodal communication, particularly focusing on the variety of interactions and their influences on design outcomes.

3 Research Questions and Methodology

Literature emphasized the importance of various types of multimodal communication; however, defining and studying interactions (i.e. tools usage) within various perspectives are largely missed. In this study, interactions are studied with the following parameters to incorporate various perspective views: multimodal interactions (verbal, graphical, gesture, text and combination), variety of interactions (tools combinations), variation of interactions (frequency of interactions change), collaboration (individual and working together), and designers' movements and positions. The research questions asked in this paper are the following:

1. How do the above interaction parameters vary between collocated and distributed designing environments?
2. How do the number of sketches and number of design solutions vary between collocated and distributed environments?

The research questions also include studying variation in original and redesign processes. To answer these questions, a set of collocated and distributed laboratory experiments were conducted with pairs of postgraduate design students as designers in each session. In total 12 experiments are analyzed and presented in this paper (i.e. six experiments each in collocated and distributed set-ups). Table 1 details the structure of the twelve experiments in collocated and distributed environments, and for original and redesign processes. This study used three design problems, and original designs were provided to improve them in redesign experiments. The collocated environment comprised two laptops operated with Rhinoceros™ CAD software and a Smartboard™, whereas in distributed environment both designers had a laptop with Rhinoceros™ CAD software, a Webcam, and a Smartboard, and used Netmeeting™ collaborative software for video and text chatting, and screen sharing. Figure 1 shows the experimental set-up in collocated and distributed environments. Since this study aims to provide an overall perspective of design stages, Smartboard was provided to use in the conceptual design, and Rhino was given to use in the detail design stage. The distinctiveness of these experimental set-ups was: it provided flexibility to designers to work with independent laptops if required in collocated set-up. Designers could work together on single Smartboard by sharing control between them (i.e. concurrent access) in distributed environment. Web camera could be adjusted to any position suitable to the designer (either to focus on a laptop, themselves or Smartboard), and provided good resolution of shared screens. This environmental set-up avoided any restriction on multimodal collaboration in distributed design. The research questions are answered from

Table 1 The structure of 12 experiments and participated groups (C, D → a pair of students)

Setting	Original			Redesign		
Design problem	P1	P2	P3	P1′	P2′	P3′
Collocated	C1	C2	C3	C4	C5	C6
Distributed	D1	D2	D3	D4	D5	D6

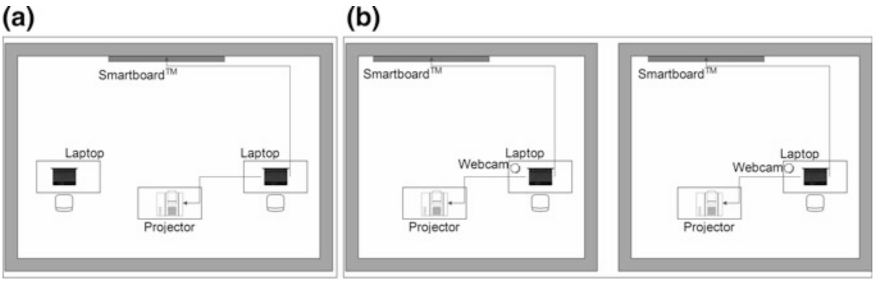


Fig. 1 **a** Collocated environment. **b** Distributed environment arrangements

Table 2 McGown et al. [6] sketch coding

Level	Description
Level 1	Simple monochrome line drawings; do not include shading or annotations
Level 2	Detailed monochrome line drawings with annotations but no shading
Level 3	Level 2 drawings with shading to suggest 3D form
Level 4	Level 3 drawings with more gradations of shading and possibly color to emphasize 3D form
Level 5	The most 'realistic' type of sketches; includes extensive shading and annotation

captured video recordings and transcribed audio protocols coded concerning each designer's statements. We have used McGown et al. [6] label categories based on the physical elements of engineering sketches to assess the quality of design sketches (Table 2). Smartboard supported the generation of sketches up to Level 3 (see Table 2), and most of Level 4–5 representations were carried out on Rhino software. The first two authors of this paper cross-checked entire coding. The next section presents the results obtained from these experiments.

4 Results

4.1 Multimodal Interactions

Figure 2 represents the distribution of the average percentage of interactions in original and redesign, and between collocated and distributed environments. The analysis reveals that only verbal communication is predominant in every set-up. Only verbal communication occupied 51.1 and 63.9% of original and redesign respectively in collocated set-ups; 65.8 and 75.8% of original and redesign respectively in distributed set-ups. On average, verbal and gesture communication is diminished by 14.7% for distributed set-ups as compared to collocated in the original design, and 11.2% in redesign experiments. This reduction in verbal and

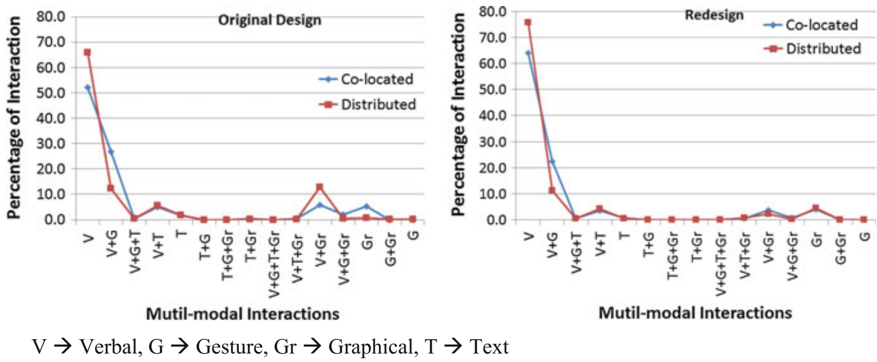


Fig. 2 Distribution of average percentage of interaction in original and redesign

gesture interactions were conceded to increase in only verbal interaction (9.1 and 10% increase in original and redesign respectively). Apart from only verbal, and verbal and gesture interactions being the top ones, the other prominent interactions are verbal and text, verbal and graphical, and only graphical interactions in every set-up. The only other major difference observed is in the verbal and graphical interaction between collocated and distributed in the original design (7.1% increase in distributed set-ups). Gesture interactions not identified independently; they were either part of verbal, verbal and text, text, text and graphical, verbal, text and graphical, verbal and graphical, and graphical interactions.

4.2 *Variety of Tool Combinations*

Within the given set-up, designers' had chosen a different combination of tools to suit the design progression requirements. Our categorization reveals that designers in the distributed experiments combinedly used 66 different varieties of tool combinations as opposed to 16 combinations in collocated environments. Tables 3 and 4 illustrate a set of tool combinations used for at least 7% of the average time in either of original or redesign experiments in collocated and distributed arrangements. The important observations between collocated and distributed experiments (Tables 3 and 4) are: among the top 7% interactions, both designers did not use Net Meeting Audio/Video function together. A further analysis of not using this function together demonstrates that distributed designer observed only on the average 21.1% of gestures communicated. This result shows that designers' perception of 'What I Do is What You See' is misrepresentative in distributed environment. Smartboard was used considerably in collocated set-ups; whereas instead of Smartboard, Smartbook used from Laptop itself in distributed environment. The movement plot of designers (Fig. 3) justifies this usage behavior. The figure shows

Table 3 The average percentage of time spent in collocated tool combinations (only top 7%)

Collocated tools usage	Original	Redesign
Laptop (Rhino); Smartboard (for visualization only—vis); problem sheet	21.0	12.2
Two laptops	18.3	0.0
Smartboard	15.1	7.6
Smartboard; problem sheet	12.3	0.0
Laptop; Smartboard (vis)	11.5	2.5
No tool (discussion)	8.7	2.5
Smartboard; laptop	4.4	15.6
Smartboard (vis); laptop; problem sheet; saved original design files	0.0	16.9

Table 4 The average percentage of time spent in distributed tool combinations (only top 7%)

Designer tool usage	Time spent (%)	
Unique combinations (D1::D2)	Original	Redesign
RhinoCAD + Net Meeting Audio::RhinoCAD + Net Meeting Audio	34.1	5.0
Smartbook + Net Meeting Audio::Smartbook + Net Meeting Audio	22.7	18.9
RhinoCAD + Net Meeting Audio::RhinoCAD + Net Meeting A/V	14.0	1.9
Net Meeting Audio::Net Meeting Audio	11.1	1.4
RhinoCAD::RhinoCAD	1.0	17.3
Saved Original Design Files + Net Meeting Audio::Saved Original Design Files + Net Meeting Audio	0.0	14.9

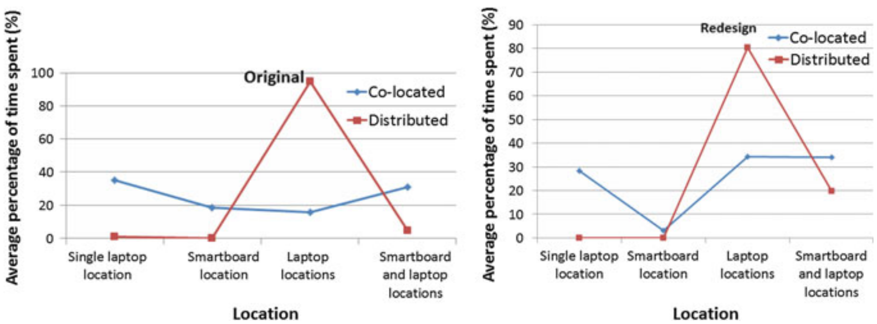


Fig. 3 The average percentage of time spent in different locations

that designers were restricted mostly to laptop locations (more than 90% of the time) in distributed environment.

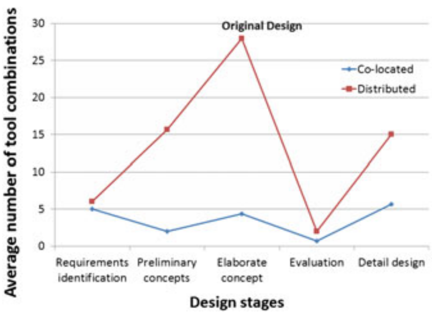
The observations show that designers were able to generate more variety of tool combinations while sitting in a single location in the distributed environment. Smartboard was used mostly as a visualization tool to aid collaboration in the collocated set-up; whereas in distributed set-up designers were largely focused to laptop based visualization. Although experimental set-ups created for individual designing in collaboration, these tool combinations were carried out predominately in collaboration, both in collocated and distributed environments.

4.3 Overall Tool Combinations Across Design Stages

Across the design stages, tool combinations were frequently changed at the concept elaboration stage, both in original and redesign experiments, in the distributed set-up (Fig. 4). The evaluation stage used the least combination tools. This reflection shows that designers need better guidance/support mechanisms at the concept elaboration stage in distributed environment.

4.4 Representation of Sketches and Design Quantities

Figures 5 and 6 illustrate variations observed in sketch design scores and the number of outcomes (i.e. number of requirements, the number of preliminary, elaborate and detail concepts) generated in various design stages across different set-ups. The reflection reveals that collocated teams were better at generating design sketches across different representation levels. List of requirements and Level 2 design sketches (a detailed monochrome line drawing with annotations) are higher in collocated redesign experiments. These variations show that initial requirements and concept exploration phases are better in collocated rather than distributed set-up.



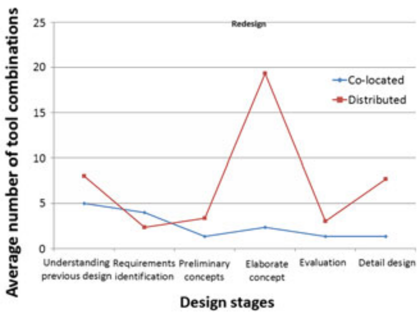


Fig. 4 An average frequency of tool combinations used across design stages

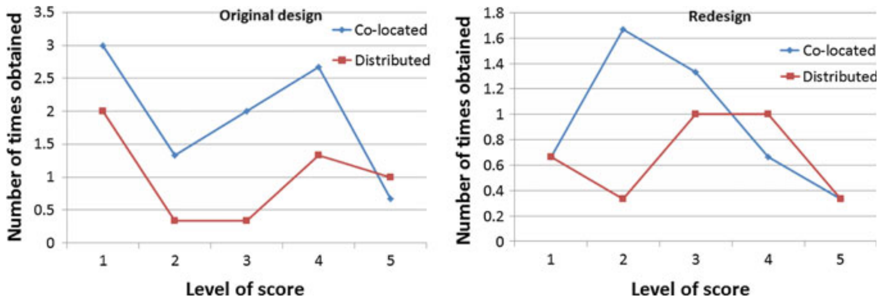


Fig. 5 The average representation scores for design sketches in different set-ups

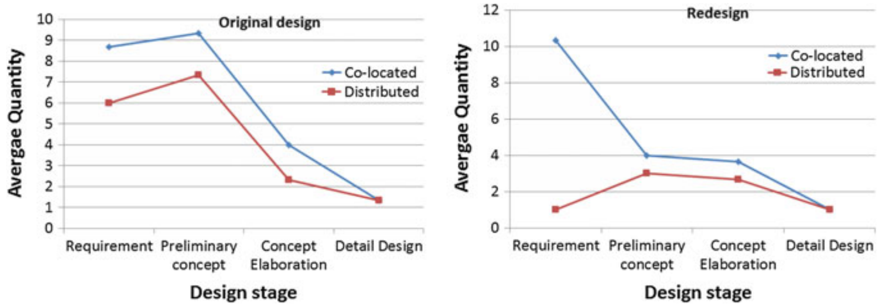


Fig. 6 The average design outcomes across design stage in different set-ups

5 Discussion and Future Work

In this globalizing design environment, companies need effective mechanisms for distributed working. There is a need to understand differences between collocated and distributed designing for developing an effective distributed collaborative set-up. Although there is literature that reported results on these differences, in-depth understanding of interactions and tool combinations in collocated and distributed set-ups is largely missing. The presented laboratory study provides insights on multimodal interactions (verbal, graphical, gesture, text and combination), a variety of interactions (tools combinations), a variation of interactions (frequency of interactions change), collaboration (individual and working together), and designers' movements and positions. Table 5 details the observed differences between collocated and distributed experiments.

This study confirms and extends the previous observation knowledge. It confirms that gesture level dropped in distributed environment, which is compensated for by a rise in verbalization (Bly [1] and Eris et al. [3]). The gesture did not act as an independent medium but always combined with other forms of multimodal communication (Tory et al. [7]). The key finding is that most of the gestural

Table 5 The observed differences between collocated and distributed experiments

Observed features	Differences between collocated and distributed design
Gestures	'Gesture and verbal' interaction was observed highly in both collocated and distributed designing. However, on the average, only 21% of the articulated gesture was communicated (i.e. seen by another designer) in the distributed environment
Movements	Designers are restricted mainly to laptop location in the distributed environment, which prevents Smartboard usage (including visualization)
Frequent changes in tool combination	Compared to the collocated set-up, designers changed tool combination much frequently in the distributed environment (particularly at the concept elaboration stage)
Design outcome	The collocated teams generated many requirements and design sketches (particularly Level 2 design sketches) than the distributed teams

information was not visualized and given importance in the distributed environment due to video visuals given least preferences in comparison to other interactional modes. The new collaborative system should aid context awareness to aid more meaning to naturally occurring gestural interactions. From the observed results, we are studying as to why designers need so many tool combinations, how designers effectively manage transitions among interactions, and how innovative tool combinations could help designers in the design process. We are studying as to why design sketches and design content got reduced in the distributed set-up, whether interactions/tool combinations influenced design sketches and generated design content, and if yes, how. We argue that enriching understanding of different collocated and distributed design set-ups will lead to the development of more flexible and adjustable natural collaborative systems, for better and faster design.

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Mapping Chandernagore: A Collaborative Approach to Heritage Conservation

Aishwarya Tipnis and Chitra Chandrashekhar

Abstract This paper explores the role of a conservation professional, as a design strategist in urban heritage management, through a case study approach of the 'Heritage and People of Chandernagore' Project. Chandernagore, an erstwhile French Town, is situated about 40 km north of Kolkata, along the Hooghly river. This project was an initiative of Aishwarya Tipnis Architects (ATA) supported by the Vieilles Maison Francaise (VMF), Paris. The project has pioneered in the use of digital technology and open source GIS mapping to 'crowd source' content through citizen engagement activities in order to spread awareness and disseminate information about the town's heritage. It demonstrates challenges of a semi-urban community, especially with inclusivity in the use of social media for citizen engagement, and corresponding solutions that encourage grass root level initiatives like participatory mapping for maximum public involvement.

Keywords Chandernagore · Heritage conservation · Collaborative design · Community engagement · Planning · Participatory approach · Inclusive

1 Introduction

Heritage is any legacy which a 'collective' or 'group' inherits from its previous generations. The emphasis is on the 'collective'. By the same definition, urban heritage is an entire community's inheritance. In his book, *Interpreting Our Heritage*, Freeman Tilden, championed for interpretive communication that evokes a sense of wonder, pride and care for one's heritage [1]. Both natural and man-made heritage have been preserved as treasures for posterity. It will not be an exaggeration

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to say that our existence, evolution and collective identity depends on this inheritance through tangible channels like buildings, streets, places and artefacts that are seamlessly woven with intangible memories, stories and ethos.

1.1 Heritage and Ownership

Urban heritage in India has been threatened by rapid and rampant urban development. Historic buildings that once were the collective identity of a town or a city are haplessly being destroyed in want of global architectural icons. Heritage conservation practice in India, has so far been concentrating on monumental edifices, while our everyday buildings which give the city its character, are rapidly disappearing. How can there be a future for these buildings when they are not even considered as valuable heritage? The community as a collective, has always organically determined what is valuable and worthy of preservation in the socio-cultural realm, as in festivals, rituals, mythology etc. However, in the physical context, whether natural or architectural, politically or economically dominant agents take control. How can consensus emerge on what is understood as collective urban heritage? While experts in conferences and seminars romanticise about disappearing heritage, the community which is the custodian of this heritage is grappling with issues like poverty, illiteracy and property ownership. With no assistance or incentives (soft loans etc.) from the Government, the question at hand is-Whose responsibility is this heritage, anyway?

1.2 Heritage Conservation and the Digital World

In this day of E-commerce, Start-ups, Entrepreneurship and 'Digital India', when Google is the unanimous answer to all our problems, why is heritage still locked up in libraries with special access? Doesn't heritage belong to one and all? The digital world offers a plethora of possibilities to create digital content and provide greater opportunities to actively engage audiences and further enrich the collective repository. Audiences across the world, have gone from being consumers to active creators and curators of heritage content through crowd-sourcing and open source digital media. The digital world is in no means, a replacement for the real experience, but it certainly augments the sensitisation and interpretation of heritage. 'Digital Humanities'(DH), a growing field of knowledge is rather nascent in India. A blog on DH [2] quotes Busa, R. A., explaining the 'new-founded' term as:

> "… precisely the automation of every possible analysis of human expression (therefore, it is exquisitely a "humanistic" activity), in the widest sense of the word, from music to the theatre, from design and painting to phonetics, but whose nucleus remains the discourse of written texts".

Anusha Yadav's 'Indian Memory Project' [3] is one of the earliest examples of DH in India. In 2006, the project began as a 'blog-site' of curated personal memories with significant historic value. In 2012, it evolved to become an interactive digital archive inviting people's contributions to grow its collections. 'Dutch in Chinsurah' [4], A 2014 collaboration between Aishwarya Tipnis Architects (ATA) and Presidency University, Kolkata, is an online archive documenting the Dutch Cemetery along with the heritage buildings and oral histories from Chinsurah (West Bengal). The archive is not interactive in the sense of its inability to allow people to add or edit information. Similar static web-archival projects are the 'Scottish Cemetery' in Kolkata [5], by the Presidency University; and 'Jewish Calcutta' by Jadhavpur University [6]. The 'Heritage and People of Chandernagore' project was different in its vision for a dynamic and organically evolving website that gives adequate support in tackling media literacy issues.

Across the world, community engagement campaigns, heavily rely upon digital and social media requiring the public to have significant levels of media literacy. Crowd sourced databases built in USA, such as Building inspector [7] and Historypin.org [8], also depend on tech-savvy users to populate rich media content. But a semi-urban setting, can pose challenges in adopting mainstream solutions, owing to moderate to low levels of tech-literacy and typical regional, socio-cultural and behavioural patterns. Amidst these issues, how must a conservation professional function as a design strategist for effective, efficient and inclusive urban heritage management? This paper demonstrates, through a case study model, how designers can employ unique context-specific strategies to design interventions that enable people's participation in heritage conservation and awareness. The following sections elaborate the case study of the heritage conservation and community engagement project executed in Chandernagore, an erstwhile French settlement and a suburban town off Kolkata (West Bengal, India), along the banks of the Hooghly river.

2 Chandernagore: A Case for Conservation

2.1 Heritage and People of Chandernagore

The Heritage and People of Chandernagore Project [9], was an initiative of ATA supported by the Foundation VMF, a Paris based NGO, Les Amis du Patrimoine Pondichérien (APP), French Heritage in India Society (FHI) and the Embassy of France in India. The project aimed at creating a grass root level initiative to spread awareness about the rich heritage of town. The project was built upon the premise that heritage isn't just about buildings, it is also about the people who lived then and now and their personal stories. The primary aim of the project was to put Chandernagore on the global map and demystify its history by sharing the untold stories of the town. It was felt that the survival of heritage had a far greater chance with community as its custodian, in the absence of legislation, local or state authorities to govern heritage. The project spread over an entire year with the help of 'Citizen Volunteers' and students from the local community to collect, collate and appropriately disseminate the strands of local history by means of workshops, events and competitions. The project's end deliverable was an interactive website that provided opportunities for audiences to engage and curate the digital content.

2.2 Challenges and Strategic Solutions

One of the most challenging aspects of the project was, that it was self initiated, without any specific client and was executed on a shoe-string budget with a seed funding from VMF. This became the determining factor for the scale of the events with an emphasis on creating voluntary grass root level advocacy. Being initiated by an architectural consultancy situated in New Delhi, and not a local government agency or NGO, it became important to anchor the project locally. The Institut de Chandernagore was therefore chosen as a local partner for community engagement events, thus allowing, a wide base for community outreach.

A critical concern throughout the project was to first, change pre-conceived, rigid mindsets of the semi-urban community, to recognize and value their own urban heritage so as to achieve greater community participation. There was a general mistrust about the intentions or vested interests of the project and its consultants. This motivated a participatory approach in strategising community engagement and further trust-building was achieved by encouraging the youth from the community to get involved in the project as 'Citizen's Historians'.

The other significant challenge was working with a community with moderate to low levels of tech-literacy and distinctive regional and socio-cultural behaviours. Engaging and training the 'Citizen's Historians' in social media and empowering them to act as representatives of their community, was adopted as a strategic solution. The visual design language and vocabulary had to appeal to the community's sensibility and was thus, intentionally kept simple, uncluttered and to the point. The cross-disciplinary nature of the project was an apparent and crucial need for project implementation with sensitive and deep rooted understanding of sociology and people management. Working with students of history, geography, political science and architecture allowed for a cross-fertilisation of ideas and development of bespoke strategies on the ground.

2.3 Strategic Approach to Heritage Conservation

The role of the conservation professional in this project was arguably more of a design strategist rather than a traditional conservation architect. The designer's role has seen a paradigm shift from an all-knowing expert to that of a facilitator and enabler of sustainable solutions that let end users or the community to take stewardship of their problems. In a community centric project, a designer juggles many roles from a recruiter, trainer, to a journalist, a PR professional, to an event planner, activity designer, performer and even an activist.

Knowing the Community. With this approach in mind, the designer's role in the Project at Chandernagore was, to first understand the premise of the citizens, their aspirations and values with respect to their own town. This would let all the stakeholders know what is valued as heritage thus needed to be conserved. In order to assess heritage awareness levels, it was proposed to connect with various citizen groups through a series of community engagement activities such as competitions, workshops, discussion panels etc. to be covered by local mass media and further published via social media. As Tilden [10] advocated in his principles of heritage interpretation, no 'One fits All' approach can inspire a sense of value in the citizens. Hence the project aimed to target significant age groups that could participate in shaping the town's future.

Youth Engagement and Creative Collaborations. Early in the project, it was felt that connecting with a more eager and tech-savvy youth could catalyze the efforts of heritage awareness. Hence the proposed community activities began targeting school children and college goers. Creative collaborations with subject experts such as architects, artists, designers, photographers etc. ensured that these events and activities were fresh and different, leaving a lasting impression in the participants' memories. The youth could also be appealed to and partnered with for their fervent support and participation in the project. This gave birth to the initiative of organically building a team of Citizen Historians through social media (Facebook). Young volunteers who were college students from in and around the town helped the project. They were trained to conduct heritage walks, numerous interviews and surveys that were used to gather valuable information such as citizen voices and personal stories, photographs, familial artifacts etc.

Continued Conversations and Peoples Participation. The pool of information thus collected were to be stored and displayed as a digital resource accessible to anyone. Thus a website was proposed as a repository of the town's heritage both tangible and intangible. It was also envisaged to act as a platform to dynamically add or revise the repository and bring various stakeholders together to have continued conversations over the town's collective future.

3 Mapping Heritage and People of Chandernagore

The key aim of planned activities was to inspire people of all age groups, to discover more about their past through active engagement with their heritage. Raising awareness and encouraging participants to visit and appreciate their local sites was an utmost necessity. One of the main objectives of the project was also, to empower the youth of Chandernagore, build their pride in their town's heritage and encourage rest of the community to follow suit. Sections 3.1–3.4 describe the various crucial steps taken to realise the project's end deliverable.

3.1 Major Groundwork for Project

Digitizing and Updating the Listing of Heritage Buildings in Chandernagore. A previous listing of buildings was done in 2011. This was updated by a young team of architects and historians who surveyed the streets of Chandernagore along with fresh round of photography to add missing buildings. Few buildings on the original list, had been partially demolished, such as the Post Office and some residential buildings. These buildings were then geo-referenced through open source GIS mapping, so that they can be accurately located on Google map to be embedded in the website. This was an important foundation for the final dynamic and interactive website for the citizen's virtual interaction with the heritage of Chandernagore.

Designing Heritage Walk for Chandernagore and Training Local Youth to Lead. A call for applications was announced, inviting enthusiastic youth from the community, to join the project. The main objective was to encourage and give a platform to passionate local youth, students of history and other enthusiasts to get involved and build a story bank of the town. Their ease of interaction with the community in their local language was advantageous in gathering personal stories. A total of 15 people signed up as citizens historians who worked through the summer in collecting the history of the place. These citizen historians were then supervised to curate a heritage walk for the town based on the information collected by them including local stories and research at the libraries. They were trained to lead this walk primarily as a sustainable revenue generating model encouraging other young people to participate and lead. This would help their heritage become more relevant to them even today. A map and brochure was designed, which was handed out to the participants and was to be made available for download from the future website.

Documenting Old memories of the French in Chandernagore through Interviews with the Elderly. With the help of the citizen historians, the team of architects from ATA, went from home to home interviewing the elderly from the local community, capturing their memories of the French in Chandernagore, on both audio and video. This was to be used as a Oral history repository in the future website. Additionally, Photographs, newspaper clippings and historical research, especially done at the National Library in Kolkata, were collected as database. Senior local historians were also consulted and interviewed and their memories were documented in the form of a blog and publication.

3.2 Engagement Activities for School Children

In order to spread awareness for the conservation of the heritage of Chandernagore, amongst school children, a series of 'Heritage and People of Chandernagore' themed workshops and competitions were planned and conducted. The hope was that these students would be inspired and become proud of their heritage while gaining new skills to appreciate and care for their local environment and further spread the enthusiasm into their community. With the help of volunteers from the town the events were publicized word-of-mouth and the team also used social media for additional impact. The engagement strategy was to let children participate in familiar activities such as painting and creative writing competitions at the same time also experience out-of-the-box events like the Lego Brick by Brick competition, Photography and Comic Book Workshop. This would give them multiple opportunities and mediums to understand and express their sensibility for heritage. The following sections briefly discuss each of the competitions and workshops.

1. **Lego Brick By Brick Competition**. The aim of this competition, held on 25th May, 2015 at IdC, was to encourage out-of the box thinking and stimulate the children's mind to look at their town and appreciate its heritage buildings in a 3D perspective. The participants were asked to choose any landmark, architectural feature that they thought was representative of the heritage of Chandernagore. The participants were provided the Lego blocks to spontaneously make a structure of their choice. A total of 7 children between 12 and 16 years of age had participated. All competition entries were documented through photographs before dismantling.
2. **Painting Competition on Heritage and People of Chandernagore**. This competition was held on 26th May, 2015 at IdC, in two parts. The first was an on-the spot competition where a total of 19 children between age 8–18 years participated. In the second round, the same brief was circulated to a total of 07 schools and a total of 22 entries were received. The children were encouraged to derive inspiration from their immediate environments, their homes, their streets and their town, envisioning what it may have been like during the time of the French. It was fascinating to see most of the children associated some fixed images with the Heritage of Chandernagore that included the Dupleix Palace, Institut de Chandernagore, the Strand and the Nandadulal temple, a couple of them drew the Durga Puja. None of the children considered any of their homes or public spaces as heritage.
3. **Creative Writing Competition on Heritage and People of Chandernagore**. This competition, held on 26th May, 2015 at IdC, was an on-the spot event where a total of 44 children between 13–17 years of age participated. The students' entries demonstrated how the physical built environment, formed a backdrop to their narratives. The event brought intangible associations of history/heritage and stories of the town to the forefront. Narratives of the national movement that form an important part of the oral history also found their way into some of the students' entries.

4. **Comic Book Workshop**. Held On 16th August, 2015, at Nritya gopal Smriti Mandir, the workshop aimed to encourage children to imagine and articulate a short visual narrative as stories from Chandernagore, through the medium of comics. The workshop, facilitated by Designer, Chitra Chandrashekhar, started by introducing the participants to the visual language of comics, leading them to create 1 page comic story on the theme of Heritage & People of Chandernagore. The brief given to the participants, was to weave a story by choosing the genre, a timeline and a location or site within Chandernagore to situate the story's context. There were a total of 13 participants. The workshop helped in learning about the youngster's perceptions of the town. It also brought to light how in everyday life the romanticism associated with a colonial town faded away into mundane and simple stories. The participants reflected the general air of casualness out of ignorance/indifference associated with heritage, both built and cultural.
5. **Quiz Contest**. Held on, 19th August, 2015 at IdC, a total of 7 schools were invited to participate and 5 teams of two students each were selected for the final quiz. There were a total of 3 rounds of questions. The quiz was designed, developed and conducted by the Citizen volunteers under ATA's supervision and guidance. It was successful in raising awareness about the heritage of the town, by planning it around the theme of Heritage and People of Chandernagore.

3.3 Community Engagement Events

1. **Heritage Walk**. Taking the heritage walk training further, on 15th August, 2015, celebrating the Indian Independence Day, a heritage walk was conducted on the theme of the Nationalist movement by the Citizen Historians. They collated all the stories they had collected over the summer to guide the participants through a thematic walk inspiring in them the historic significance of Chandernagore in the Indian Independence Movement.
2. **Photography Workshop**. A photography workshop was conducted by renowned photographer Sanjeet Chowdhury, on 16th August 2015 at Nrityagopal Smriti Mandir. He shared the basics of photography, followed by a curated photo-walk which gave participants an opportunity to see the hidden treasures of Chandernagore. The key purpose of the workshop was to encourage people of all ages to discover more about the town's past through skill-based active engagement with heritage.
3. **Community Engagement Campaign at Strand**. A community engagement Campaign was conducted on 17th August, 2015 at The Strand, with the permission of the Mayor of Chandernagore. A series of 4 interactions were planned and designed by to stimulate every age group of citizens in order to capture (a) what they understand by Chandernagore's heritage; and (b) what is the future

they envisage for Chandernagore. Strand, being the centre of the town, was accessible to all. The outcome from this engagement was envisioned to be displayed on the website as a repository of the community's perceptions of Chandernagore. Following paragraphs describe the interactions briefly.

(a) **Two Game-based Interactions**. A creative game-like interaction was designed for school and college goers on the theme of Heritage and People of Chandernagore. It included four rounds and required players to mark with thumb pins on the map of the town. The first round was to identify a favourite place in and around Chandernagore. The second was naming and marking favourite streets; the third was to answer a 'What if' question and finally the fourth round was a general knowledge quiz on Chandernagore.
A simple heritage awareness exercise modeled after the memory card game was planned and well received by younger age group of school goers. The objective was that children could indirectly learn about photographs of places and landmarks used in the game. Game based interaction helped to capture the participant's innate level of sensitivity and also build awareness about their heritage in an unconscious manner. The act of play itself became a memorable experience and had many participants give a positive feedback about the event.

(b) **Other Planned Interactions**. There was a live scribing session by Chitra Chandrashekhar, to document the essence of the place and activity as a visual journal, at the same time to engage passers-by visually, so they may stop, wonder and question about the buzz during the event. Facilitated conversations with older groups of citizens, encouraged them to talk about the changes they wished for their town. These were captured on a board titled 'Mapping Community Stories'. Finally all participants were encouraged to leave their mark of support on a signature/finger stamping board titled 'I Care for Chandernagore'. There was immense excitement and pride sensed by those who signed off.
The Community Engagement Workshop was able to bring to the surface multiple insights in a short span of time through innovative game-based interactions and one-on one conversations. It was possible to extract issues and aspirations about what the citizens envisaged for their town. The hands-on manner of capturing key ideas and issues in a colorful and concise manner allowed curious and knowledgeable passersby to inquire and also involve themselves in the event.

4. **Franco-Bangla Food Competition**. The aim of this competition, held on 19th August, 2015 at IdC, was to encourage housewives and enthusiastic young adults to creatively experiment with the food of Chandernagore. There were a total of 5 participants and their brief was to create a fusion between French and Bangla cuisines, using local ingredients and spices but inspired by French Cuisine. Each participant could make either a starter, main dish or dessert and bring it to the venue for judging. It was a great beginning to a culinary

experience. the competition could have been more successful if there was possibly a workshop with some famous chef handholding the ladies who has limited exposure to French cuisines. Also a reason why participation was limited.

3.4 Website for Dynamic Mapping

Designing and presenting the project through a user-friendly interactive website [11], to be launched in February, 2016, was the primary deliverable for the project. It has effectively put Chandernagore on the global map and become a medium for people across the world to see and virtually interact with Chandernagore. The website has been designed to allow crowd sourcing of data and populating stories of Chandernagore even after the project is over (Fig. 1).

Website Launch and Award Ceremonies. Launching the website as a public event was important as a key marker in the minds of the people and as a way of culminating the project. The occasion was also opportune to celebrate the talents at

Fig. 1 Website Launch Ceremony, 3rd February, 2016, Chandernagore (*Source* http://www.telegraphindia.com/1160203/jsp/calcutta/story_67185.jsp#.V80waJh96hf)

that surfaced at various competitions and events through award ceremonies. The event was of local and regional significance and was featured in many local and national newspapers. The active media interest and award ceremonies were critical in piquing the interest of ordinary citizens regarding their own town's heritage and its importance in the world at large. The intent was to keep them interested about their own collective heritage and contribute towards the website long after the project.

4 Assessing the Project

4.1 Success Markers

The Heritage and People of Chandernagore project, started off with citizen engagement activities and workshops. Their success was demonstrated by the number of people who learnt about heritage, developed skills, changed their attitudes towards heritage of their town and had an enjoyable experience. The project has pioneered and set a model in using digital technology for interactive content, encouraging users to be co-creators and contributors rather than just mere audiences. The successful completion of a "web home" for Chandernagore, using open source GIS technology, can go a long way in spreading awareness about the history and heritage of the erstwhile French town. Not only local citizens but stakeholders in other parts of the world with shared cultural roots, can contribute towards the project. The project has demonstrated that even with negligible funding, voluntary efforts and digital technology can be powerful in spreading the cause of heritage awareness and conservation.

4.2 Further Efforts

The content curated for this project are valuable cultural, social and historical strands of local identity. They can be effectively used as a tool for urban planning and for further physical improvements and interventions in the public spaces within Chandernagore. The website can be used as a base for the development of other grass root level advocacy projects as well as governance and bringing about social change. The response from engagement activities conducted within the school children's group, reflected a great potential of developing dedicated 'Education and Awareness Programmes' for continued interest of citizens in the Heritage of Chandernagore.

5 Conclusion: Learning from Project

Heritage has the power to connect people with the collective identity of a place. At a time where there is a paradigm shift from expert driven to community led, the methodologies for urban heritage conservation demand to be re-written and re-interpreted making heritage relevant to the local community. When collective value of heritage is embodied in layered histories, narratives and non-monumental buildings, challenges of urban conservation become far more complex. In the current scenario with negligible legislation to protect heritage buildings, survival of heritage can be better ensured with the community acting as its custodian.

The urban conservation and community engagement strategies for Chandernagore have been built on this premise. The experiments at Chandernagore have been able to successfully demonstrate how history, urban geography, interpretation, design, communication technology and conservation architecture complement each other. This multi-disciplinary project shows how the urban fabric can itself become a museum for diverse stories and meanings that are accessible to all both locally and globally. It has taught, how conservation that actively involves the youth can help in inculcating in them a sense of pride for their environment. The website and social media are a platform not just for the residents but also for those who live elsewhere but have roots in Chandernagore. These virtual platforms celebrate the life of the place and its citizens by showcasing talent, understanding how the place has grown and changed over time what problems it faces and allow possibilities for conversations to solve these issues collectively.

The enthusiasm and awareness generated in this project is only the beginning. It has shown that there is a long way to go before heritage becomes a significant starting point of the urban development process. Future endeavors must consciously embed multipronged strategies to involve the community for shared participation, responsibility, decision making and action. The role of a contemporary conservation professional, is indeed critical in establishing dialogues, interactions and collaborations that work towards this democratized vision for the future of inclusive urban development.

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Exploring Distributed Cognition as a Conceptual Framework for Service Design

Ravi Mahamuni, Pramod Khambete and Ravi Mokashi Punekar

Abstract Service Designers envision, systematically plan and choreograph unique solutions. Design is a creative activity of problem solving to create desirable solutions. Service design is the natural extension of the design activity where multidisciplinary collaboration extends over a period. Hutchins developed a theory of distributed cognition, which redefined 'information' as the propagation of representational states of mediating structures of any complex system. This research paper presents observations from the organizational recruitment service case study, which displays the use of distributed cognition concepts in the service design process for a multidisciplinary team collaboration and recognizes the influence of non-human agents on service. During the case study, working in a team on the same artefacts, the artefacts played a role in supporting each other's thought process through a mental structure of problems and solutions. It has implications on the design process and the artefacts generated.

Keywords Service design · Distributed cognition · Participatory design · Multidisciplinary team · Organizational service

1 Introduction

Services evolve over time through a sequence of events and steps that produce value for the customer [1]. Design of these services is a customer centric activity of planning and organizing people, infrastructure and communication as a holistic

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socio-technical system [2]. A service designer must take into account the needs of the entire world, including the environment [3]. Similar to design, Service Design is a creative problem solving activity, which involves thinking with your body and externalization of thinking through in-process artefacts. Unlike product design, service design incorporates temporal relationships making it complex. Services are multidimensional as they involve socio-technical and user centric aspects. Hence, people from various domains need to contribute during service design. The quality of the outcomes of service design process can be accomplished only through multidisciplinary participation and effective collaboration [4]. Multidisciplinary participation also helps to gain deep insights of customer expectations and to add innovativeness in the service being designed [5]. In order to improve design thinking, there is a need to involve professionals with diverse experiences from relevant disciplines in the design teams, and effectively integrate their knowledge in the outcomes. We explore in this paper how Service design activities in a multi-disciplinary setting can be carried out effectively and productively if informed by ideas from the distributed cognition (DC) theory.

Hutchins [6] developed a theory of DC, which offered a new perspective towards cognition. Challenging the idea that cognition is confined to an individual's head, he proposed that it is a group process, and must be viewed as the property of a socio-technical system. Externalizations are assigned a crucial role in this perspective. The complementarity of DC and service design, with regard to the external representations was noted [7]. Techniques used in making external representations for service design are related to the cognitive processes. They help in articulating insights, learning, communicating and collaborating. Further, they make intangible aspects of services accessible, storable and sharable [7]. Fischer proposed a conceptual framework for design based on DC, but its focus was on people with cognitive disabilities [8].

This research paper explores and elaborates the idea of the congruence of DC and Multidisciplinary Service Design using an organizational recruitment service design case study. We propose that the application of DC concepts can be beneficial in informing multidisciplinary, collaborative service design process, so that the efficiency and effectiveness can be enhanced.

2 Related Work

Design is making things better for people [4], and design outcomes influence people's lives. Designers' decisions are based on the synthesis of insight, intuition, and reason. Aspects of 'designerly' thoughts are that they are holistic, provable and based on envisioned future possibilities [9]. Apart from the traditional techniques, recent approaches such as Design thinking are used as a driver for innovation and to develop superior solutions to problems [10]. Evolving design discipline like Service design requires a systematic approach for applying design methodology and principles [11]. Service design discipline is a fusion of design thinking and new methods aiming at innovation and improving quality of services delivered to its customers. Five foundational principles for service design are user-centeredness, co-creativity, sequencing, evidencing, and holistic perspective [12]. As part of co-creativity and evidencing, external representations corresponding to mental representations of the designers provide a structure that can serve as a shareable object of thought [13].

Further sub-sections, elaborate on the linkages among service design principles, DC concepts and Human centered design.

2.1 Distributed Cognition (DC)

Cognition is the mental process of knowing through perception, reasoning, or intuition [14]; and it is distributed in time, location, and across human and non-human agents [15]. DC theory identifies a set of core principles like: as a part of cognition process human beings establish and coordinate different types of structure in their environment, it takes effort to maintain coordination between them, and so on. Humans use their surroundings to enhance their memory [15]. This theory took a culturally constituted functional group as the unit of analysis rather than an individual mind and redefined 'information' as the propagation of visible states of mediating structures of any complex system. These structures include internal as well as external knowledge representations like skills, tools, memory and culture [6]. Hutchins [16] argued that DC concepts help in comprehending aspects of structured experience and individual learning. DC helps understanding how people think and act through continual interaction between brain, body and contextual situations [15]. These interactions happen mainly through external representations supporting more intricate, holistic and involved 'thinking'. The key components of the DC theory are the 'cognitive system'; 'communicative pathways', and 'propagation of representational states' [17, 18].

In contrast with traditional cognitive science, Hutchins [18, 19] believed that human beings create their cognitive powers in parts by creating the environments to exercise those powers. In this process, cultural practices play a key role. Clark [20] advocated an active externalism, based on the active role of the environment in driving cognitive processes. In a similar vein, Latour [21] proposed that objects, which are actors in social processes, assume the role of intermediaries and participants in the action. Along with this, these objects also provide continuity during the participatory design process and have appropriate form and content. We noted the resemblance of these ideas to the role of externalization in the distributed cognitive processes.

2.2 Human-Centeredness and Co-design of Services

As stated above, one of the most desired characteristics of service is being human-centered to achieve customer satisfaction and in this endeavor, it requires effective collaboration within a multidisciplinary team participating in design [11]. As co-design involves collaborative decision-making and combining creativity of multiple people, it helps collectively create more number of innovative concepts and ideas than while working on their own [22]. Participants in co-design can be users, designers, professionals and domain experts who together create value for customers. In order to augment the process, a common language or vocabulary should be available to exchange the ideas effectively within the team. Co-design supports effective engagement of the participants in a process of creative conceptualization, implementation and evaluation [4] where involved immersive activities are the main drivers for participation [23].

2.3 Human-Centered Design and Distributed Cognition

Service design draws on several ideas from another human centered design field, Human-computer interaction (HCI). It was advocated that HCI design should be derived from an understanding of service interaction since the information systems are often used to deliver or support some kind of service [24]. Service design shares the HCI field's commitment to working with and for people in the development of useful services and can borrow the user-centered mindset and techniques from HCI Design domain [25]. HCI design makes use of DC analysis such as, revealing the constraints that are implied by the representational media or other factors, understand individual as well as group dynamics [15]. Hence, use of DC concepts, which are found useful in HCI, can be extended to service design.

2.4 Design Theories and Externalization

There are many theories that explain the design process, but they mainly focus on creativity, teamwork, management, social aspects, aesthetic or ethical aspects, analytical or visual thinking [26], without significant consideration of the role of externalization. Externalization facilitates the computation of more explicit encoding of information; enables the construction of complex structure; and helps the coordination of thought. These functions allow people to think more powerfully and creatively with external representations [12].

Design process is characterized as a thinking and social activity comprised of the transformation of abstract to concrete; that is from the vision in the designer's head, through an increasingly detailed operative image, to a complete specification and a final product [26]. This happens through reflection-in-action and reflection-on-action. In order to cope with a complex design process, a designer needs to externalize the actual design thinking through representations: sketches, drafts, models, and the like. With the external representations, the designer carries out a dialogue about the design situation and solution ideas. There is an ongoing conversation between the designer and the situation and the representations like sketches, drawings, and so on that can be understood as tools for thinking and as mediators in the dialectic relationship between the vision, the operative image, and the situation [27]. These externalizations help designers to experiment and evaluate their ideas early and cheaply.

A key construct from design theory is the Conceptual Model, which is a high-level description of how a system is organized and operated [28]. A Conceptual Model, also called as mental model is a structure, which exists in people's minds [29]. Design patterns is another example of the externalized mental model [18]. People create mental models of themselves, others, the environment, and the things with which they interact. These mental models come into existence through experience, training, and instruction; and serve to achieve understanding of the world. The designer's mental model as the designer's conception of the look, feel, and operation of a product [30] becomes the shared system image in participatory or co design. Externalization helps to evolve this shared system image [31]. Representing work during system design enable coordination and control of complex, distributed activities. In addition, adapting appropriate representations in the design process could help in bringing together disparate knowledge [32].

All these theories suggest that the externalizing various structures in the design process is recommended and its importance is well known [33]. In the same vein, externalization is explained through the idea of boundary objects. A boundary object is defined as, "an artifact or a concept with enough structure to support activities within separate social worlds, and enough elasticity to cut across multiple social worlds" [34]. Boundary objects bridge the functional knowledge and stakeholder power gaps and have the capability to promote shared representation, transform design knowledge, mobilize for action, and legitimize design knowledge [35].

3 Motivation and Objective of Research

The examples given by Hutchins [6, 15, 16, 18], pertain to relatively short duration activities. For instance, in the example of ship navigation the activities last for a relatively short duration. However, service design comprises a set of interconnected activities that occur over a longer duration and call for tailored DC concepts to enrich its process.

As indicated in previous sections, external knowledge is an essential part of collaboration. Though lot of research has been done in this field, it seems, building a knowledge base has not been studied from a DC perspective. As we understand, DC can be a fruitful framework for understanding how people in a collaborative situation think and act; not because of brain activity alone, but also because of the constant interplay between brains, bodies and situations [26]. External representations play a special role in this interplay, and allow holistic and complex thinking [26]. It appeared looking at DC theories, collaboration and multidisciplinary concepts that tailored theoretical concepts coming from them might be useful in service design, which is a collaborative endeavor.

4 Case Study Observations

While we were evaluating the DC and its applicability in the service design context, side by side the service design project was initiated to reimagine the incentive based employee referral for recruitment in our organization (Called Bring You Buddy—BYB). The aim of this service system was to improve the perception of the service among employees, and facilitate a desirable experience of referral so that the business objective of high-quality recruitment at scale could be met [36]. Instead of the then prevailing almost exclusive focus on the Intranet Web site for BYB, we framed it as 'service' to the employees. We took this opportunity to observe the real life service design process and look for the patterns of DC concepts getting instantiated during the process (Fig. 1). Participants of the multidisciplinary service design team had different areas of expertise with diverse set of knowledge. It was comprised of employees who are the users of the service, service owners, developers of the technology platform used for recruitment and its solution implementers [36]. This service design project was carried out as nine full day workshops over a period of four months, and certain allied activities like data collection done asynchronously. We were looking for interplay and use of externalization mechanism in multidisciplinary team setting for creative activity of service design.

Following are our observations during this service design case study:

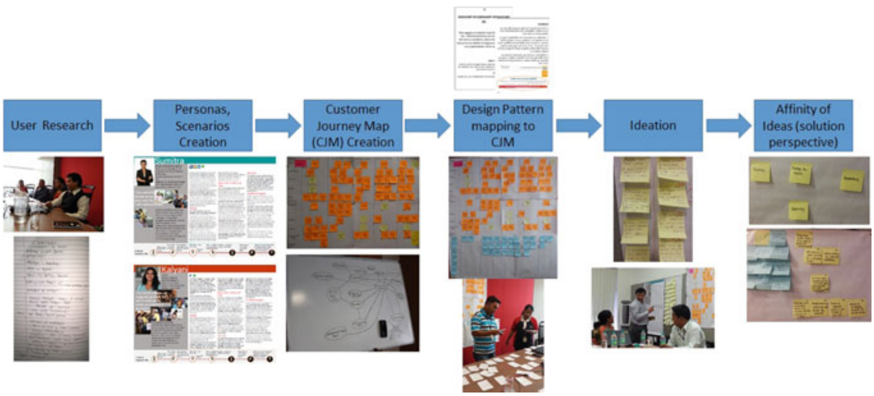

Fig. 1 Externalized representation associated with stages in the service design case study

4.1 Domain Familiarization and Data Collection as Part of User Research

Initially, two external experts and their research associates from a premier design school were sensitized about the organizational services, specifically the recruitment through employee referrals and its challenges. The two of them acted as observers and facilitators. From the DC perspective, the mental structures were externalized using white boards and through presentations to communicate and form a common mental model about the said organizational service across the team. Subsequently, user research activity was planned to discover the service experience goals, contexts and current issues. Semi structured interviews were conducted in various Indian cities—Pune, Mumbai, Chennai and Hyderabad by four different teams. Each team covered average 10 employees per location. These interviews were audio recorded and photographs were taken for future use. During the semi-structured interviews, all interviewers formed their own mental model about the interviewee.

4.2 Creating Personas and Identifying Key Scenarios

The use of personas in the design life cycle is well known [37]. The team developed personas and key scenarios from the user research. As part of the user research, the team observed the users and came out with an understanding about them and their relationships. Together all this knowledge transformed as a structure in people minds, which subsequently reflected into personas as external representations. Due to the participation of the multidisciplinary team during the user research, multiple mental structures (reflecting different understanding by each design team member) were formed about the users of service. Together they arrived at a shared mental structure that is, a common understanding through synthesis. We also observed that the structures were continuously evolving and new structures were formed through an iterative process of discussions and progressive understanding. This resulted into a common understanding that was translated into two personas, which were used afterwards during the design process. From the DC perspective, the team had unconsciously created internal structures, and associated external structures [38] such as field notes during and after the user research. The team arrived at the personas and key scenarios through discussions and use of white boards.

4.3 Creating Customer Journey Map (CJM)

The Customer Journey Map (CJM) is a chart, which describes the orchestrated customer journey by representing the different stages in a given scenario that characterizes the individual's interaction with the service [39]. The major inputs while creating the CJM are the personas, scenarios built during the previous stages and the mental structures of all the team members.

The details of the setting in which the CJM creation took place are worth noting. The posters of the identified personas were visibly displayed at all the time at the workshop/design location while creating the CJM. The agreed upon template of CJM was also displayed on the wall and was made interactive through use of post-its. The CJM evolved through the iterative process where externalized cognitive artifacts such as personas were constantly referred along with the notes taken during the user research and previous workshops. We also observed that arriving at the decision of what knowledge to externalize in the CJM happened through several iterative group discussions and progressive synthesis to reach a common understanding. The externalization of mental structures happened unconsciously, were visible through small activities such as annotating which post-its were interconnected and putting post-it indicating 'intentionally kept blank' to avoid any confusion during future stages of service design (Fig. 2).

It took several full day workshops to arrive at the holistic and complete CJM. Every stage of CJM was captured through photos and in-process artefacts as a mechanism to maintain continuity across multiple workshops. These photos and

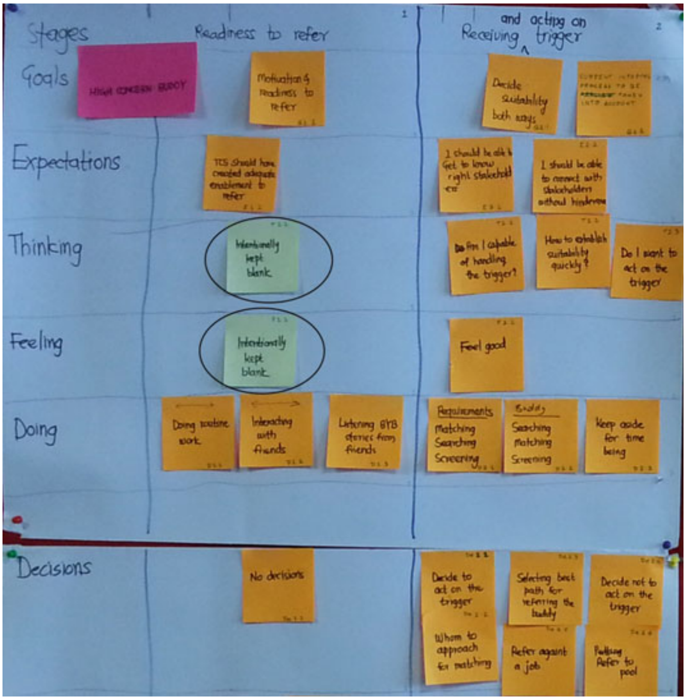

Fig. 2 Use of 'intentionally kept blank'

artefacts carried the mental structure across the workshops and the team could start immediately during next workshop only with brief recap. This helped participants to readily recollect their mental structures, and build on top of them. These observations are not only consistent with the concepts of DC but also strengthen the case of their relevance even when the mental structures need to be carried forward intermittently over a longer period.

4.4 Mapping of Design Patterns to Customer Journey Map

From the DC perspective, pattern language is the previous knowledge and mental structures about solving certain problems along with its creative solutions, which are externalized and made available for future use (Fig. 3). During this case study, the design patterns were shared as physical cards with the team. In addition, the full pattern language was also available as a navigable MS Excel workbook. Thus, two representations of the same externalized knowledge were provided. They were marked as primary and secondary patterns for better understanding [40]. The team associated the design patterns to different stages of the CJM, that is, arrived at a

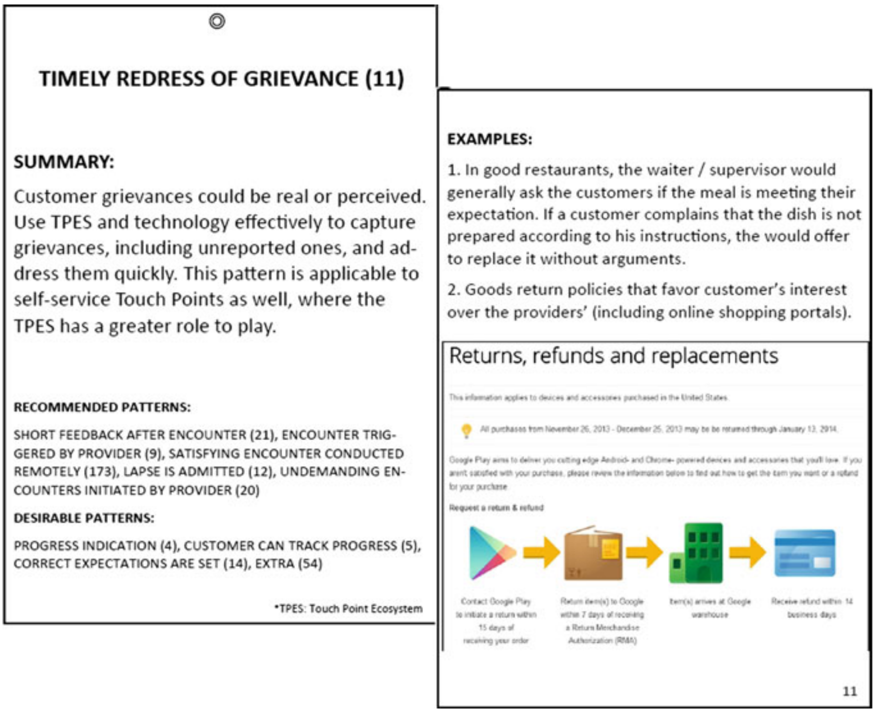

Fig. 3 Sample design pattern card

common structure through verbal exchange with frequent reference to the pattern cards and the workbook. The process led to a rich synthesis of various individual mental structures about the relevance of specific design patterns in the context of the CJM. It was also observed that the mental structure got refined throughout the process and participants sometimes removed the already selected design patterns, added new ones and recorded affinities among the patterns.

4.5 Ideation and Affinity of Generated Ideas

After refined CJM and design pattern association, solution ideas were generated and noted for each stage of CJM and sometimes across the stages. These design patterns triggered the different mental models leading to the discussion for arriving at a common understanding. Single design pattern triggered one or more solution ideas. This ideation process was iterative and the ideas were evolved over a period. Ideation process generated many ideas across every stage. It is very cumbersome to detail out every idea. So it was decided to cluster together the ideas from implementation perspective to make it manageable. Post-its were used extensively during this phase and team members discussed and arrived at the different idea groups and assigned the ideas to that group. Idea groups refined during the entire stage.

4.6 Insights Consolidation and Sharing

All the artefacts created through previous phases along with the individual's understanding helped in consolidating all insights. Consolidated insights, that is, some form of service specification handed over to the solutioning team for implementation. From the DC perspective, the role of specifications is to externalize the mental future state and visualize the future structure. As design is all about future [29], service specifications provided the path from moving the current state to the future state and specifying which mental structure need to accomplish.

4.7 Revisiting the Team to Understand Longitudinal Effect

We revisited this service design team after a gap of six months to understand the participants' experiences after the service design project. During this visit, we refreshed their memory by narrating the overall process along with the in-process artefacts and the actual photographs. These external structures helped them trigger their own internalized metal structures. During the participants' semi-structured interviews, they reflected on their involvement and feelings about the project.

A significant finding was that the participants had successfully internalized concepts and the knowledge gained.

They have been creatively applying and transferring to others the newly acquired cognitive structures ("When I have to convince someone about a design concept, I refer to my notes from the workshop", "Sometimes, when I get a design idea, I look back at what we did and validate it"). It seems that the experience and the structured knowledge helped develop organizational expertise and creativity, where the service design attitude, process and use of pattern language were imbibed in the participants and they were able to practice it regularly. Further, the participants appeared to successfully expanding the boundaries of the distributed cognitive space.

5 Proposed Actionable Recommendations

As explained above, we observed multiple DC concepts in use during this case study and hence we believe that it works and there is a possibility of generalizing it. We suggest doing these activities formally; will improve the overall effectiveness of the service design process. Following are some of the proposed actionable recommendations, which need validation through future investigation. The recommendations proposed seem obvious however reflecting upon the service design process at present, they add value for long temporal service design process spanning across multiple weeks.

1. Reframe the problem statement as a catchy one-liner like "How to an enable organization to act like a magnet." Always displaying it so that all the service design effort is driven towards it.
2. Annotations like date, place and purpose provide the backward traceability to the previously created representations and help refresh mental structures that would degrade with memory.
3. Use of design patterns to learn from the past as well as from other domains.
4. Capture moments like group interactions from various vantage points through photos and annotate it to enhance the overall recall.
5. Focus on synthesis of all information instead of just consolidating would help in arriving at common mental models.
6. Externalize the explicable knowledge during every phase will help to recollect the designer's mental structures during next phases of service design life cycle.
7. Capture the in-process artefacts like sketches evolution along with final artifacts during the service design process to record the mental structure progression.
8. Techniques like replaying of the actions done during service design process would help reflect and refine the artefacts.
9. Maintain the continuity and constant referral of mental structures by displaying all relevant artifacts at the design location.
10. Have diversity of mental models to help in arriving at a holistic design. Multidisciplinary team can provide the diversity of mental models.

6 Conclusion and Future Direction

During this organizational service design case study, we studied how multidisciplinary teams used the previously externalized cognitive structures and in-process artefacts to articulate thought processes, communicate insights, maintain empathy about users, collaborate within the team, and transfer knowledge and learning. In this process, we noticed that the teams iteratively created and worked on the same artefacts representing the shared cognitive structures. These artefacts played a critical role in supporting each other's thought process by transferring and refining commonly held mental structure of problems and solutions, in turn converting them into sharable artefacts. Typically, the nature and representation mapped to the internal structures (for example, in case of personas, the evocative photographs, captions and the "story of their life" mapped to the complex understanding of the behaviors and circumstances; the customer journey map mapped to the broad temporal progression and important aspects at each stage such as emotions and thinking). We observed that team members developed internal mental structures as part of the various phases as well as due to past experiences and knowledge, which got transferred as personas, scenarios, CJM and solution ideas. It was also evident during multiple phases of service design process that the structures were continuously changed and new structures were formed through an iterative process leading to one common understanding wherever required. These synthesized common understandings were then used during the further design process. Multiple in-process artefacts were created along with the final artifacts. Process of harmonizing all these artifacts using DC concepts need further investigation.

We observed the strong evidence of the instantiation of DC concepts during service design process, which is a long duration, intermittent activity. As previously stated, in contrast with short duration focus of Hutchin's and other studies, the service design is a long duration activity and would need an adaption of the DC perspective. We have prima facie support to the relevance of the DC concepts in such a situation as well, which is a new finding. Service design process must recognize the need to deal with several of mental models of participants and incorporate elements to externalize it appropriately after synthesis and apply it effectively as the design evolves. The multidisciplinary team was exhibiting the implicit use of DC concepts during the service design process and would need mechanisms to externalize the internal thought process that is, mental models, harmonizing them and maintaining the continuity across them. Our study has pointed to the likely characteristics such externalizations should have to serve as effective vehicles to support distributed cognition. Iterative development, synthesis of multiple individual mental structures and a form that can be "intuitively" comprehended regardless of the domain of expertise (for example, Persona, Scenarios, CJM and Design Patterns in our case) seem to be the attributes.

This theoretical study and the observations from the study has produced useful practical insights. Even, though they are based on a single case, they are relevant as a new perspective and approach, which can be judiciously applied by practitioners.

We are conscious of the limitations of an exploratory, albeit serious attempt, this study represents. Further investigation to validate and enrich the early insights are needed. This would help to generate knowledge that can make service design process more efficient, rich and handle challenges of multidisciplinary settings. Clearly, further investigation and validation in various multidisciplinary settings and service domains is called for. A study in which several kinds of knowledge artifacts from different disciplines (for example, service design patterns and software design patterns), domain specific standard representations (for example, flow charts) and structures created during the design process get integrated can be expected to throw rich insights. Another interesting area relevant for theory as well as practice is the observed phenomenon of participants internalizing and propagating the newly acquired cognitive structures (see Sect. 4.7) over a period as well as in new situations. How this happens, what supporting processes are needed and what kind of externalizations can help can be an interesting direction to study further. In spite of its limitations, we hope that this study will serve as the starting point of discussion around distributed cognition concepts and its implication in the service design process.

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From Design Thinking to Design Doing—A Procedural Approach Creating Socially Responsive Artifacts—A Case of Designing Towards Affordable Dental Care (for India)

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Abstract This paper aims to promote discussion that inquiring through visual stimulation like prototypes add a new dimension to designing socially responsive artefacts. The social challenges are complex in nature and demands for creating responsive artifacts for addressing these issues The research promote discussions on the role a designer should adopt so as to establish desirable elements and attitude that respond to social design challenges. These attitudinal elements could work in addition to the existing tools and methodologies and may add to the process of co creation and design innovation. This research suggests that the designer should be working with the user on same plane for optimal development of a new approach. This framework was put to test and applied through industry sponsored social innovation challenge. The challenge was to "Design for affordable dental care for Indian masses". A low cost dental chair was developed through this action research (How design-based research and action research contribute to the development of a new design for learning. Designs for Learning 4(2): 8–27 [1]). This paper focuses on the elements that model the role of the designer and impact of protecepting that encourage behavioral change. We describe "protocepting" as a tool of visual thinking among designers, users and clients to gain first hand experience of the existing and desired conditions. We illustrate value of protocepting in critical design research activities.

The typical type socially driven innovation considered is a design innovation that is aimed to make dental care facility affordable for Indian masses.

Key elements of the approach that has been developed include: acknowledging user input, and building prototypes to test at the earliest.

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- Understanding existing scenarios.
- To develop a change in existing scenarios.
- To communicate design ideas/changed user interface.

Keywords Protocepting · Prototypes · Co-creation · Dental care · Design research · Dental chair

1 Introduction

India has also become increasingly popular as a destination of medical tourism. The primary reasons being high quality of medical treatments are available here at a very reasonable cost, the use latest technology and equipment and world-class medical professionals. With the efforts put forward by the Union Government of India and the State Governments, healthcare is now primary requirement and is accessible alike to rich or poor, urban or rural. Amid all these developments in healthcare, Dentistry in India has struggled to keep up with the pace and it still has a long road to travel. As the numbers suggest, For a population of over 1.2 billion, there are currently over 180,000 dentists, which include 35,000 specialists practicing in different disciplines in the country. The dentist population ratio is reported to be 1:9000 dentists in metros/urban and semi urban areas and 1:2,00,000 dentists in the rural area. There are more than 35,000 dental specialists in different disciplines. The number of dentists is expected to grow to 300,000 by 2018 and the dental specialists to 50,000. Every year more than 24,500 dental graduates are added to the list [2–4].

1.1 Identification of the Problem Area

Dental issues in India can be considered more of a social technological and cultural phenomenon rather than just a healthcare problem. Lack of awareness for oral hygiene and most importantly systemic infrastructure deficiencies prevent proper screening and dental care of oral diseases. The consequences of widespread poor oral health can be seen on the personal, population, and health systems level and deteriorate individual health and wellbeing, decrease economic productivity, and act as significant risk factors for other systemic health ailments. This wide spread problem raises a curiosity for a designer to develop infrastructure that is functional and affordable so that it can be made accessible for mass population in India. This paper is focused on development of a low cost[1] dental chair while applying tools of design thinking through out the research and development process.

[1]Low cost in the this research used only for cost comparison and not for quality.

1.2 Understanding the Context of the Problem

The current dental scenario in India involves a number of stakeholders and each of them has their own priorities towards an ideal dental system.

The major stakeholders are:

1. Dentist
2. People (Patients)
3. Government
4. Institution (hospitals) and Non-Government Organizations
5. Manufacturers.

For reaching an effective solution to any problem, it is imperative to understand the users and stakeholders involved with the problem. The user centric design process drives the research keeping the user of the solution as the prime member of the research. It was observed and identified that the critical point is that people in India are not going to the dentist and it could be a problem of transportation, awareness, fear or money, lack of resources etc. and it required in-depth research of the problem to further refine the problem.

1.3 Primary Research for Researchers Standpoint

Understanding the problem and user in its context is of foremost importance and field research often shows a clearer picture of the context of the problem. For building a better dental system in India several field visits were conducted to understand the environment of the problem and to judge the scope of improvement.

Field research[4] was majorly conducted in Kanpur and Lucknow, Uttar Pradesh, India at:

Rama Dental College, Kanpur.
Sardar Patel Post Graduate Institute of Dental and Medical Sciences, Lucknow.
Lala Lajpat Rai Hospital, Kanpur. and
Several Private Clinics in Lucknow and Kanpur (Fig. 1).

1.4 Understanding Needs with the User

For understanding the specific point of view it was identified, whom to talk with, how to generate empathy [5] and recollect stories. Empathy is one of these relevant tools. Empathy is addressed by exploring two main aspects, the emotional and the cognitive. To generate empathy and recollect stories one has to converse with the users in context and observe them very closely. To have better information, it is

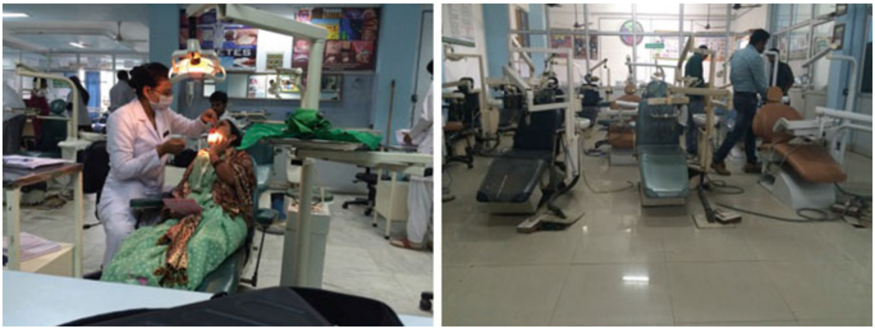

Fig. 1 Images from field research

essential to find the appropriate people to talk with and to pay attention to all parties involved is fundamental for the investigation; these could include gender, social classes and ethnicities. Following the above, the extreme users were identified by excess and absence. Excess users are those who would use the service a lot, for example, patients recovering or patients under a treatment and that are able to afford treatment with the dentists in contrast absence users are those who would not use the system much, for example, people that live in remote areas and do not have access to dental service and those who can nor afford the treatment. Also identified were the experts, which can present detailed information like dentists, chair producers and patients. Dentists gave a clear idea that a dental chair is the most important medium in the dental treatment and what are the shortcomings of the existing system. Speaking to manufacturers gave important insights for the project, about effective manufacturing and defining the main functions in a product.

2 Research Summary

Before moving on to the conceptualization and prototyping stage one must define the need statement, which directs the further development of the project. Understanding the problem during research reflected a clear vision about the problems to be addressed and different touch points of the solution. Dental system in India affects an extremely large set of masses and it is necessary to judge the scope to he project beforehand. The major touch point and requirements of the system are indicated. Looking further into the problem it was identified that the over all poor oral and dental health of Indian masses were majorly due to cultural notions and dietary habits. Also the lack of infrastructure and support from the government coupled with transportation and cost play a pivotal role in making dentistry accessible to the every Indian. Making dental facility accessible to mass population in India requires design intervention in two key areas. First in providing low cost solutions to dentist and government so that it can reach the audience in greater numbers and secondly to build a stronger infrastructure and to motivate people towards dental care.

2.1 Purposes and Aim of the Research

The purpose of this study is to investigate the influence of Design thinking approaches on social innovation [6] in Indian context, with focus on dental healthcare scenario in India. The research explores, from a practice perspective, ways of staging visual design thinking activities in social innovation spaces, posing the argument that designing for socially responsive artifact in developing country like India is designing between boundaries of utility and beauty, and can design thinking help in reconfiguring these boundaries. The main audiences of this research are design researchers, firstly those working with social issues, secondly researchers in other design disciplines, and thirdly those in the borderlands between design practice and design research.

3 Research Method—A Designer's Toolset to Innovate

To address this complex challenge we needed to adopt methodology that can help in enhancing the voice of all the stakeholders at the same time. We looked at the different approached of participatory research. However Stanford Design Innovation process provides a canvas and framework to build and reflect quickly on the ideas we create and engage stakeholders at every touch point. Stanford Design Innovation Process is applied in ME310, a project-based design-engineering course at Stanford University. It is a course where students must design a complete system while being mindful of not only the primary function but also the usability, desirability, and societal implications. Throughout one academic year, student teams prototype and test many design concepts and in the end create a full proof-of-concept system that demonstrates their ideas. The design process in ME310 is cyclical. By going through the process multiple times, not only does it maximize student learning, it maximizes project insights for the student teams. "Fail early and fail often so you can succeed faster," is one of the mantra for ME310 [7, 8] (Fig. 2).

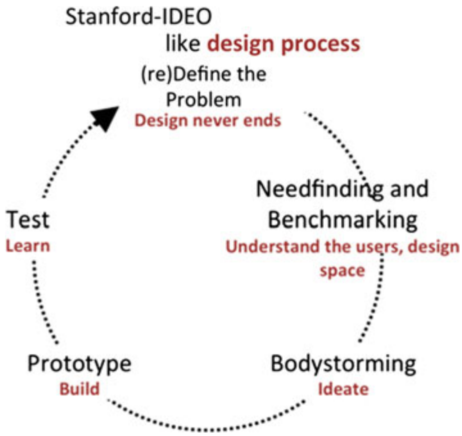

Fig. 2 Typical example of stanford design process

3.1 Learning by Doing Through Different Stages of Prototyping

We followed Stanford's ME310 design research methodology lays emphasis on learning by prototyping. The problem is addressed in the research phase 4 and the solution is derived from different types of prototypes. Each prototype takes on critical questions related to the problem to come up with a possible solution and prototypes are improvised at each stage to reach a final solution. Each prototyping stages brings on new insights and constraints hence deriving the best possible solution [7, 9, 10]. The various stages of prototyping are as follows:

Critical Function Prototype The team finalized on flexibility in seating as the most critical function as to help the patient for comfort and helps the dentist in accessibility (Fig. 3).

Dark Horse Prototype The critical question here evolved to "Can we make the reach of dental facility to last home in India." To answer this two prototypes were developed (Figs. 4 and 5):

3.2 Researchers Standpoint and Redefining the Need Statement (Problem Statement)

After the completion of first two prototypes and insights generated from them, It was identified that most critical component of the dental system is the dental chair and it is highly impossible to conduct a treatment without the dental chair, though through other means the reach can be extended in areas where dental care facilities will still take some time to penetrate. Also keeping the cost as a major factor in the

Fig. 3 Images from critical functional prototype

Fig. 4 Inflatable accordion bed: an airbed with an accordion like structure where volume of air controls the recline of the bed

final solution to benefit both of our personas and bring the cost of the treatment down. Redefined need statement:

> Making Dental Facility Accessible to Mass Population In India: Designing a Low Cost Dental Chair for India

Product Analysis The key components in a dental set-up are:

1. Dental Chair: For patient. 2. Dental Tools: For treatment. 3. Dentist Stool: For dentist 4. Light: For illumination in the oral cavity. 5. Spittoon or Suction: For rinsing and spitting thus cleaning mouth.

Fig. 5 Dental suit: an exclusive suit for a dentist, that has all the components that can be worn by the dentist; it is a take away from the astronaut's suit. E.g. the glove can have functions of light function and all tools are embedded in the glove or suit itself

Problem Identified in existing dental chair

- The base is kept heavy to balance the bulky structure.
- Only for right handed dentist.
- The overall aesthetics of the chair is too bulky and intimidating.
- The instrument panel, light and spittoon surround the patient from all sides creating a trap.
- Instrument panel is nearer to the patient than to the dentist.
- The spittoon is fixed and the patient has to get up overtime for spitting.
- No neck support for patient.
- Backrest intrudes with dentist working space.
- Unnecessary bulk added to the light.

All these problems cumulatively create a bigger problem of perception of dental treatment as fear in patient's mind. Unnecessary use of material inflates the cost. Moreover it is only suited for right handed dentist, left handed dentist need to custom build their dental chair which can not be used by right handed dentist. The current chair gives no scope of modularity or portability. It takes huge amount of space and increases the working area. The spittoon remains a major pain point for elderly as the patient need to get up and spit number of times during the treatment. With the long base, getting on and off the dental chair itself becomes a difficult task. The lack of neck support creates difficulty for patient during the treatment.

FUNK-tional Prototype (FUNKY) The design team did this prototype by dismantling the existing dental chair and tried to relocate the components of the dental set-up to explore its feasibility and ease of use for the dentist and patient. Major design interventions in relocating the functions were as follows:

1. **Tray**: Relocating it from the dental chair to the dentists stool, so as the tools are close to the dentist and more accessible.

Fig. 6 FUNK-tional prototype

2. **Spittoon**: The idea behind the spittoon was that as per observation, the older people have difficulty getting up and reaching it to spit in it. It also causes back pain for the patients. So making the spittoon reach the patient instead of patient reaching the spittoon, by using a spitting bowl with a retractable mechanism so that you can pick the spittoon and bring it closer to your mouth, after which it goes back to its original position.
3. **Light**: Thoughtful reduction in the arm of the light to remove the clutter and also increase the maneuverability of the light arm. The prototype shows the mechanism similar to the ball and socket joint in the arm (Fig. 6).

Functional Prototype one: Based on our insights from the funky prototype, the functional prototype needs to be an improvised version of the same prototype to make it testable for dentist and patient (Fig. 7).

4 Final Prototype of the Proposed Dental Chair

The final prototype is the closest prototype for the mass manufacturing of the product. Though minor alterations are often done on final prototypes before manufacturing but it has to function like a real product in real scenarios. Taking all the positives from previous prototypes the final prototype of the dental chair included the following:

- Retractable spittoon
- Flexible light
- Neck rest
- Synchronized movement for back and leg support (existing on high end dental chairs)

Fig. 7 Images from functional prototype

- Horseshoe shaped head rest
- Modular instrument trolley
- Horse saddle dentist stool (existing) (Fig. 8).

4.1 Final Product Description

The final dental chair is an improved dental set-up, which is, designed taking into consideration the various aspects and problems of existing dental chairs. It addresses the needs of the major stakeholders i.e. the hospitals, The dentists, The patient and the manufacturers. Reducing the cost of dental setup so that the dentists can setup the facility in larger frequency in Indian villages, since the cost factor is much less does this. The final prototype costs about 20,000 where the cheapest Electric dental chair available in India is about 60,000. So since the cost is reduced, more number of dentists can afford to setup a clinic in rural India, which also increases the accessibility to these dental facilities.

The Dental chair showcases innovation in many aspects.

1. Synchronized movement of leg and back supports
2. Neck Support pillow
3. Head rest with a hole for women with buns and pony.
4. Bluetooth Speaker for entertainment and engagement.
5. Instrument tray and trolley away from the patient and closer to the dentist. It adds to modularity as well, as it is asseverate unit and can be carried
6. Spittoon in a cup form adds to ease of access and solves the problem of getting up many times during the treatment. The suction keeps it clean.
7. Flexible light arm and battery operated LED light to provide ample illumination for the treatment (Fig. 9).

Fig. 8 Images from user testing

Fig. 9 Final prototype of dental chair

Fig. 10 Images from user testing

4.2 User Testing

The dentist at Sardar Patel Post Graduate Institute for Dental and Medical Sciences, Lucknow did final user testing, with real life patients with real dental problems. The features of Dental chair were tested with multiple doctors from various departments of dentistry and with patients from various age groups (Fig. 10).

5 Conclusions

This project addresses to a socio cultural problem in a very specific context. The scale of the implementation due to the massive population in India posed challenges to the feasibility of the solution. The dental chair developed in the end proves that small design interventions can help the bigger causes. Personally, there has been immense learning from this project and throughout the project timeline there was always something, which kept us on our toes. Understanding dentistry in India with a critical eye has been a great experience and it has shown a new perspective towards healthcare in India. Few major takeaways from this project are discussed further:

5.1 Product Development Process

The product development process typically consisted of several activities that answer the complex process of delivering new products to the market. The project went through a series of stages from ideation through design, manufacturing and testing. The development process basically had three main phases:

1. Fuzzy front-end development, which had the set of activities, employed before the formal and well defined requirements specification is completed. Requirements are a high-level view of what the product should do to meet the perceived market and user need.

2. Product design is the development of both the high-level and detailed-level design of the product: which turns the requirements into a specific how this particular product will meet those requirements.
3. Product implementation is the phase of detailed engineering design of mechanical or electrical hardware, as well as of any test process that may be used to validate that the prototype objects actually meet the design specification and the requirements specification that was previously agreed to.

The next step could be the Fuzzy back-end or commercialization phase, which will represent the action steps where the production and market launch occur.

6 Future Scope

The final output of the project has opened various avenues in the field of dentistry. A new range of dental equipment's can be developed the research results. Since project is still in the developmental stage where a working prototype was made, more clinical testing is required which helps in fine-tuning the dental chair before mass production. More users testing at various geographic regions are needed to collect valuable data about the use of the product. The product life cycle is to be taken into consideration. A good public campaign is needed to spread awareness about dental system in India. A side-by-side comparison with its nearest competitor can yield critical analysis and establish a benchmark. In near future since the cost of the setup is much lower, the government can install more number of setups in rural areas for masses to avail dental care. Also unemployed dentist can take these setups to open their own private practice at a lower cost.

6.1 Product Scope

In future, there could be better versions of this chair with technological interventions like the light can be connected with kinnect sensors and a camera to detect the mouth and automatically move with the patient to allow touch free operation. The modular design of the chair also allows each part to be customized as per specific requirement like the instrument tray can be made portable with a suitable packaging for emergencies.

6.2 Cost

One of the primary target of the project was to bring down the over all cost involved in the system. With our efforts we have been able to bring down the cost to nearly

1/3 of the current cost. The cost of the chair is INR 20,000 (Approx.), in mass production we expect the cost even go down. We have currently used mild steel and fiberglass for the basic structure and stainless steel, foam and PU Fabrics for components. In manufacturing we want to try the structure with aluminum and alloys to further reduce the weight of the chair. Logistics is one major factor for getting the cost down as smaller overall dimensions allow the dental chair to be shipped in a smaller packaging thus saving a substantial investment.

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Collaborative Research Model for Designing Sustainable Water Usage Solutions

Gareth Loudon, Clara Watkins, Angelo D'Onofrio, Huw Hopkins and Elora Ancelot

Abstract The paper describes the process followed and the insights gained from a collaborative design project between design students in the UK and in India. The aim of the project centred on the design and development of new sustainable water solutions for users in both Ahmedabad and Cardiff. Reflections are given on the benefits and drawbacks of using such a collaborative design research model in terms of developing culturally appropriate solutions for two contexts of use; the effectiveness of prototyping and user testing remotely; and the benefits and challenges of undertaking a design research collaboration.

Keywords Design thinking · Human-Centred design · Collaboration · Sustainability · India

1 Background

One of our main areas of research interest relates to culturally appropriate design and exploring how collaborations between different countries can lead to innovative solutions for both countries. Previously we undertook a large-scale research project developing appropriate medical solutions in Zambia with the people from different communities in Zambia being actively involved in the design and development process [1, 2]. One of the major outcomes from the research project was the development of a low-cost First Responder Trauma Pack that is designed to treat victims of road traffic accidents (a major issue in Zambia). The solution developed was also trialled with paramedics in the UK and feedback from the paramedics suggested that the solution would also provide benefits in the UK over existing solutions. As a result of the research project we developed a set of guidelines for

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future research projects based on a parachute design approach [3] together with IDEO's Design Thinking model [4, 5].

This paper describes how this approach was explored further in a collaborative research project between design students at the Cardiff School of Art & Design (CSAD) in the UK and the National Institute of Design (NID) Ahmedabad in India where the students were asked to create new design solutions for sustainable water usage.

2 Introduction

As part of the MSc Product Design course at CSAD, students have to study key aspects of the Human-Centred Design (HCD) process [6, 7] including rapid ethnography, design issues for sustainability, and user testing and evaluation techniques. From January to March 2016 the CSAD students were set a project on sustainable water usage where the overall aim for the project was to design and develop a new and improved, low cost, washing and/or cleaning solution where ecological considerations such as water re-use, grey water management, and purification processing were considered. The target market for the solution could be either domestic or commercial, but had to meet the needs of target users in Ahmedabad, India and Cardiff, UK. One of the main motivations for asking the students to design for users both in Cardiff and Ahmedabad was to see if insights gained from the design research in Ahmedabad resulted in new solutions for users in Cardiff. They were also told that their final design solution must be desirable, functional, low cost, sustainable and have a clear target market.

As part of the project the CSAD students spent the first week of February in Ahmedabad, India conducting field research together with product design students at NID to gain insights into current methods of washing and cleaning in domestic and commercial contexts in Ahmedabad. For the remainder of the project the CSAD students were back in Cardiff designing, prototyping and testing a range of concepts.

This paper initially describes the design process followed throughout the project including the field research undertaken and insights gained in Ahmedabad, and the design, development and user testing work undertaken by the CSAD students back in Cardiff. The paper concludes by reflecting on the benefits and drawbacks of using such a collaborative design research model in terms of developing culturally appropriate solutions for two contexts of use; the effectiveness of testing concepts and prototypes remotely; and the benefits and challenges of undertaking a design research collaboration between design students from two different institutions based in the UK and India.

3 Design Process

There are various design processes to consider when conducting a design project, however the most commonly used design processes place the end users at the centre of the process [8] so that their needs, desires and context help inform the generation of new solutions. Common design processes include Human-Centred Design [6], Participatory Design [9] and Contextual Design [10]. Design Thinking is a HCD process developed by Kelley and Kelley [5] at IDEO that highlights the importance of balancing three factors when creating new concepts: desirability (human factors), feasibility (technical factors) and viability (business factors).

Donaldson [3] argues that the design process should take place in the intended environment of use, rather than undertaking "parachute design (design from afar with visits)" due to the lack of "comprehensive customer involvement and ready access to the environment". However this was not a viable approach for this project due to the costs of all our students staying in India for a long period of time. In addition, our students had to develop a solution for the needs of people in Ahmedabad, India and Cardiff in the UK. Our approach was therefore to follow the parachute model of design but combine that with a Design Thinking approach and a close collaboration with design students based in Ahmedabad, India to try and increase customer involvement and to gain ready access to the environments of interest. In a further effort to overcome some of the challenges of parachute design and development, the students were also encouraged to conduct user testing of their prototypes in CSAD's Perception Experience Lab (PEL). PEL is a synthetic reality facility that creates realistic simulations of environmental and social settings, through vision, directional sound, smell, air movement and temperature control.

3.1 Design Thinking Process

The design thinking process described by Kelley and Kelley [5] has four main stages:

1. Inspiration—encourages the designer "to go out in the world and proactively seek experiences that will spark creative thinking." One of the common techniques used in the inspiration stage is rapid ethnography [11] with the aim of "connecting with the needs, desires and motivations of real people" to help "inspire and provoke new ideas". Ethnographic research methods include observation, participation, dialogues with end users and local experts, group interviews and story gathering.
2. Synthesis—focuses on the need to "recognise patterns, identify themes, and find meaning" from the data gathered during the inspiration stage. This stage helps to reframe the problem, provide focus and extract key principles and frameworks.
3. Ideation/experimentation—is about "exploring a range of ideas without becoming too invested in only one". This stage is about rapidly prototyping

ideas and getting feedback from end users and stakeholders. Through an iterative process of prototyping and user testing what emerges are "workable solutions".

4. Implementation—is about refining the design and preparing "a roadmap to the marketplace".

3.2 Secondary Research

Our CSAD students were given their project brief in January 2016, and before travelling to India at the beginning of February they conducted secondary research into the history and traditions of the Gujarat region of India. They also looked into differences in terms of water access and usage between India and the UK and the latest technologies being developed globally in relation to water re-use, grey water management, and purification processing. Other areas studied included socio-economic data and the different industries/sectors dominant in Cardiff and Ahmedabad.

3.3 Field Research

A key part of the project was the weeklong trip to India at the beginning of February as part of the inspiration stage of Design Thinking. The aims of the trip were to gain an understanding of the current methods of washing and cleaning in domestic and commercial contexts in Ahmedabad, and to gain an understanding of the cultural context including peoples' beliefs, values, needs, desires and motivations. To aid these aims, and to minimise the problems associated with parachute design, the CSAD students teamed up with product design students at NID. Each team comprised of two students from CSAD and two students from NID. After an initial team-building activity on the first morning, the teams went out and conducted the fieldwork together. This approach had several benefits for the CSAD students. Firstly, the NID students had been briefed on the project beforehand so had already gathered some initial insights and planned key places to visit. Secondly, language and cultural barriers were reduced when conducting the field research. Thirdly, students from CSAD and NID could share their different insights and ideas, and fourthly, the NID students knew the best ways to travel to the different places of interest.

The ethnographic research approach taken for the fieldwork included observing people's behaviours in terms of the tools, technologies and materials they used; the cultural context in which they worked; and the mode of community involvement in washing and cleaning. The students collected a range of stories and insights through dialogues and observation, and documented their research findings through field notes, photographs, and audio and video recordings. Places visited by the students included commercial laundry cleaning facilities, train and car washing operations, restaurant kitchens, traditional and modern homes, temples, as well as manufacturing sites including bamboo manufacturing, paper recycling and pottery production (for water storage). Some examples of the photographs collected during the fieldwork are shown in Figs. 1 and 2. During the field research the students were also tasked with collecting data to facilitate the creation of a simulated environment in PEL when back in Cardiff for user testing purposes e.g. scents, audio and video recordings, clothing, photographs etc. Note that all participants in the study gave their consent for photographs to be taken.

The last day in Ahmedabad was spent at NID where all the teams got back together and shared the stories and insights gained from the fieldwork. This workshop was the first part of the synthesis stage of the Design Thinking process to try and "recognise patterns, identify themes, and find meaning" to the data collected (see Fig. 3). Key insights from the fieldwork included the use of locally sourced materials for cleaning and washing, such as terracotta pots for water storage to keep water cool, the sustainable use of bamboo, the use of coconut husks for scrubbing, the use of activated charcoal and copper for water purification, and cow dung for fuel. The fieldwork also highlighted many examples of what is known as Jugaad Innovation [12]—the ingenuity that people show to fix and improve solutions in a

Fig. 1 Photograph taken of industrial cleaning in Ahmedabad, India

Fig. 2 Photographs taken of cleaning and washing methods in Ahmedabad, India

Fig. 3 Photographs from the idea generation workshop at NID

resource effective way. However the research also highlighted problems that needed tackling including untreated water going into the sewerage, the use of strong chemicals for cleaning, plastic waste used as fuel, high water usage, and the access to fresh drinking water.

3.4 Design, Development and User Testing

Back in Cardiff the CSAD students conducted further field research looking at different contexts in Cardiff and further synthesizing the data collected. They then moved onto the ideation/experimentation stage of the Design Thinking process. Based on analysis of all their research work, they developed their concepts using an iterative process of prototyping and user testing. The students initially started exploring a range of concepts through sketch development. Some of the concept ideas and sketches developed by the students are shown below in Fig. 4.

The students were encouraged to gain feedback on the desirability, feasibility and viability of their concepts from the NID students back in Ahmedabad as well as from fellow CSAD students. The students then chose a selection of these concepts

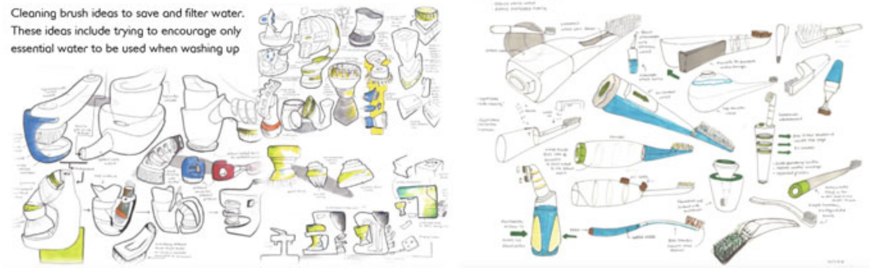

Fig. 4 Concept sketches of water filtering, water re-use, and solutions for brushing teeth with fresh drinking water integrated into the product

for further development. Low-fidelity prototypes were developed and tested to gain further feedback on the desirability and feasibility of the ideas. Further research was also undertaken into options for materials and manufacturing options to gather additional information of feasibility and viability. Some examples of the initial low-fidelity prototypes are shown in Fig. 5.

Some of the user testing of the prototypes was undertaken in our simulation environment (PEL) in CSAD, where different environments seen in Ahmedabad as well as in Cardiff, were simulated with the use of panoramic background photos and audio recordings taken during the field research. Figure 6 shows two photographs of user testing taking place in PEL where users are interacting with a low-fidelity prototype and undertaking a set of prescribed tasks, whilst also wearing authentic clothing worn in the Gujarat region of India. User testing in this simulated context was undertaken for two main reasons: firstly, because context can affect how people interact and respond to a product or prototype [13]; and secondly, because it was not possible for the students to test their prototypes in the real context in Ahmedabad.

After developing initial low-fidelity prototypes, the students developed more functional working prototypes for user testing. For example, the four prototypes

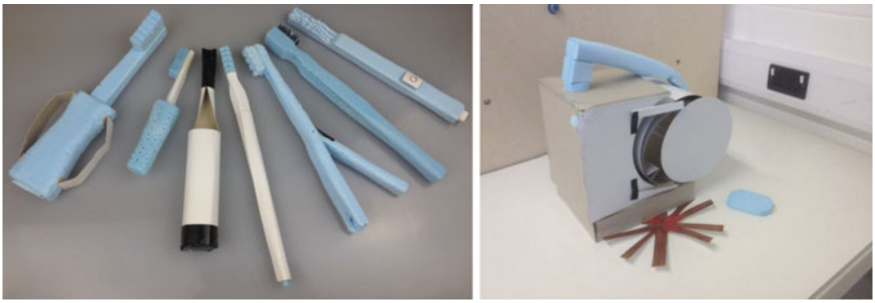

Fig. 5 Examples of initial low-fidelity prototypes created

Fig. 6 User testing in a simulated context

shown in Fig. 7 were tested in the real context of use (at homes in Cardiff) in four weeklong trials to gain data on overall desirability and feasibility. The students also conducted further research into the feasibility and viability of their solutions in terms of material and manufacturing costs.

At the end of this iterative process of design, development and user testing the students presented their final product ideas. Examples of two of the products created are shown in Figs. 8 and 9. Figure 8 shows the design by Angelo D'Onofrio of a

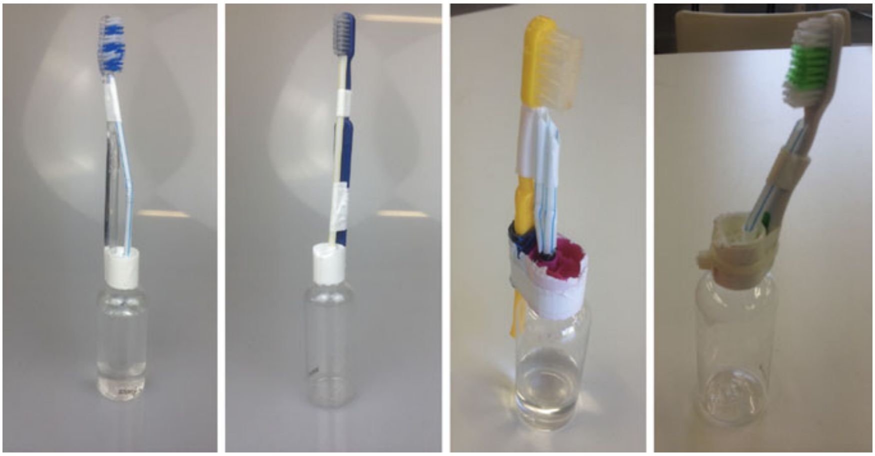

Fig. 7 Four functional working prototypes used for a weeklong trials in context

Fig. 8 Sustainable water storage bottle with active filter

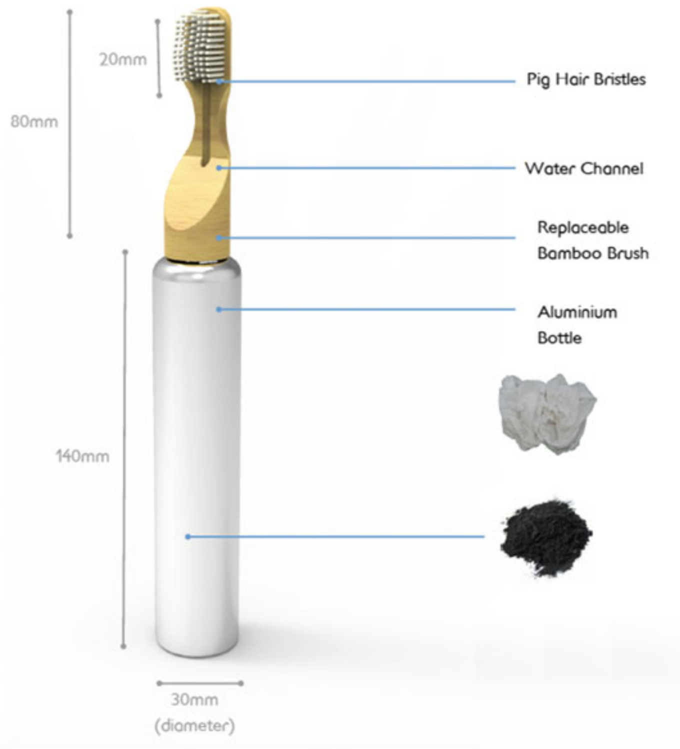

Fig. 9 Sustainable water saving toothbrush with active filter

water storage bottle made from glass and stainless steel. The design, targeted at markets both in Cardiff and Ahmedabad, seeks to give transparency to consumers in the elements that filter water, to tackle the idea of perceived obsolescence and plastic packaged replacement filters. The aim was to create a product that can last a lifetime, be infinitely recycled and gives the user control over the consumable elements. It uses activated carbon made from bamboo and anti-bacterial copper to filter the water.

Figure 9 shows the design by Huw Hopkins of a sustainable water saving toothbrush made of aluminium, bamboo and pig hair, which reduces water usage to just 100 ml. It uses activated carbon made from bamboo wrapped in a cloth for water filtration. Again designed for people in Ahmedabad and Cardiff, including UK tourists to India.

4 Reflections

At the end of the design process the students and staff reflected on the design process followed and the benefits and drawbacks of using such a collaborative design research model in terms of developing culturally appropriate solutions for two context of use; the effectiveness of a parachute design approach; and the benefits and challenges of undertaking a design research collaboration between design students from two different institutions based in the UK and India.

4.1 Research Collaboration and Parachute Design

Overall the feedback from the CSAD students suggested that the collaboration with the NID students worked very well in terms of mitigating problems traditionally associated with parachute design. The collaboration provided ready access to the environment as well as customer involvement while in Ahmedabad. For example, one of the CSAD students highlighted that "the knowledge of the [NID] students was essential in making the trip a success". Other positive comments related to the way the fieldwork was structured—"I think pairing up with NID students worked well because they had done a lot of research already (with regards to locations etc.) and so we were able to conduct a lot of research in a short space of time". There were some language barriers between some of the NID and CSAD students but this did not affect the work in any significant way.

The workshop at the end of the field trip also got positive responses as it was seen as a good way of sharing all the findings gained by all the teams and a way to highlight the key themes and issues.

The CSAD students saw advantages and disadvantages of coming back to Cardiff to undertake their design, development and user testing work. Some of the positive comments related to being in a "comfortable and familiar environment"; having access to the facilities they knew well; and having a chance to quietly reflect, as the fieldwork in India had been a "big culture shock" for some. However the user testing of prototypes in Cardiff that were meant for people in Ahmedabad was highlighted as problematic. Even though the NID students and CSAD students stayed in contact online, gaining valuable feedback remotely was difficult. This was partly because the NID students were not continuing with the design part of the project themselves. As a result, the CSAD students were unable to confirm the suitability of their developed solutions to one of the intended environments of use, Ahmadabad, India. However the CSAD students did comment that they would be sending their final design ideas to the NID students to get feedback. In addition, the use of the simulation environment (PEL) in CSAD for user testing seemed to have limited benefit above and beyond testing in a normal studio environment. Students reflected that this might have been due to the nature of the project. However it might have been more to do with an understanding of how to setup and use the space effectively. Another reason was the problem of getting access to people for user testing who had experience of the Gujarati culture and who understood the context created—most students ended up using local people for testing, which was not the target user when trying to see the suitability of their designs for Ahmedabad. Finally, the tight time constraints of the project and the extra time needed to setup the simulated environment in PEL also had an affect.

4.2 Designing for Two Cultures

Generally the students found it difficult to try and design for people in Ahmedabad and Cardiff at the same time. As a result of the ‘overload’, some students focused on one context more than the other. Other students took the strategy of gaining inspiration from the trip to India in terms of using different materials, or designing for people from the UK travelling to Ahmedabad. On reflection, it might have better to ask the students to only design a solution for people in Ahmedabad initially and then reflect on the design’s suitability for the UK (as we did in our studies in Zambia [1, 2]).

5 Conclusions

Overall the approach taken of using a parachute model of design, combined with a Design Thinking approach, and a close collaboration with design students based in Ahmedabad, India did mitigate some of the problems associated with parachute design, mainly due to the insights gained from the collaborative fieldwork. The structure of the collaborative fieldwork worked extremely well even though the CSAD students were only in India for a week. We would therefore recommend such an approach to others. However the design and development stage back in Cardiff had some problems. This was partly due to designing remotely, but also because the NID students were not directly involved in this stage of the work. We would recommend that collaborations should cover the whole design project not just the initial stages of the field research. The use of the simulation environment in CSAD (PEL) to try and overcome some of the challenges of parachute design and development had limited success. Therefore this area of work needs further investigation. One recommendation would be to provide more time and training for students in terms of how to setup and conduct user testing in simulated environments. In addition, the challenge of designing for two cultures at the same time proved difficult and perhaps a future strategy would be to focus on one context first.

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Design Intervention in the Handloom Industry of Assam: In the Context of a Debate Between Traditional and Contemporary Practice

Umme Hani and Anusmita Das

Abstract Handloom sector of Assam is one of the oldest as well as important sectors of this region. In Assam it is mostly accomplished as a home based industry. Hand-woven textile is practiced here both for commercial as well as domestic purpose. Apart from economic importance, the handloom and textile culture is also a part of traditional belief and practice. With the phase of time, the commercialization of traditional hand-woven textile has taken place. It has helped the weavers in earning a better livelihood and also in popularizing this craft. The textile craft has gone through some changes in modern context, like the design of the fabric, its development and also marketing. If we look into the current scenario, young designers, entrepreneurs, non-governmental and governmental organizations etc. are playing different roles in shaping this system. But it is really very important for us to understand about the benefits gained by the weavers. How is it actually helping the weaver's community? Is it going to affect the cultural identity of the textile craft? How is it helping in economic development? The aim of this study is to answer certain questions, which are very important for a designer to understand before he/she performs any activity in this particular field. It is about knowing the importance of certain cultural elements. Designing is about improvising but it is important for a designer to retain the cultural identity of a product before bringing any changes. It is about understanding the current scenario regarding the contemporary practice of the handloom industries in Assam.

Keywords Handloom · Textile · Contemporary practice · Design · Cultural identity

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1 Introduction

Assam is a land of mixed culture, tradition and tribe, which in return provides this state the beautiful gift of wide range of Handloom and Handicraft practice. Handloom has always been the most striking feature of this land, which provides an extensive collection and variation of Textile products. The local weavers and artisans of a particular locality have kept these traditions alive.

The History of Assamese Handloom and Textile culture have seen many changes. In the contemporary Scenario, where various keywords like, economic viability, skill, expertise, marketability etc. holds importance, its is essential to include these keywords in the framework of handlooms and handicrafts too. Intervention of Design actually plays a vital role here by contributing additional value and improvising the competency of the handloom industry. The above contribution ascends various types of arguments and questions related to Designer's participation in the handloom and handicraft sector of Assam. How Design Intervention is actually helping the Weavers in this global market? How the Design activity in the craft sector influencing the traditional practice of the handloom culture? What should be the role of designers in order to maintain the traditionalism and the culture of a particular craft society? Is there any need of guidelines for upcoming designers/Design students so that they can maintain decorum of maintaining a balance between tradition and modern requirement? How can Design play a role in providing a solution in preservation of craft tradition along with ongoing process of commercialization?

In this paper overall discussion about the identification of handicraft sector will be done in global as well as Indian scenario along with its connotation with tradition, culture, weavers and designers.

2 Background Study

2.1 Handloom Culture and Its Importance

In the economy of India, Handloom has a great impact. Agriculture industry of India is the largest economic sector and after that comes the Handloom sector, which provides employment to about 65 lakh weavers, among which around 60% are women employees. It is really astonishing fact that, among those 65 lakh weavers, North-Eastern states comprises of 16.83 lakh of weavers, Out of which, 12.41 lakh comprises of Assamese Weavers [1].

The existence of Handloom Culture in Assam is since time immemorial. Handloom industry in Assam is basically, rural and home based cottage industry which includes different kind of activities like spinning, drafting, denting, weaving etc. All theses activities are completed manually. It creates income generation along with economic development.

The term Handloom has a great significance in rural Assam. It also provides women employment. As mentioned above, 60% of Indian weavers are women. This sector has proved to create income generation capacity for women [2]. The techniques and manufacturing processes of Hand-woven textile in Assam are handed down over many generations. It is basically silk oriented. Traditionally, it was a important and basic requirement to know the skill of weaving for a young girl. This gives a reason to believe the fact of extensive practice of handloom in Assam [3].

2.2 The History of Hand-Woven Culture

The popularization of overall weaving practice took place in India during the rule of Ahom Kingdom. King Rudrasingha (1696–1714) had given a new direction to the Handloom Industry of Assam. He included new ideas, Designs, techniques etc. from different part of India [4, 5]. This system was known as 'Jajmani System' as mentioned by Sethi [6].

2.3 Designers and Weavers

In the past, the weaver or the artisan was in direct contact with the consumer and knew their aesthetic and socio-cultural requirement. The artisan never had to depend on external sources to understand his client.

It is further explained by Balaram [7] from an Indian perspective, "Innovative men from all walks of life- the poorest street vendor, the social worker, the engineer, the craftsman and the teacher are designers without being called so". It is well understood that the indigenous sensibility of design was always existent and resulted in flawless designs and compositions.

In the paper "Anyone anything?" Philip Pacey [8] argues about the non-professional designers that have been designing throughout the history of design. The Indian craftsmen can also be considered as non-professional designer. Over emphasizing on design as a "professional activity" has resulted in the underestimation of the value of an artisan, i.e. a non-professional designer in this case. If we consider an artisan as a non-professional designer, we can clearly see the context of the statement in relevance to craftsmen and their skills.

2.4 Design Intervention and Its Influence

Designers and their participation in this sector have helped in gaining a global importance of traditional Hand-Woven fabrics and its products. The old techniques, the colour of the fabrics, the designs etc. were replaced in order to gain global market importance.

In this era of Globalization, a global influence is seen in this Handloom sector also because of the inclusion of designers and their innovations. Handloom has added one of the major contributions towards the state revenue of Assam. State of Assam is famous for the production of Different silk products, which are locally termed as, Eri, Muga and Paat. Around Rs. 190 crore is generated from silk industry of Assam Annually. There is a great demand of Eri Silk in the countries like USA, UK, France, Germany, Netherlands, Japan, Belgium and Australia. Japan imports Plain hand woven Muga for designing Kimono [3]. Not only that, Eri silk and its home furnishing products are of huge requirement for European countries. Sometimes it becomes difficult to supply the bulk orders since the entire production process is manual. To reduce the overall manual labour some steps were taken by few entrepreneurs by including spinning machines for the yarn spinning process. This could help in reduction of entire spinning activity. But, unfortunately it was observed that the look and the precious texture formed on the surface of the fabric because of handspun yarn was missing in case of the usage of machine spun yarn. Even after that the machine-spun process continued in some privatized industrial level organizations and also could get huge markets and create employments.

Some craft practitioners believe that, it is important to retain the original essence of the togetherness of Handspun and Hand-woven textile and they are also able to create good market demand in their own styles.

Design Intervention and contemporary practice have also played an important role in creating demand of this sector in and outside the nation. Designers, Governmental and non-governmental organizations, middleman, business people and many others together are moving in and around this sector. Some of them are here for their own business development. Whereas some for the benefit of the craftsmen and their economic rise. It is a job for few to fulfill governmental requirement. Designers come to use the skills of the artisans in order to create their own collection and some designer finds it as inspiration in their design practice.

Design interventions also assist in creating awareness among artisans of methods, materials, tools, processes and clientele base. In many cases the artisans of a region have lost or rather do not have a documented form of the craft. Traditional crafts are memory based, and only memory is the knowledge bank of their traditional methods and materials. Also in a situation where a material may not be available at a region, and is a significant part of a craft production process, is at times available in nearby regions and states [9].

Design intervention can help in the documentation of processes and materials involved in a craft, to form a knowledge bank that can be accessible for an illiterate weaver, who lacks in the knowledge of traditional methods and processes. Thus design interventions can help in preservation of cultural resources. Since, handloom industry of Assam is a direct outcome of culture, preserving its essence is equivalent to preserving the cultural nuances of a region and community.

The importance of Handicraft Industry, Panda [9] in the Indian context is indispensible, and thus calls for proper documentation and review in its current status and existence, so as to create awareness and database for future preservation of theories and processes. The inter-connection of culture, tradition and crafts are established, to clarify the importance of identity of crafts and the stakeholders associated with it.

The overall understanding of Design intervention here in this section can be categorized in two sections. In one part it describes the involvement of designers in the Handloom sector for the contemporary practice of Hand-Woven textiles, innovation and competence. And the other parts describes about the need of design intervention which can help in designing a guideline or propose a design research for the preservation of traditional practice.

2.5 Objectives of the Study

The main focus of this study is on the role of Design intervention in bringing the contemporary aspect in the Handloom sectors. Also, to understand the thought process of the Designers while making changes in the craft sector, especially in handlooms in the context of Assamese Textiles. This study also wants to know the satisfaction level of the artisans or the weavers while working with the Designers. Objective is also to find the changes brought in the traditional practice, which might influence the cultural identity and heritage.

To understand the actual need in the current context and try to find out the future of this handloom sector. To analyze how the design intervention is going to affect the future of handloom industry if practiced in the way it is being practiced now. To find the factors which might help in the survival of the traditional practice of craft. Also, along with continuous process of Design practice and design interventions, which is important in this competitive world of market demand.

3 Methodology

In order to fulfill the objectives mentioned above, it is required to conduct some study. Literatures based on the selected title were searched using electronic search Engines. Followed by proper study along with ethnographic research. And then identification of need based on the overall study and research.

4 Ethnographic Research

The ethnographic research usually is involved in observation. To know the natural condition of the area or the people involved in the research. In this particular study also, an observational research is involved. It includes personal observation of the author and her personal experience of performing design activity in a handloom cluster as a government appointed textile designer at Sualkuchi East cluster. Sualkuchi is a village of Assam involved in Hand woven activity. This village is also considered as “Manchester of east” because of the weaving activity, which is the most dominant activity of this village.

The Design intervention was done in order to fulfill the market demand, which already existed. The main aim was to improve the earnings of the weavers, which in turn will improve the economic condition of the weaver’s community. The Design activity involved includes designing of diversified products, in terms of colours, motifs, patterns, etc. The designing was mostly done on the basis of modern requirement and needs of the consumers.

Most of the time the buyer or the consumer used to provide their own requirement and the manufacturing process use to follow their instruction. Activities like branding of the products, conducting exhibitions, attending fairs to get international markets etc., were performed with the help of government. Overall process seemed to be of great help in terms of economic development and upliftment of the weaver’s community in terms of income generation. During the period of the performance of the Design activity, the designer could feel the necessity of design intervention in this particular sector, which definitely could be responsible for earnings of foreign exchange. Overall experience of the designer was very good in terms of creating economy through creating demand of the traditional textiles of this particular region by diversifying the product range and by bringing change in the primitive traditional designs.

5 Need Identification

There is need of requirement of a proper guideline for a designer to follow, so that while performing design intervention in any kind of craft sector, he or she can maintain the decorum of preserving the original craft practice. Craft is an identity of a particular cultural background and it needs to be continued so that the cultural heritage remains integral. There is a need of balance for both traditional as well as contemporary practice based on the requirement of the globalized world.

There is a need for design researchers having interest in Craft sector to undergo a study in the debate of traditional practice of craft versus contemporary practice. A lot of discussions went on since many years on the said topic. As already mentioned above that Assamese culture of hand-woven fabrics have cultural characteristic. It defines the ethnicity of being an Assamese. Similarly other craft cultures of different parts of India definitely have its own unique identity depicting a particular community or society.

Tyabji [10], says that traditional textile crafts in India carry their own cultural, social and emotive baggage, with designs colours and motifs, each having their own significance and different communities each having their own distinctive techniques and style. So adapting these traditions to contemporary urban markets and global consumers has its own dangers and challenges. It requires sensitivity and awareness-creating trust and partnership between craftsman and designer. Crafts people are not just a passive pair of hands but creative artists and professionals in their own right.

She also says, why is preservation important if we aren't mourning its loss? My take on this is that eventually we will realize that, we have lost most of the colours textures sounds flavours folklore and imagery that made us distinctive and special. Handlooms are a part of India's history, economics, aesthetic, culture. If we loose them we loose a part of ourselves [10].

6 Observation and Discussion

While performing the Design activity and intervention, the designer is just using the craft techniques of the weavers and their skills. They do not think the after effect which can lead to the fading away of precious cultural heritage of traditional weaving of a society, which is an identity of a particular society or a community. These cultures determine the history of a place.

According to cultural Historians, the preservation of traditions and its context is of primary importance, but for marketers, the demand and market trends are of main concern. Government officials and policy makers on the other hand, have specific concerns concerning to the sustainability of the handloom and handicraft sector, its influence in terms of employment, and its comparative impact in the perspective of gross domestic product and foreign exchange earnings [6]. These factors concerning the different opinions, of the people related to different profession brings in a practical and constant debate of craft in the context of traditional and contemporary practice. An ongoing debate continues between craft promoters, craft organizations and textile academicians regarding what is termed as design intervention and traditional practice of handloom and hand-woven textiles. Some of them think that, the artisan's role is only of a producer and through the designer's influence; the cultural context of the craft is lost when the products are developed for a consumer market, which is unknown to the artisans. Indeed the designers should attempt to understand and respect the historical, cultural and social context of the artisan communities with whom they interact." Emmett [11].

In a traditional society, design existed within the interaction between the artisan or the craftsmen and the client where the designer had to play no role. But today designers act as a middleman between the artisan and the client [6].

7 Conclusion

It can be concluded by saying that a design guideline is a necessary element for today's world of designers who are keen practitioners in the craft sector. A guideline for design schools, so that the future designer having interest in performing design activity in craft sector or taking craft as an inspiration. This might help in maintaining a balance in the design intervention and ongoing traditional practice. It has been observed that the artisan's role becomes that of only a skilled labour, who has got no connection with the buyers and the international markets. Just the documentation of craft is not going to save the heritage of craft culture. Design Researchers need to work on the above debate and come out with a proper solution. It is a demand of current scenario about making an effort to make the designers understand their role before performing design activity in a craft society.

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Media Representation: Design for Positive Imaging

Payel Chakrabarti and Debkumar Chakrabarti

Abstract Innovative information representation in print and electronic media is an emerging field of effective communication design and human factors application. This paper deals with means and methods of constructing media reality as perceived by users with reference to the reporting of violence in Northeast India. Design research has many fold emphasis that includes the responsibility of creating a positive motivation to its intended users' when it comes to communicating information. The present study looks into various elements for developing a structured process of representation in media. It requires balancing the mirror reflex kind of imaging and abstraction. An exploratory inquiry into the procedure and criteria that goes behind the production of news content representing Northeast; criteria and strategies that media practitioners employ to make relevant judgments regarding information collection, production, projection and presentation formats, was conducted on 112 respondents from the media fraternity and consumers of media as a researcher as well as working journalist. In trying to figure out the frame work for positive imaging and representation of events other than violence only in communicating through the media world, from the derived responses an attempt was made to evaluate if such system can be practiced, feasibility studied. Media houses are required to have a design evaluation and research section that may guide graphical and layout representation patterns. Active media audiences may be open to accepting and interacting to information and not media created negativism. News representation falls under the periphery of communication design, and design is considered to be the process of changing current situation to a preferred one. In this context it needs to be addressed that how much media representation of violence is performing towards the goal of betterment of the society.

Keywords News reporting · Image creation · Design representation

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1 Introduction

Media and entertainment industry may be said to be one of the most flourishing sectors in India, which has grown immensely. And moreover the industry, mainly after liberalisation of the media, is a developing sector with developmental works, and newer methods, applications and of technologies. This has raised business opportunities in Indian media and entertainment industry enormously, leading to extended scopes and areas of academic study. The role of media, in the present information centric life, may be scrutinised and evaluated as perennial in constructing reality through its representations of places, people, events and society as a whole for a diverse group of media consumers to consume and believe.

1.1 Expression of Violence Through Media

Media has the capacity to change attitudes, opinions, and behaviours, but to what extent. Empirical research, surveys and experimental methods have proved over time that media-audience relationship is complex and a mediated one rather than simple and direct. In numerous studies the role of media is found to be more limited and implicit and benign in society with emphasis shifting to active audiences, from 'what the media do to the people' to 'what people do to the media'. Overcoming the impression of media being the 'ominous persuasive and other anti-social power' media is found to be just reinforcing prior dispositions and not changing them, not cultivating escapism or passivity but a medium capable of satisfying multiple uses and gratification, not instrument of a levelling of culture but of its democratisation [1].

As Uses and Gratification Theory states that the media products are designed in a way for the intended users, keeping in mind their needs and aspirations. Thus the media producers concentrate on market audience research programmes to design media texts. And this often results in homogeneity of products with no media wanting to loose on its consumer base. Fights, shootouts, brutality, car crashes and sadistic violence are common gimmicks designed to capture and hold viewers' attention [2]. And moreover economic competition for viewers leads to more and more depictions of violence in media [3]. Thus it can be stated that the increase in violence in media in a way may be linked to its understandably growing acceptance and popularity among the masses. In similar lines, representation of violence in media and its effect on individual as well as the whole society is a serious concern. All media content producers thus need to analyse and understand the consequences before putting forward any content to public. Means and methods are to be thoroughly studied in context specific environment.

Innovative information representation in print and electronic media is an emerging field of effective communication design and human factors application. This paper deals with means and methods of constructing media reality as perceived by users with reference to the reporting of violence in Northeast India. Design research has many fold emphasis that includes the responsibility of creating a positive motivation to its intended users' when it comes to communicating information. Considering the large and varied audience of the mass media with social, psychological, cultural, regional and age differences; their acceptances, rejections and reactions and effects on them are undoubtedly varied as well.

With reference to media focus on reporting of violence specific to Assam and patterned presentation of the entire Northeast region in regard to professional competence and social responsibility, the present study looks into various elements for developing a structured process of representation in media. It requires balancing the mirror reflex kind of imaging and abstraction.

2 Methodology

An exploratory inquiry into the procedure and criteria that goes behind the production of news content representing Northeast; criteria and strategies that media practitioners employ to make relevant judgments regarding information collection, production, projection and presentation formats, was conducted. In-depth personal interviews were held to get first hand information from 112 respondents, over a span of five years (2010–2015) from the media fraternity and the consumers of media as a researcher as well as working journalist. These interview transcripts served as the primary sources of date for content analysis. The analysis process was inductive and took a Grounded Theory approach with the interview transcripts emerging into categories on their own. Thus derived responses were thematically coded and analysed based on emergent themes. Survey of producer's intentions in communicating certain social violence in Northeast of India, and receiver's perception creation as per acceptance of the information through representation in media and impact of media violence was carried out.

Along with interviews (verbal data), visual data (selective media texts collected from selective media houses and archival information) and mediated data (available documents, news reports and other representations in media on violence in media in Assam) were also used for study. Comparative analyses of representation trends followed by media houses and individual journalists, with reference to specific location, events and people of Northeast in general and Assam in particular was done using Theoretical sampling method. The aim of data analyses was to find out the representation patterns of violence in media with specific reference to Assam and Northeast India as a whole, purpose and intentions. Through the process of qualitative content analysis the paper makes an attempt to analyse not only the manifest content material but also the latent content as themes, ideas and contexts of the derived texts.

3 Results and Discussion

It was observed that shocking open ended information of direct violence images and visuals create uneasiness and insecurity leading to psycho-physiological stress, anxiety and trauma in people. On the other hand the physical work environment in respect to work hours, schedules, field work environment and constant pressure to sell their media products for the practicing journalists in the region is another area of concern. The responses derived also identifies the dominant perceptions, intentions and responses of media practitioners, along with the hidden factors that work behind reporting of purposive and selective instances of violence. The practice may be said to be more of market influence over journalism activity in the media industry. In the present context the media scenario may be deciphered primarily in terms of corporatisation and commodification. With media ownership increasingly being concentrated in the hands of big business groups and prominent political affiliations, news gathering and media representation has been highly motivated and dictated by Television Rating Points (TRPs), circulation figures, generated revenue and profits.

Apparently news about violence has become a priority in media communication today, especially in reference to Northeast India as a whole and Assam in particular, where stories in long existing trend of media representations, have been projecting and propagating the region in negative light to the rest of the nation and beyond. Content analysis proves that "political violence-murders, bombings, kidnappings, extortions militants, killing of militants by security forces in actual or staged encounters—has become a routine part of news from the Northeast" [4]. Thus there is a constant pressure for the journalists working in the region, to focus and highlight on stories of violence and unrest to survive in the highly consumerised and competitive media industry.

In contrast to the ideal media belief of strategic use of violence content forwarding commercial gains; it is perceived that the region is negatively portrayed in the national canvas and beyond causing lot more harm to the society and people. Media space and time is provided to incidents expected to be of massive potential, enough to grab mass attention. And thus media representation is often criticised of creating negative impact regarding the place, people and society though selective and excessive violence, where factual reporting has created a certain kind of inappropriate perception. Significantly, comparative analysis of private owned media houses and state broadcaster *Doordarshan* reflects upon the diverse approaches of media towards representation, specifically reporting of violence in Assam. Most of the private television channels represent the region through stereotypical projection and has a huge following; whereas state owned channel tries to cover a broader prospect of the region in its varied programmes but is unable to cover-up the perceptions already created, strengthened and reconfirmed by the private business players.

Varied user groups were enquired about their perception creation and impact of media representations. While the youth were found to be negatively informed about the society leading to mistrust, dissatisfaction and stress; the elderly consumers of media were apparently found to be rendered worried with hopelessness and stress of surviving in dangerous living conditions. This led to think if Northeast in reality provided such horrific living conditions or was most of the negative image created and propagated by media to use sensitive open-ended information as profitable commodity. This present study may be said to be an attempt in identifying the instrumental factors of negative news representation of as against time and space allocations in media. Thus tries to counter the practice forwarding the concept of peace journalism than war journalism in more solution oriented reporting rather than only facts and figures.

3.1 Conflict Reporting and Peace Journalism

Usually in conflict reporting only the conflict, politically or mass movement etc. gets reported where people on the other end get to know of the conflict and its results in terms of damage, deaths, disruption of daily life and fear. Afghanistan, Pak-Afghan border, Pakistan, Sri Lanka, or conflicts in parts of India many Asian countries have been areas of conflict in the last few decades, where conflict reporting was by and large practiced. In conflict reporting media producers, journalists have the perception that the role of media is to report events, and never play a part in resolving conflicts. Contrary to this school of thoughts is those who look beyond fact representation and believe media coverage of the background and causes of conflict can lead to rapid resolution and normalcy. From this emerged the concept of peace journalism in the 1970s, which is seen as an alternative to war reporting that suggests media should tell the complete story about conflict truthfully with more informed discussion of significant issues like causes and resolution of the conflict [5].

The prevalent media practice is more inclined towards war journalism-violence-oriented, propaganda-oriented, elite-oriented and victory-oriented. Kirsten Schwartz Sparre, points to another aspect of conflict journalism, the norm of social responsibility, which was laid down on the British media in the aftermath of the Second World War. This is to provide to the masses with accurate up-to-date information with explanation and comments and with clear separation of fact from comment [6]. Sparre believes that a real possibility of media lies in the social contract between the media and society. Media should ensure that their impact is positive while keeping the spirit of the social responsibility theory. Denis McQuail furthers the concept of media accountability in conflict situation, and suggests that media has two fold functions-firstly media content and format can be crucial for transforming the conflict into sustainable peace and secondly, a balance between media freedom and social responsibility can effect post-conflict situations as well [7].

3.2 Summarised Findings of the Study

1. Media commercialisation has lead to producers concentrate on market audience research programmes to design media texts which often results in homogeneity of products.
2. It was confirmed that as stereotypical projection has been neglecting many other facets of reality, the role of media in specific reference to Northeast and Assam requires to be re-looked into for proper projection.
3. It is a concern today that if media disposes enough responsibility that comes with the immense power, to handle serious social issues, to take human emotion further to social development without hurting sentiments and not enraging people.
4. Points that emerge from interviews and gathered views:

   - A majority of the respondents do show a serious concerns in the way Assam has been and is being represented in media.
   - Commercialisation is a factor for which media content has been stereotypical.
   - The region only gets attention and space in media when a large number of people are affected usually by violence or by flood.
   - Geographical location makes the region out of reach and proximity area of the so called mainstream media organisations which makes authentication, validation, and understanding difficult with negligence and lesser knowledge.
   - There are norms which media houses need to follow regarding representation of violence in media, but is less maintained.
   - The print media still has certain control on its content of violence, for direct depiction of violence usually images are selected over a span of time.
   - In case of television media, there is no thumb rule for direct representation of violence. Most of the time acts of violence are telecasted under the '*LIVE*' tag with no scope for selection or editing of footages.

The present study identifies the conflict in the persistent media scenario. Whereas the image of the Northeastern region is understood as "paradise in peril" the media representations are found to be unwilling to break the prejudices and stereotypes that have been constantly feed to the media consumers, not confining to the boundaries of the locale. The gathered views from a cross section of respondents comprising of students, academicians, experts, local residents of Guwahati and around representing local as well as non-local sentiments; reflect upon resentment over media texts containing factual information of mostly violence against the experienced reality. The survey transparent a need to relook into the media representation of the facts and figures that necessarily do not serve as only news but also serves as an after effect tool towards creating a assertive or non assertive ambience in the mind of readers and viewers regarding the region.

3.3 Media Strategies Lacking Efforts

Today's commercialised media seems to be unaware of the negative precedent that reports of violence have on a greater audience. This has even proved to be one of the reasons of outsiders refusing to venture into the region and also local intellects moving out to find peace and growth. Now the image is changing, by self-realisation of the situation by the locals and with induction of national institutes that allow intermixing and exchange of ideas and thoughts. People stay back and even venture into the region's development with the strengthening of the idea of local live-able environment. If media representations facilitate, such issues would get a total face-lift from the violent and fearful image of the region.

Considering the large and varied audience communities of the mass media with social, psychological, cultural, regional and age differences; their acceptances, rejections, reactions, and effects on them and requirements are also supposed to be varied. The producers and practicing field journalists also combine into an important mix that are well or even more affected by the process of representation of the region through a patterned projection of violence. Violent content in media has not only raised quantitatively over the years with media boom, media commercialisation and consumerism in the regional scenario, but also qualitatively with visuals, images and even texts becoming highly disturbing, graphic and detailed. Media coverage of some of the events in the Northeast raises worrying questions about objectivity and responsibility of the media; and this may be seen seriously with its social consequences and ergonomic issues.

It appears to be very difficult to change the commercial attitude of the media makers who bank upon unrestful happenings, expand and express selective information to be a part of the competition and win *headlines* or *breaking news* slot. Most of the regional media houses not only aim at their own TRPs but also answer to the requirements of the mainstream media houses. The decision makers in most of the media houses are away from the ground realities, physically distant, lacking understanding and awareness; but they are the ones who decide and design the media content. The ones on field have less control over the final product. A lot of research has been done on impact of media violence on the consumers of media, but less of work has been done on what exactly goes behind the prevailing system. What is being represented and why? And how much of the representations are authenticated, and if in the affirmative, is there nothing beyond theses representations that can define a place, event or people of a particular region as their aspirations?

3.4 Positive Imaging Through Media Representations: Context and Feasibility

The responses (Fig. 1) on Positive imaging through Media Representations: Context and Feasibility may be categorised as below:

A majority of 51% of respondents (Fig. 1) refer to the following of ethical practices as the only way to solution. 27% of respondents refer to media education specifically among media practitioners as the required element to change the patterned representation in media. Media education on the whole also includes media literacy, generating public awareness along with educating the practitioners about the norms and guidelines regarding representation of vital issues such as violence. Respondents also hinted that along with educating the media practitioners about the ground realities and the impact of media representation of violence it becomes equally significant to educate the media consumers about media representations.

3.5 Towards Positive Imaging

In trying to figure out the frame work for positive imaging and representation of events in communicating through the media world, from the derived responses an attempt was made to evaluate if such system can be practiced, feasibility studied. Though most of the media practitioners interviewed seemed to be well aware and practicing the known method of representation of violence, a section of respondents were apparently found to be disapproving of the prevalent politics of representation. The responses (Fig. 2) on desired alterations in the prevalent media practice and Representation of Violence in Media may be categorised as below:

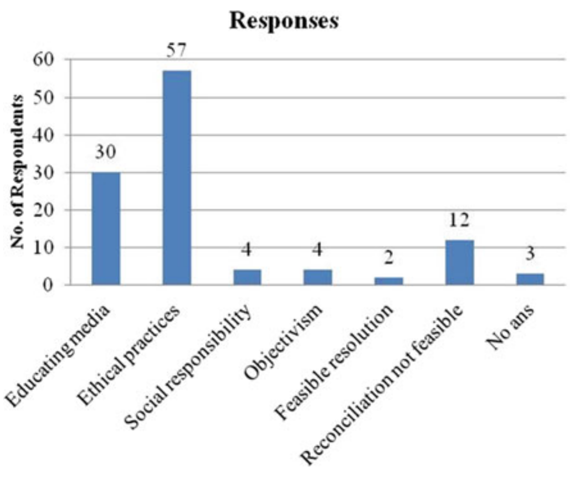

Fig. 1 Responses on positive imaging through media representations: context and feasibility

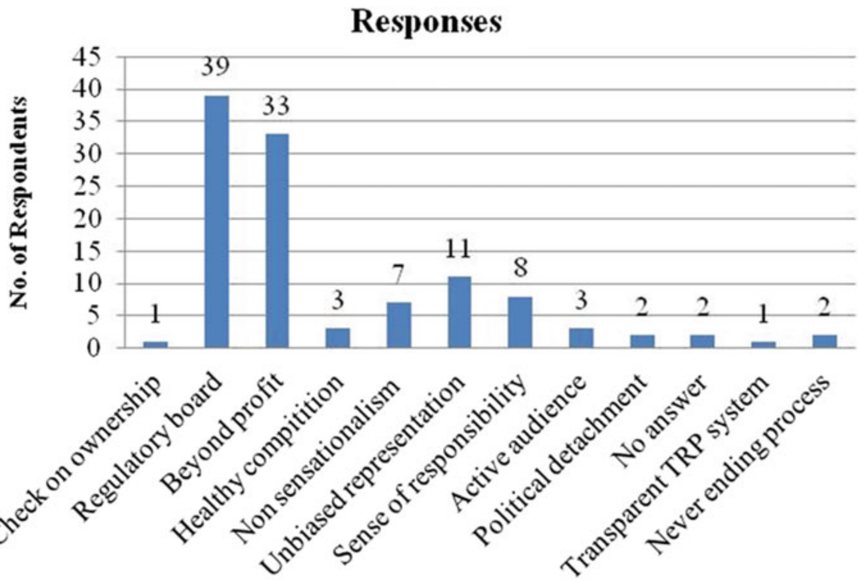

Fig. 2 Responses on desired alterations in the prevalent media practice and representation of violence in media

Majority of 35% of respondents feel only way to overcome the obstacles of the politics of representation of violence is setting up of strict regulatory bodies. Majority who fault the media representation of selective violence in content and explicit presentation feel the need of censorship. But simultaneously they also problematise censorship as hindrance to the practice of constant and rapid media productions with time constrains. 29% respondents raised the point of over-commercialisation of the media industry. As stated by a respondent, "rethinking business" is the only way of overcoming the obstacles of the politics of representation of violence in media towards positive imaging.

The usability of a piece of information to be worthy of media representation is understood to be the magnitude of violence and number of people affected by it. In context of politics of representation, the intended message to be communicated by the media producer works in correlation with the audience perceptions and leads to an understanding of constructed realities as real, which stands the biggest obstacle to be overcome by media- practitioners as well as consumers. Media reports need to work independent of influential factors like politics, authoritative control, peer pressure, unethical practices, so as to serve the society of non-passive consumers and defy existing negative representation pattern with focus on violence.

3.6 Consequence and Relevance

There has been considerable amount of academic research in the field, regarding violent media content, impact of media violence on consumers, media violence evaluation and improving practices, but the question prevails, if all the researches, findings, discussions and recommendations on media violence have changed the actual journalistic scenario and the process of violence representation in media. Coverage which have over time proved to be very well accepted and saleable are report stories about acts of violence especially on innocent and vulnerable individuals or groups, human rights violations, and the failure of the relevant official bodies to address the matter or to deliver justice, sufferings and terror struck people. There are two distinctive view gathered about representation of Assam in media. Firstly the one that states Assam has managed little to gain media attention and reach the public consciousness. Second, it requires being a huge massacre like the one of the gruesome killings in Nellie (Fig. 3) to qualify to gain worldwide media attention [8] which left nearly 3000 dead. Similarly Assam figures in cover story of an international current affairs magazine with the violence termed as "India's Biggest Human Tragedy" (Fig. 4).

Another view emerging of late through comparison of various other representation patters of similar incidents of violence in other places has been a combination of the two, which states that even though violence of higher decree manages to grab media attention and reaches a wider section of audiences though electronic and print media, there remains the gap between ground realities and the represented realities in news reports. Though in practice the role of mediation of news was found to be that of production of a commodity for mass consumption with exceptional preference to violence from the region; in contrast to the rein of media

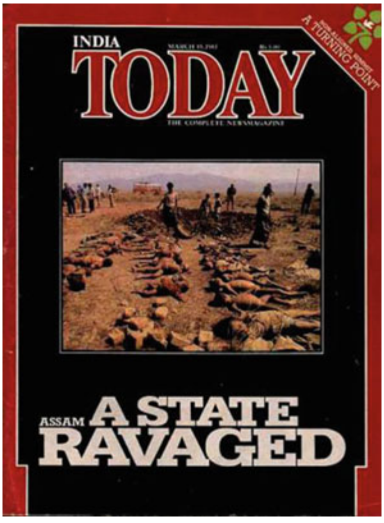

Fig. 3 *India Today's* cover on the Nellie massacre, 9 December 2011

Fig. 4 Children and women portrayed as victims of ethnic violence in Assam, on *India Today* cover of 13 August 2012

violence some media practitioners also emphasis on the need of positive imaginisation as further exploration for the media industry.

3.7 Consumers Shift from Traditional Media Captivity to Multi-source Information

Apparently monotonous consistency, homogenous products and offensive stereotypes in media representations, in approaches towards content, production and technology, needs to be challenged. A major element of studying representations also focuses on the consumers as to how they receive, consume and react to the media constructed realities. Media consumers are seen demanding more accountability, relevance and interactivity; stereotypical projection and perception patterns created and furthered by media are being questioned, suspected and objected. Apparently the residents of the region both living in the region and those settled out of the region have started to express displeasure in the representation patterns and thus have felt the need for change of persisting perception and the role of media. There have been studies identifying the communication and information gap in media. This may be the reason why media consumers have started to shift towards social media and internet to avail more avenues of news. A section of media consumers have been discarding traditional news media- television news channels and newspapers, or additionally exploring the internet looking for validation and interaction. Audiences prefer multi-platform news over information from single sources of news media. Discarding the media effects model which describes media audiences as passive and uncritical, and they respond to same material in the same way; the study comes in conformation to the idea of an active audience.

3.8 Innovative Experimentations Against Violence Representation Practice

As for Stuart Hall meanings are generated through representations done by individuals or groups [9]. And according to his model of encoding and decoding, the intended meaning of a text as encoded by the producer may be way different from the perceived message by the consumer upon decoding the media texts. Thus extending the concept of an active audience still further comes in the Reception Theory of media. It becomes equally crucial to understand how the consumers of media interpret media texts [10]. The process of interpretation in this context is defined as the process of negotiation between media texts and media consumers "situated within specific social and cultural contexts" [11].

As studies reveal as against the popular perception of audiences beyond the region not interested in news from Northeast apart from violence, conflicts and follow-up stories, media consumers are actually open to experimentations and welcoming to news from the region other than violence. Though the traditional mainstream media is found to ignore such revelations and carry on with customary representations, it is seen that some individual media houses and individual journalists are considering the importance of consumers' feedback. Apparently efforts are seen being made by mostly non-profit initiatives like *Jeevan Magazine, Eclectic Northeast* and *The Thumb Print: A magazine from the East* to deviate from the presiding norms of media representation with focus on violence, conflict and distress only; and are attempting to portray the region in better way, adverse to the popular beliefs of the region.

3.9 Unconventional Representation for Inclusive Reporting

As earlier researches reveal all constructed identities of the region are invariably in relation to the so called "Indian mainstream" where Northeast apparently is presented as the 'sub-stream' or 'side-stream' [12]. In this regard the present study found that few respondents problematised the term "mainstream" and rejected Assam or Northeast being the sub-stream or the side-stream as against the distant mainstream. As a regional journalist proclaims "coverage of news is mostly city centric and this happens in every region. Being situated in the peripheral location it is bound to happen. Here is where media persons' responsibilities come into being. Their ability to cover inclusively and report on each and every aspect becomes important." This implies that in order to change the so called mainstream attitude, media representation need to be relooked into, beyond the existing reporting patterns. Thus raises need for media practitioners to focus on non-local and unconventional objectives, and practice inclusive reporting.

3.10 Identity Retention Through Media

Western domination, as it started aiming at social revolution, prevails in our communication system; we have followed the basic structure developed by the West and then developed or elaborated on that and many aspects of our culture and tradition have been disremembered in favour of western influences. They also confront the limitations of conventional theories on media and globalisation in understanding these relationships. But what we seem to have overlooked so far is the thought that going global requires retention of one's own identity and pride. In this effect, India is trying to showcase its culture to others, where as within country we are yet to honour our own traditional good practices. This with media's easy access can play a great role. Some Indian media sectors are investing on retelling Indian history and ethos to young minds, demystifying western understanding of our traditions in innovative ways. Media can well frame the honour of Indianness. Need today is to focus on the media representation of events and information in tune to the required public perception of looking for wellbeing.

There is a lot of scope in the region for media education, training, skills development, understanding media, responsible journalism, utility aspect of media and improving information availability in content and context, rather than preordained concentration on reporting of violence only. Taking inputs from researches being carried on in the academic field, relevant recommendations and rectifications might be made to the representation content and context. Probably the quantity of violent content and the nature of representation both needs to be equally monitored. Perhaps a kind of violence rating system may be established by which media content can be monitored. Media needs to method ways of representation and perhaps look for innovations not only in presentation styles like it has been in most experiments in media industry and news but also needs to work upon strategies that would improve the content and quality of media. Finally as Chomsky asserts "As long as the general population is passive, apathetic, diverted to consumerism or hatred of the vulnerable, then the powerful can do as they please, and those who survive will be left to contemplate the outcome" [13]. It draws attention to understand the residents of this region, of their aspirations and representation of their being in media, to appropriate positive identity, to motivate self and for others to express their being.

3.11 Design for Positive Imaging and Community Well Being

Media in a way is the process of creating the image of recording the visual history of our time, may it be the still photographs in newspapers and current affairs magazines or the television documentaries. Then can the present day news coverage not be termed as coverage of countless chaotic stories in various forms and formats for various media outlets and a large varied spread of media consumers. Thus the need raises for positive imaging and considering community well being as a whole.

In addition questions on compromising media ethics are often raised in churning out desired and preordained media texts. Apprehensions regarding opting for journalistic ethics, freedom of speech and expression, social responsibility and commercialisation is intense in the media practitioners. To thrive in presently evolving media environment, individual journalists and organisations as a whole need to inculcate efficiency with innovation; adopting innovative approaches to content selection and development, processing, distribution and technology along with commercial gains and social responsibility. Media representation falls under the periphery of communication design. Active media audiences may be open to accepting and interacting to information. Design is considered to be the process of changing current situation to a preferred one. In this context, it needs to be addressed that if at all violence representation in media is performing towards the goal of betterment of the society or towards self promotion. A proper design study along with the hierarchical presentation and placement of content and context requires to be re-looked into as against popular perceptions of print spaces and electronic time allocations.

Information gathering, processing and presenting in order to formulate news continues to evolve. The problem with media representations has been identified as several influencing factors that dictate the content and context, as evident in Figs. 3 and 4 images two popular magazine cover page presentations. While media design in a way claims responsibility for informing the consumer community and thus is designed in such a way concentrating, selecting, and also omitting facts for a larger community to consume and accept, on the other hand the same representation is found to work against the community well being of the society it is representing with various layers of community addressed and layers omitted.

4 Conclusion

Journalism in practice has fundamentally been serving one's own people, a particular social class, community, race, religion, nation or any such factor that distinguishes a particular group from the 'others'; these acknowledgements and affiliations are often reflected in media texts as media bias and strengthen stereotypes. Furthermore there is constant endeavour to maintain the existing patterns that reinforce the dominant ideologies so that the constructed reality does not challenge the existing perceptions, an attempt which often tends to ignore greater communities. One important issue may be said to be the idea of separatism/sub nationalism and media representation in the context of Northeast. In this context there are strong marginalised representations in respect to region, locale, indigenousity, ethnicity etc. with media ignoring, misrepresenting or stereotypically representing certain sections of the society.

It is evident that in terms of Northeast news reaching out to widespread consumers, mainstream media with huge spread of viewership/readership throughout the nation and abroad, plays a significant role. The metropolitan based houses usually accept and explore certain levels or categories of violence, the conventional violence, mostly in accordance to the popular audience beliefs and media understanding. Also confirming the theory of News Framing and the dominant hegemonic perspective is the fact that media, local as well as mainstream, is found to select content and context of reporting, construct representations considering demands and popular beliefs of the dominant section of society. As evident, in India most mainstream media houses are either controlled (if not directly owned) by the large political party at power or by the opposition at the centre, reflecting either groups' popular ideology or propaganda through definitive media representations.

Survey and content analysis confirm that Northeast India is used as a fertile plot for such marketisation of violence. Apparently excessive violence and selective reporting has lead to propagation of negative image of the region to the media consumers, mediated and largely distorted. Moreover in respect to violence from the northeastern region making to the mainstream media, reports often are given strong political connotations. This may also be seen as a likely explanation from the media point of view of the peace efforts not extensively covered by mainstream media instead focusing on reporting of violence.

News is the window to the society for a specific end user groups and representation in media that are skewed toward violence could encourage people to believe that the world is a hostile place [14]. Viewing news about tragedy is certainly upsetting. This section of end users' of media product develops negative feelings from viewing of unpleasant news items about the region [15]. Good works are going on in Indian soil and mind; yester years youth are today's elderly who wish to see that the world they are leaving behind is liveable for next generations; can media project the feeling of trustworthy positive, what would be the representation means and methods needs to be figured out. Rather than following the western influenced theories or elaborating upon them to fit into Indian context, it may be feasible to develop newer avenues of Indianness in projecting images to serve trust, even our mythology expresses 'win over evil' to give positive attitude to life rather than blindly concentrating on commercial gains and negativity.

Though there is limited substantial work in the area to validate that perception creation about Northeast may be directly or indirectly related to media representations, but certainly media reports have never tried to correct the perceptions or break stereotypes as well. Northeast India in general is widely accepted as "politically and culturally insignificant" [16]. Thus media mentions of the "backward and exotic" people only while reporting on violence and terrorism as "violent anti-national separatist bent on destroying India" [17] that fits the universal news context. The responses were in confirmation to the derivation from literature available, media representations have been propagating a terror prone image of the region, while many also believe the region to be marginalised in the mainstream media consciousness.

There has been considerable amount of academic research carried on in the field, regarding violent media content, impact of media violence on consumers, media violence evaluation and improving practices, but the question prevails, if all the researches, findings, discussions and recommendations on media violence have impacted the actual journalistic scenario and the process of violence representation in media in any way. Cognitive issues relevant to information perception, its physiological effect and overall well being is a major concern today. Therefore media design requires aiming at the benefits of the society moving beyond the process of representing patterned facts and figures in selective conflict situations. Proper design evaluation and research sections in media houses introspecting content and context, may challenge and channelise the prevalent explicit graphical and layout representation patterns in productions. Active media audiences may be open to accepting and interacting to information and not media created negativism. Ergonomics and media may complement each other, in looking into the issues of optimisation in violent media reporting, can create an overall well feeling to life which should be a concern for media journalism. Thus journalistic inquisitiveness along with academic interventions and design research together may yield prospects to uncover the stories that drive a society forward and not restrict media representations and related perceptions due to commercialisation or dominant ideology.

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Past, Present and Future of Collaborative Design: From User Centric to User Driven Design

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Abstract Agents, artifacts and environment together constitute an interconnected, and interdependent social system beleaguered with complex palimpsest of concerns. How can design thinking visualize the contradictory and controversial nature of matters of concern, where perspectives and stakes are unequal, contesting and conflicting, but with inter dependencies, not all of which are entirely predictable? Prompted by advancing technology and increasing complexity of the design inquiry, role of the user in negotiating such contestations has lately been in flux. Increasingly, the user is perceived not as a mere consumer driven by immediate self-serving gains, but as an inter-dependent actor negotiating for an empowering and equitable solution for all. This necessitates the exploration of how blurring of strict boundaries between user, designer, and a social agent is diluting dichotomies between user/designer, social-worker/capitalist, consumer/producer, use/profit, or need/desire. Hence, this paper is an epistemic inquiry into the trajectory of user participation in responsible decision-making through the analysis of six design frameworks holding different kinds and extents of social accountability. Thereby seeking, twofold objectives: (a) to establish the theoretical antecedents of user participation in design for social responsibility, and (b) to assess the future of responsible design decisions in discourse and practice.

Keywords User driven · Empowered user · Social responsibility · Future of responsible design · Collaboration in design

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1 Introduction

Today, we face harsh consequences of inequitable participation of agents and artifacts in design decisions triggered and propelled by the selfish agenda of industrialization to lure people to buy things they don't need. This phoney consumer culture has led to insatiable consumption demands, depleting natural resources and the consequent impregnation of social inequality and political uncertainties in the social environment [1]. In the Sciences of the Artificial, Simon characterizes "design as central to what humans are and what they do". Humans create artifacts to control the natural world by creating an artificial world [2, 3]. Designers are particularly responsible for artifacts, making "Design" one of the most powerful professions, demanding immense social and moral accountability towards society and environment as a whole. Papanek criticized designers for using a myopic vision of design intervention, limited to micro issues of "created need" which blindly promotes consumer culture without considering the harsh and long term imbalance in social system. He proposed a new design agenda of Socially Responsible Design (SRD from hereon) focusing on designers' responsibilities towards environmental and social needs [1]. Socially responsible design is "designing for real world concerns of social, environmental, economic and political system" [4–6]. Design researchers have indicated the urgency of incorporating scientific techniques and social inquiry to assimilate prevailing values and common concerns into design decisions [7]. SRD must strategize appropriate interventions for collective concerns of the real world without compromising needs of the future generations.

However, this call for responsibility is not entirely novel. SRD practices can be traced back at least as far as the Industrial Revolution William Morris and John Ruskin responded to what they perceived as a decline in design standards caused by machinery and factory production [8]. Design frameworks are constantly evolving and emerging to address the challenges of humanistic, social, and environmental concerns. Increasingly, in these frameworks the user is perceived not as a mere consumer driven by immediate self-serving gains, but as an inter-dependent actor negotiating for an empowering and equitable solution for all [9]. Prompted by advanced technology and increasing complexity of the design inquiry, role of the user in negotiating contestations has lately been in flux [3, 10–13]. For instance cloud computing and IoT has transformed the role and process of participation of a user in the SRD frameworks. It has further instigated "Global" and "Local" interactions with "real" and "virtual" world providing immense opportunity for developing user driven community platforms for SRD interventions for real concerns [14–16]. Design researchers are leveraging the advantages of such social technologies to increase user participation in decision making to gather a heterogeneous perspective on problems [14, 17, 18]. This necessitates the exploration of how blurring of strict boundaries between user, designer, and a social agent is diluting dichotomies between user/designer, social-worker/capitalist, consumer/producer, use/profit, or need/desire. Hence, this paper is an epistemic inquiry into the trajectory of user participation in responsible decision-making through the analysis of six design frameworks holding different kinds and extents of social accountability. Thereby seeking, twofold objective: (a) to establish the theoretical antecedents of user participation in design for social responsibility, and (b) to assess the future of responsible design decisions in discourse and practice.

2 Trajectory of Design Frameworks

In this section, we attempt to elaborate the trajectory of design discourse on user participation in design for social responsibility. The significance of any design framework lies in the central aspect of problem solving, participation of agents in design process and nature of design outcome. Hence, here we observe, analyze and comprehend the trajectory of design framework and the extent of SRD from 3 aspects; (1) changing "Centrality of the framework", (2) Changing role, participation and process and (3) Changing design intervention. Centrality of the framework can be defined as the principal construct on which problems are approached and solved. It is generally understood in two ways, first "User Centered Design", and second "Concern Centered design". In the former approach user is the center of design. Users are an essential actor in design research, study and practice. They provides the psychological, social, economic, and contextual dimension to design process and intervention for SRD. Users are visualized as end-users for whom artifacts are designed, therefore, user ergonomics, user need, user satisfaction, user empathy, and user experience are thoroughly studied and practiced before and after designing. Such design problems are "factual" in nature. On the other hand, in "Concern Centered Design" collective shared problems become community concerns that require in depth understanding of the system consisting of multiple user groups with interlinked complexity and localized conflicting conditions.

Besides, Centrality of the framework, the changing role, participation and process is also in important indicator of SRD providing insights on the extent of collaboration amongst users, stakeholders and designers. Degree of participation of each agent (user, designer and stakeholder) assists in comprehending the consequences of decisions and predict the future of collaboration for SRD. Lastly nature of "Changing design intervention" provides insights on the sustainable aspect of design and extent of SRD. With this in mind, we have selected 6 design frameworks i.e. user centered design, participatory design, co-design, social design, community driven and user driven design to understand, analyse and comprehend the association of all these 3 aspect of study and their relation to SRD.

2.1 Six Design Frameworks

User centered framework is the most extensively used design framework to solve usability aspect of design. Participatory design and co design approaches are grounded with the participation of user and other stakeholder in the design process to bring empathy and heterogeneous perspective in design. These frameworks had been widely applied as both "user" or "concern" centered design process. In our work, we are studying these frameworks under "user centrality". Social design, community driven and user driven design frameworks are participatory approaches with concern centrality. Table 1 elaborates the distinct characteristics of all six design frameworks to compare the trajectory of user participation in responsible decision-making, different kinds and extents of social accountability.

3 Design Discourse on Changing Collaboration

In order to study, analyze and comprehend the trajectory of above mention six design frameworks and the extent of SRD from the aspects of changing "Centrality of the framework", Changing role, participation and process, Changing design intervention Table 1 is designed to encompass sub aspect of above mentioned criteria. Frameworks of design are arranged in chronological order. In the table all selected frameworks mentioned are compared based on following sub-aspect; (1) Nature of problem, (2) Factors affecting design (magnitude of complexity), (3) Role of: Consumer as User, User as Designer and User as Consumer, (4) Role of Designer in the process, (5) Role of design, (6) Goal of design. Here, changing centrality of the design framework elucidates the shifting nature of design inquiry and factors affecting the design decisions of each design framework. Changing role, participation and process elucidates the factor affecting the design decision, changing role of user (consumer as user, user as designer and user as consumer) and changing role of designer in each framework. Lastly, the changing nature of intervention is associated with the role and goal of the framework from the table. Each of the three broad aspect of design framework derived from explains the extent of SRD in the further section of the paper.

3.1 Changing "Centrality": User and Social Concern

The nature of problem of user centered, participatory and co-design frameworks as shown in table are directly associated with the user problem, need and wants. Centrality of "user" approach addresses "factual" design problems. On the other, in social design, community driven and user driven frameworks are associated with "social concerns" with the centrality of "common concern". Social concerns are

Table 1 Elaboration of 6 frameworks to study the extent of SRD from through following factors: Nature of problem, Factors affecting Design Decision, various role of user, role of designer, role of design and goal of design [10, 11, 13, 15–17, 19–24]

Framework	User centred (1970)	Participatory (1978)	Co-design (1978)
Authors	Harker, S. D. P. Eason, K.D. (1984), Jordan, P. W. (2000), Johan Redström (2005), Donald Arthur Norman (2015)	FINN KENSING, JEANETTE BLOMBERG (1998), Johnson (1998), CLAY SPINUZZI (2008).	Doullas schuler (1993), Sanders, Elizabeth B.-N. Stappers, Pieter Jan (2008), Deborah Szebeko1, Lauren Tan (2010), Marc Steen (2013)
Nature of problem	User problem, user experience	User issue, user experience	User experience for design
Factors affecting design decisions	Human factors issues	Actual use context and workers need knowledge of possible technological	Co-design originate from business or marketing, rather than for end-users
Role of user as			
Consumer as user	Personas of end users: usability testing with a small sample	Personas of End users: Usability testing with a small sample	Personas of End users: Usability testing with a small sample
User as designer	No direct role: user data assists designers to design for End user	Active participant: to bring empathy in design	Co-designer: share experience and knowledge and collaborate
User as consumer	End user and consumer	End user and consumer of the designed artefact	End user and consumer of the designed artefact
Role of designer	Design according to the user data to meet the needs of the user population	Design with shared experiences of user	Co design, learn and empathise with the people affected by the problem
Role of design	Meet user needs and capabilities	Improve usability, ease of use	Negotiated interpretation of the work organization in question
Goals for design	User satisfaction	User satisfaction	Improve usability, ease of use, sustainable system
Example	Consumer products	Workstation design, tool design, participatory architecture	www.NIKEiD.com (customised shoes) Utopia project (organisational alternatives), Florence project (health sector)

(continued)

Table 1 (continued)

Framework	Social worker (2002)	Community driven (1995)	User driven (2005)
Authors	Victor Margolin (2002), Lucy Kimbell and Joe Julier (2012), Niedderer, Kristina (2013), Vardouli, Theodora (2015)	Narayan, Deepa (1995), Alina Huldtgren, Christian Detweiler (2013), Sanders, Elizabeth B.-N. Stappers, Pieter Jan (2008), Cinnamon L. (2015)	Hagen, Penny Robertson, Toni (2012), Erling Bjögvinsson, Pelle Ehn, Per-Anders Hillgren (2012) Susana Nascimento, Alexandre Pólvora (2013), Vardouli, Theodora (2015), Irwin, Terry (2015)
Nature of problem	Real world need, solving social problem	Situation-centred, community concerns	Complex socio- cultural and environmental concerns
Factors affecting design decisions	Political and social circumstances, and organizational structures	Complex, multidimensional understanding of people and their environment	Solving problems within multi-stakeholder "ecologies"
Role of user as			
Consumer as user	Community member or stakeholders	Community ownership and inclusive participation, volunteers, solutions are proposed for, and even implemented within communities	Person with common concern
User as designer	Member of intervention team		User shape artefact through use, in community settings. It is a user driven design
User as consumer	End user and consumer empowered for change	Community member are consumer	Empowered community member
Role of designer	Member of intervention team aiding Collective negotiation	Designer has to place himself as community member	Designer is facilitates platform for negotiation. No direct input in design decisions
Role of design	Empowering user with appropriate intervention	Empower community by consensus intervention	Social technologies platform for negotiating common conflicts and bring consensus
Goals for design	Sustainable benefit to society	Sustainability and efficient long-term co-creation	Empower multiplicity of voices, democratized designConnecting local with global
Example	Elderly environment for living alone, health care, education, devices that address pollution problems	UNICEF in low income housing in Guatemala, Rural water supply in Kenya	Nnub electronic community noticeboard

complex concerns with conflicting needs of stakeholder. User is the subject of the study in user centered design approaches and conceptualized as the possible end-user, for whom artifacts are designed, therefore, user ergonomics, user need, user satisfaction, user empathy, and user experience have been thoroughly studied and practiced in design discourse [2, 25]. Factual design can resolve issue of users with design intervention, where a generalized solution will cater to the need of user. The heterogeneity of user is not considered in terms of their context and capabilities and follows a top down centralized design approach. While concern centered design are bottom up decentralized systemic approaches, where complexity of concern and conflicts from heterogeneous stakeholder's to system level are mapped and intervention is proposed or emerged from collective consensus. Dynamics of conflicts in social concerns are unique in nature which requires a more focused and co-created intervention. Problem perception for SRD from the lenses of user will differ drastically from the lenses of community concern; a user problem will be associated with the direct consequences of discomfort, usability issue etc, on the other the magnitude of common concern are highly complex associated with the goodwill of community and environment as a whole. Designer while addressing user "factual problem" in isolation might lead to adding to more conflicts in the social concerns as criticized by many researchers. It has led to, still leading to bombardment of product in the market, and neglecting its consequence on social and environmental level. Factual approaches are not appropriate design framework for bringing sustainable and socially responsible design solution. Designing for social concerns purposes, benefit to all community members through collective actions of heterogeneous user with equitable negotiation in design decisions. Collective action towards common concern can resolve complex concerns in most effective manner. With the advancement of technology, real and virtual world interaction or IoT, localized communities with similar concerns are connected without the limitation of geographical boundaries and are emerging as one global community collectively acting for a common goal. In user driven framework, active and empowered agents with common concerns are connected with each other to resolve concerns locally and a "Global community" action emerges. Advancements of technology, open design or IoT provide a platform for equitable negotiation to address complex concerns of society most appropriately for SRD where communities are emerging out of the 'common concerns'.

3.2 *Changing Role, Participation and Process*

The magnitude of problem addressed in terms of factors affecting the problem in design inquiry are increasing left to right in the table. The magnitudes of design concerns are changing from simple "factual" problems of user, to social problem of community, to more complex socio-cultural and environmental concerns. It is interesting to observe with increasing complexity of design inquiry degrees of participations are increasing to bring heterogeneous perspective and conflict negotiation among stakeholders as shown in the table. The role of user is changing in the design process as shown in the table (consumer as user, user as designer and user as consumer) from left to right, user is changing from being a "subject" of study with passive role to "empowered member of community" capable of resolving common concern through localized actions. With changing design, discourse from centrality of user to social concern a stark difference in design process in terms of roles of designer user and stakeholder can be observed moving left to right in the table. Design process is becoming more decentralized upto the extent that user and designer shares equal power in user driven framework where designers are facilitating the process of design and user are the active decision maker at local level. With the advancement of technology, nature of participation has changed drastically; it provides a medium for participation both at "local and global level" and "real and virtual world" in the design process. User is no longer seen as isolated entity, they are member of networked society capable of inspiring many others to act collectively for the common concerns. This provides another interesting insight; designer and non-designers no longer stay at distance both learn from each other. Informal practices of design are becoming more formal or vice versa in this process. A user driven framework is most appropriate for SRD where social responsibility is shared among all the stakeholders and solution emerges from collective actions for a sustainable intervention.

3.3 Changing Design Intervention

Moving from left to right in table it is evident that design is shifting form "consumer product" to user satisfaction to "sustainable community intervention". Designers of user driven framework have realized an intervention alone cannot resolve "complex social concerns". It empowers end user with appropriate tools and knowledge (local and global) to solve issues at local levels and eventually lead to collective negotiation for "complex concerns". With Advancement of technology Intervention are no longer tested and evaluated on the concept of "use before use" but it is changing to evaluate and test "design after use" or "design with use" [19]. Interventions emerges with usage, this implies the interventions is no longer static they are dynamic and highly customised for each user to tackle localized contextual problem in most appropriate manner and these action will create a global pattern of activities of the intervention which will define its functionality. Interventions are mode to connect, interact, share knowledge and negotiate conflicts for common goals.

4 Assemblage Towards Community of Design Practice

From the current trends, it is evident that design for “concerns” with empowered users to resolve localized concerns in decentralized way is most appropriate SRD where social responsibility and accountability is shared among all the agents of society collectively negotiating for sustainable future. With advance of technology interconnected “local and global” and “real and virtual world” dilutes the boundaries of sharing geographical spaces and emerge as “new collective”. In our coming future we are about to witness a new model of collaboration for SRD among “**new collective**” with **common concerns** becoming a community to resolve localized concerns with globalized practices with appropriate **intervention** to facilitate tools and knowledge for collective actions.

This form of collaboration is completely aligned to the philosophy of community of practice (CoP) proposed by cognitive anthropologist Jean Lave and educational theorist Etienne Wenger in 1991 [26, 27]. The term communities of practice describe collective learning through practice and participation among groups of people with similar concerns or a passion interacting regularly to learn collectively and evolve practices with situated learning. The most important features of CoP are: domain, community and practice.

Domain is explained as shared interest among the members, where membership is based on the commitment towards the interest. Members are not forced with any duty, but to commitment to pursue their own interest. **Community** emerge from the group pursuing their common interest, engaged in joint activities, help each other, and share information. **Practice** can be defined as the continuous development or acting towards the common interest collectively with shared repertoire of resources: stories, experiences, tools, process of addressing recurring problems [26, 27].

Further, the aim and purpose of Idea of domain, community and practices in CoP perfectly corresponds to the idea of common concerns, new collective and intervention respectively for appropriate SRD. Hence, we comprehend that Community of Design Practices is the future of collaboration for SRD. Community of design practices is a promising framework for complex problem solving methodology, capable to understand interlinked multi-layered problem and local interconnected actions required to address the complex social concerns. Community of design practices are emerging and will lead to a complete user driven system where entire aim is to bring change in local action for sustainable global change.

5 Conclusion

Design world is slowly but surely moving from design for facts to the design for concerns. Concerns are global systems with decentralized sub-components on which singular universal solutions cannot be easily adopted. Here, users are not merely subject of a study or a targeted consumer persona, but active and empowered participants of local resolutions. Therefore, problem solving emerges from localised knowledge, resources and skills of a community of practice who share a similar but not the same concern. Small localised practices of multiple and heterogeneous agent enables the community to resolve a shared common interest/concern. Unlike a user, group which is dependent on external entities for resolving facts, communities of design practice share the responsibility of the concern as well as its resolution. However, design concerns are contested unlike design facts which are the consequence of a consensus itself. This increases the kind and extent of negotiations required to resolve a concern. Consensus emerges amongst active agents in practice where each agent is an empowered decision maker, unlike the conventional design world where a small majority (active designers) negotiates for the large majority (passive non-designers or users as consumers). However, with the shift in the passive role of users to active agents of change, design is fast transforming into the result of negotiations of a community of practice whose individual members contest as well as resolves a shared interest. Empowered with social technologies, these communities do not necessarily share a common space, time or resource, yet they not only affect themselves but also all other communities grappling with a similar concern as they practice and learn to practice it better with regular interactions amongst each other. However, such learning trajectories based on the alignment of the design concern in the interest, aspirations and intentions of the participant are informal and learned in practice. Design world is currently not geared towards such situated learning for non-designers participating in a community of practice. Self-organised learning methods, of course exist as pointed out by Lave & Wenger, but scaffolding the learning path will strengthen the emergence and sustainability of such communities.

Although, pedagogical tools for community of design practices are not yet designed, but advancement of technology has opened channels for the development of artefacts as tools for negotiation and democratisation. Artefacts developed for communities of practice mediate collaboration among heterogeneous agents bridging the gap of space and time. Interconnected artefacts (directly or indirectly) asset in the negotiation of content (wikipedia), resources (ola app), actions (vote), and conflicts (waze). They also facilitate democratisation of participation of agents, their activities and voices. However, most of such design platforms either do not address a design concern directly or transform the user into a decision maker. But, if pursued, they do have the potential to address these lacunas. Community of design practices will emerge as complex problem solving methodology, capable to understand interlinked multi-layered problem and local interconnected actions required to address the complex social concerns. Artefacts for community of design practices are emerging and will lead to a complete user driven system where entire aim is to bring change in local action for sustainable global change. Extensive research is desirable in the domain of artefact-artefact and human-artefact interactions for local and global equitable negotiations and actions within a community of practice.

From the trend of design and innovation model presented in this paper, we may conclude that we are heading towards a future with no designer. Community of design practice will emerge as a decentralised model of design where user and designer will share the similar role and power. Soon it will be a completely user driven system where designer has created tools to empower user to solve issues at local levels. Every agent will be acting locally around them and change the dynamics of the overall complex problem to a favourable state of a self-organised and self-adaptable system. With advancement of cloud computing and ICT (information communication technology) we are going to witness such collective actions really soon. Such community of design practices will lead to two possibilities: one a state of utopia where every agent is working and solving issues at local level for collective reasons and the design tools are getting used with the maximum efficiency. And second, state of complete chaos with negative consequences of designed tools implementation for local context which may emerge as destructive system with much more complex problems.

We are at a nascent stage of community of design practice research. We are about to face the complexities of community of design practices emerging as platforms for collective negotiation for common concerns and it is inevitable. This poses a bigger challenge in design discourse to create design tools for collective benefit and not a mad mob. We need human decision simulation, behaviour prediction and positive persuasion with the help of technology and better design method and design approach.

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Decision-Making Support in Engineering Design Based on Collaborative Dashboards: Integration of Business Intelligence Techniques

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Abstract Nowadays, the companies' data sources are multiple, large and complex. That's why the difficulty is not to collect data, but to make them available in the right form at the right time and for the right person who will exploit and benefit from their added value. There is a need to analyze data in order to have a global vision and to create, from the raw data of the company, an operational and profitable information helping project monitoring and decision making. Therefore, in this paper, we aim to propose an approach to support decision making processes. This approach implemented thanks to an Information Technology (IT) architecture, combines three business process modules (multiple actors and data sources). Our main objectives are to extract Key Performance Indicators (KPI's) from different data sources and to visualize them using Business Intelligence (BI) techniques (precisely data visualization techniques and dashboarding). Our approach is finally illustrated by an implementation on a case study.

Keywords Business intelligence · Key performance indicators · Decision making · Dashboard management · Collaborative design

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1 Introduction

Whatever the company, its activities and its business model, the success of its strategy heavily depends on its consistency with the information system (IS), supporting decision making.

To be responsive, prospective and effective, each expert can support his/her decision process by dashboards elaboration and utilization, consisting in carefully selecting Performance Indicators (PI) and Key Performance Indicator (KPI). The dashboard can thereby be considered as an assistant of the decision maker in its efforts to continuously improve performance within the meaning of the strategy pursued. With the great increasing volume of data in industrial and business environments and the multiplicity of data sources, it becomes increasingly difficult to consider all the information for decisions and company's strategies elaboration. To support these processes, establish Business Intelligence (BI) solutions can be considered as decisive to extract, analyze and visualize data.

The aim of this paper is to propose an architecture to support BI techniques to pilot collaborative engineering projects. It is organized as follows. First, we present the different company data sources, such as Product Lifecycle Management (PLM) systems Enterprise Resource Planning (ERP) systems, etc., some methods for KPI's extraction and data visualization techniques, BI system and engineering collaboration context. Then, we propose an architecture which can help decision making in a collaborative engineering environment by the implementation of BI system based on data visualization (especially dashboarding technique). Finally, to validate this proposal, we present a prototype, implemented on a case study, to illustrate our approach.

2 Context and State of the Art

2.1 PLM and ERP as Rich Company's Data Sources

PLM is the name of business area whose purpose is to create and maintain the definition of products throughout their lifecycle [1, 2].

The data related to the product development and production processes (starting from the design, through the development and to fabrication) is in both cases more diverse, numerous and expensive to handle [3, 4]. PLM manages that information through flexible data models, able to withstand the complexity established between processes, projects and product design [4]. PLM also provides easy access to expertise across the product lifecycle to help manufacturers to design well and produce better innovative products faster and cheaper [2, 4]. The PLM system's implementation for the company can generate an important and operational database and product/process knowledge can be extracted from it [1, 2, 4]. PLM system plays a crucial role in managing the strategic planning and development of a company. Other IT systems also contribute to information storage and sharing. For example, ERP, Customer Relationship Management (CRM) software and Supply Chain Management (SCM) can also be considered as a great data source.

ERP is a software that manages all company processes, integrating all its functions such as human resources management, financial management and accounting, sale, distribution, supply, production or even e-commerce [5, 6]. PLM and ERP are generally connected allowing to communicate information from design department to the production department in a transparent manner. Similarly, PLM users need to have access to ERP information, because it has an impact on quality measures and subsequent design decisions [7].

Considering the product data as business information circulating through various companies' modules, companies are able to develop good practices that enable them to improve their competitiveness [2]. After defining such practices, companies can assess the needs of their IS in all areas and particularly for PLM and ERP. So we can say that, from a collaborative engineering point of view, PLM and ERP can be considered as two important information sources.

2.2 KPI's/PI's Extraction from Company's Data

The company's decision-makers cannot catch and understand the whole information located in the data in its raw format. However, available data on company's IT systems are crucial to the success of any business strategy. So one challenge is to make these data understandable and usable.

The idea behind PI's (Performance Indicators) is to be able to transform data to represent them in a comprehensive way by all business partners or decision makers [8]. PI's are mainly built from rates, quotients, percentages, averages and other mathematical treatments. On the contrary to raw numbers, they put the data in a specific context by providing explanations instead of presenting tabular manner [9]. To fulfill its mission of assisting and facilitating decision-making, a PI measures the performance in the direction of the chosen strategy. It is adapted to a specific context and is consistent with the specific expectations of each decision maker [9].

A KPI (Key Performance Indicator) is a measure of a critical aspect of the overall project performance [1, 2, 9]. That is why KPI's drive to the critical decisions to business strategies [10], "KPIs can be used to monitor systems, to supervise the quality of services, detect issues and trigger appropriate actions" [3]. For our paper, we take an interest in KPI's extraction and visualization.

The relationship between KPI's and business data sources (ERP, PLM …) was for a long time a subject of research. The tremendous amount of product data in company databases presents a rich source of strategic information to build KPI's. "From ERP point of view, it is important to choose the right KPI's after having a good understanding of what is important to the organization" [5]. "A lack of studies on how to appropriately extract and analyze KPI's from PDM databases deterred manufactures from using the product data to evaluate product development" [11].

The performance measurement system through KPI's is a tool for aid, assistance and anticipation. The information for decision making must be formulated, available and exploitable; one of considered as KPI's presentation support is the dashboard.

2.3 Data Visualization and Dashboarding

Only by using visualization, the human brain succeeds to elaborate, develop, absorb and interpret at the same time large amounts of information. Passing of arrays to dynamic and interactive graphics, the human brain acquires a synthetic view of company's activities.

Data visualization is defined as visual exploration and interactive graphic representation of data from all volumetric, nature and origin. It is characterized by a graphical approach to describe quantitative and qualitative information to allow the identification of trends and evolution that might be invisible [12, 13]. On one hand, it is a concept that combines the study of behavior and perception of the human being (not our field of study). But on the other hand, it can be considered as an intuitive approach to interpret data and make business decisions in a short time. It helps making the right decisions at the right time [12, 14]. It can be applied in different domains: data analysis to create and share consistent reporting; optimization of business processes; analytical predictions to identify and anticipate future trends etc.

A dashboard is a data visualization tool that displays metrics and KPI's for a company on a single screen. Dashboards are informative support presenting summarized information, aiming for example to assess the project progress or the objectives' achievement with indicators [14]. Dashboarding is a set of techniques that allows seeking information relevant to business activities, to get immediate value from company's data, through a visual approach [15].

Thanks to dashboards, decision-makers have easily access to information to understand and share information. It also allows to constantly keep KPI's under control. So we move from disparate information from the most diverse sources, to shared and consolidated information.

Thus, thanks to data visualization, and especially dashboarding technic, company leaders and decision makers have instant access to information and have the ability to use advanced analytical capabilities, without the complexities inherent to original data structures. But the elaboration of a decision-making system passing from raw data to useful information go through a chain of techniques and tools constitutive of BI approach.

2.4 Business Intelligence Approach: Techniques and Main Components

A BI approach is a solution to collect, analyze and process all company data according to specific criteria. The results of this analysis allow managers to obtain an overview of their activity [10, 16]. The main BI's objectives are to help making the right decision at the right time. So, BI helps ensuring coherence between strategic objectives and management actions [17]. BI approach is defined as all resources, tools and methods supporting collection, consolidation, modeling, analysis and delivery of information [18]. The BI process is designed to recover raw data (contained in tools such as ERP, CRM …) and transforms them into information and disseminates them as dashboards and reports.

Finally, it seems essential to define the main components of a BI system:

- ETL (Extract, Transform, and Load) is a middleware software technology allowing performing massive synchronization of data from one database to another [16].
- Datawarehouse is a database used to collect and store volatile information coming from other databases [16].
- OLAP is an abstract representation of multidimensional information that enables simplicity and speed of access to information already aggregated according to user needs, and provides the ability to manipulate them within different dimensions [2, 16].

The implementation of a BI system is generally linked to a specific context within the company; for this paper, our center of interest is the collaborative engineering.

2.5 Collaborative Engineering

Given new industrial challenges, the concept of collaborative engineering has been developed within companies and has become compulsory [19]. The collaborative engineering allows various business entities to share knowledge at different project's stages or product lifecycle (design, industrialization, maintenance, recycling …). Therefore, it allows a remote working and aims to facilitate the development of products by providing simultaneous and collaborative work of different stakeholders in a business or workgroup [20].

In this context, a collaborative platform is a system that communicates with tools and applications of an IS (ERP, CRM, administrative tools, financial planning tool …). It offers a broad vision of information by sharing all operational data within a single repository [20]. The implementation of a collaborative platform has been facilitated by the emergence of digital data exchange systems that helped to involve various company departments [20]. Thus, all stakeholders know at any time the project's progress. Once a company system makes a change to a project or product data, other systems are notified automatically.

In this section, several topics such as PLM, ERP, KPI's extraction, dashboarding and collaborative engineering have been presented in order to present the context and the state of the art of this paper. In the next section we propose a solution to exploit business data and extract useful information for decision making by combining several presented approaches.

3 A Framework for Piloting Collaborative Engineering Tasks: From Raw Data to Decision Support Using Dashboards

For this paper, the proposal is to specify a platform that provides collaborative dashboards, facilitating project management and decision making in a collaborative engineering context. As illustrated on Fig. 1, its main idea is (1) to extract information from data available in company IS, (2) to give the ability to exploit, analyze and exchange information extracted through various means technically heterogeneous and (3) to provide dashboards which display KPIs, that reflect the state of collaborative projects by giving an idea of the project advancement, according to different views (time, human resources, costs …). These dashboards provide useful information for analyzer and decision maker through different forms of data presentation (graphics, charts, diagrams …).

The first module of our approach is focused on the data collection process. For this objective, we propose a data warehouse storing collected data, after a cleaning and loading phase through an ETL. Datawarehouse and ETL are fundamental techniques for all BI solutions; they allow feeding system with operational data for analyzing and decision making [21]. Like illustrated on (cf. Fig. 1a), for collaborative engineering purpose, data mainly come from IT components like ERP, CRM and PLM systems.

The second main challenge of our platform is to ensure interoperability and to make data accessible through several ways and through multiple protocols and networks. To access the datawarehouse from different networks, SOA architecture [22] has been chosen (cf. Fig. 1b) to interact with the system and consume the data available in the data warehouse via Internet browser and through web services.

Finally, as the third part of our approach, KPI's will be extracted from data warehouse and visualized on dashboards, according to decision maker and analyzer needs (cf. Fig. 1c).

With one glance at the dashboard, the decision maker captures all information and can assess the situation without wasting time and can take the appropriate decision. Figure 2 illustrates the fact custom dashboard building is made possible and considered as essential. To be effective, each decision maker has to build his/her own dashboard, consisting of carefully selected indicators. But some parts

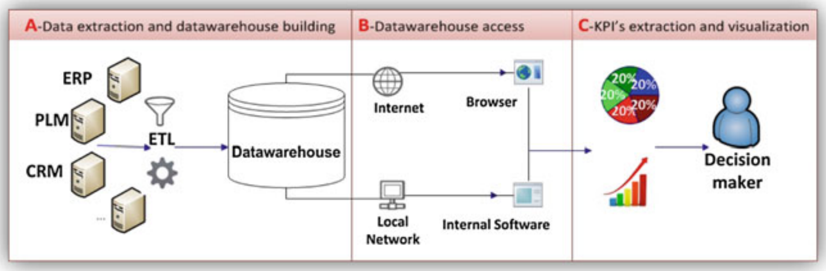

Fig. 1 Framework architecture for KPI's extraction analysis and visualization from company's data through BI tools

(widgets) of his/her dashboard could be interesting or critical for other colleagues or superiors. So he/she has the opportunity to share indicators and/or associated widgets. A widget can be considered as a generic term for a part of a GUI (Graphical User Interface) that allows the user to interact with the application. Widgets display information and invite the user to act in a number of ways. Typical widgets include buttons, dialog boxes, pop-up windows, menus, icons, scroll bars, progress indicators, forms, etc. In our case, the term "widget" is used to refer to the graphical component that composes the dashboard.

Dashboards include one or more widgets, which offer an overview of dimensions and metrics that interest the most decision maker. This allows him/her to give

Fig. 2 Dashboards based on KPI's visualization and shareable widgets as project monitoring and decision making support

to his/her team an overview of his/her contribution to the overall company performance. Defined a set of KPIs to monitor, and identifies the relationship with the performance of other services and project actions. So, monitoring becomes clear and everyone can see lively where he/she is in relation to objectives.

In this section, we propose an architecture of a platform that provides collaborative dashboards facilitating project management in collaborative engineering context. In the next section we present an implemented prototype to illustrate our approach.

4 Case Study

This case study is based on the usage of the presented collaborative platform in a research laboratory, with the purpose to drive collaborative projects, implicating nine researchers.

4.1 Prototype Structure

Our approach is based on a software called Odoo,[1] an open source platform that includes numerous built-in features and interoperability support. The founding principle of Odoo is to build modules for various purposes, knowing that these modules are independent of each other, but sharing a single database. Odoo, with its integrated BI module, offers navigable graphics, custom statistics and enables to display custom dashboards for each user. Thanks to this BI module, we offer for each researcher his/her own personalized dashboard that is composed of widgets that expose selected KPI's. These KPI's are extracted to drive collaborative projects and provides an overview of project situation. Odoo, with its integrated BI module, offers navigable graphics, custom statistics and enables the display of custom dashboards for each user. Thanks to this BI module, we offer for each researcher his own personalized dashboard that is composed of widgets that expose selected KPI's. These KPI's are extracted to drive collaborative projects and provides an overview of project situation.

On another side, Odoo proposes great opportunities in term of interoperability. Thanks to the web-services architecture, it provides excellent integration with other company's software and information systems. In our case, we are communicating with Odoo directly from Microsoft Outlook[2] via XML/RPC web services.

[1] https://www.odoo.com.

[2] https://www.microsoft.com/en-us/outlook-com/.

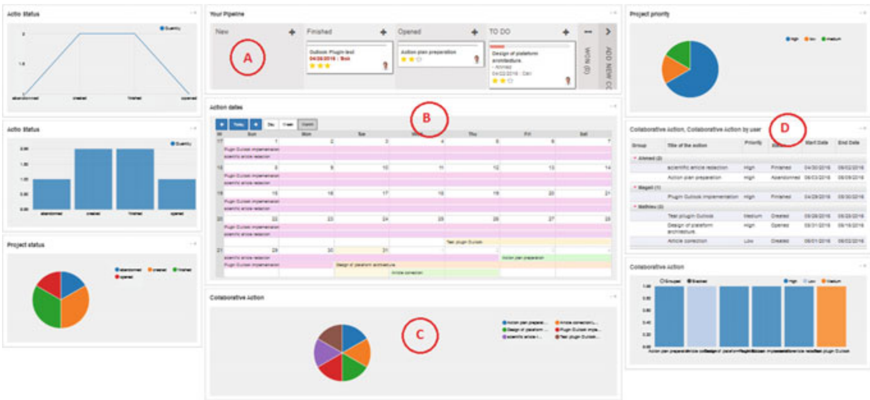

Fig. 3 Customized dashboard based on different graphic forms to visualize information in the most adequate way

4.2 *Dashboards Building and KPI's Visualization: Experimental Results*

As indicated previously, our approach is essentially based on providing a personal dashboard for each user, who can be alternatively actor or decision maker.

So each user has the opportunity to select widgets and configure them to visualize specific KPI's. In the example presented in the Fig. 3, a customized dashboard for a researcher is introduced.

In this example, the researcher uses different widgets to visualize chosen indicators in the adequate forms: Kanban view for tasks management (cf. Fig. 3a), Calendar view for deadlines and projects planning (cf. Fig. 3b), Pie views to visualize project status and priority (cf. Fig. 3c), Tree view to illustrate all actions and items grouped by assigned personals (cf. Fig. 3d), etc. By giving the opportunity to each user to choose the useful information and the associated widget, the framework allows to build tailored graphical representation, supporting decision making process.

5 Conclusion and Future Work

In this paper, an architecture to facilitate decision making in a collaborative engineering projects context has been proposed and illustrated. The framework, issued from the approach proposed in this paper, allows users to extract information from company's data sources, to generate KPI's reflecting business strategy and to visualize them, using BI methods, precisely dashboarding.

A case study, based on a collaborative project management in a research laboratory, has been built with a limited user number and data volume. The future challenge is to apply this approach in an industrial context in which data is characterized by a huge volume, and a wide variety (structured and unstructured data). Specific mechanisms to calculate KPI's from extracted data will also have to be proposed.

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