A Forward Look at Computational Support for Conceptual Design

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Abstract. Future research needs for computational support for conceptual design are examined. The material is the result of the work of a so called *design cluster*. The cluster has, through a series of workshops, defined what it believes are the salient areas in which further research is needed. The work has a strong people centred approach as it is believed that, for the near future, it is only through a combination of man and machine that acceptable designs will be achieved. The cluster has identified 5 key areas and 39 sub-classes. The discussion focuses on the key areas and how these link to future research requirements in people centred computation for conceptual design.

1 Introduction

In 2004, two of the UK's research councils, the Arts and Humanities Research Council and the Engineering and Physical Sciences Research Council launched an initiative to set the future design research agenda for the UK. The initiative invited bids for funding for "*design clusters*". These were to be groups of people who would spend a year looking at a design area of their choosing. The bids were to contain information regarding the people within the proposed cluster, the programme of work and the deliverables. Bidders were encouraged to be as innovative as possible in their thinking and also multi-disciplinary. It was hoped that by bringing together people from diverse backgrounds that generic ideas and concepts would emerge.

The call for proposals was aimed as widely as possible, including, for example, choreographers, as well as more traditional design backgrounds. A substantial number of bids were received from which 20 clusters were selected. One of the successful clusters is entitled *Discovery in Design: People Centred Computational Issues* and the work and findings of this cluster form the subject matter of this paper.

2 The Discovery in Design Cluster

The cluster consists of both academics and industrialists. As well as people from traditional engineering backgrounds such as aerospace, military, chemical and civil engineering, there are people who work on drug discovery, art based product design, user interfaces, design of new materials, biochemical sensors and software. The

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cluster has a central core of people who have experience in the usage of software techniques to support conceptual design and particularly in the use of evolutionary computation. Also, the cluster has an emphasis on human factors. Cluster members believe that the way forward is a cooperative blending of knowledge and skills between humans and computers. To ensure that human factors are fully considered, the cluster also contains psychologists and social scientists. The objective of the cluster was defined as "… *to identify primary research aspects concerning the development of people-centred computational design environments that engender concept and knowledge discovery across diverse design domains"*.

The cluster's main way of working has been through a series of four workshops. The participants have been the members of the cluster (typically some 15 of these attended each workshop) plus invited guests. Most of the guests have strong track records in design. However there were one or two people from other disciplines such as, for example, a specialist in detecting and predicting trends relating to lifestyles and fashions. In all cases the guests gave presentations on their particular speciality. Further information about the cluster can be found at www.ip-cc.org.uk.

3 The Workshops

The first three workshops were used to explore ideas and concepts and to highlight problems and weaknesses in terms of conceptual design and its computational support. These were then explored as potential areas for future research. This was an essentially divergent process. The fourth workshop was convergent, with the work of the previous workshops being analysed and synthesized.

4 Previous Work

There have been a number of other efforts to develop *roadmaps* for future research directions. For the construction industry alone notable examples which have concentrated on IT are the FIATECH / NSF initiative [3] and Amor at al [1]. Predicting what technologies will succeed in the future is always difficult and often the real breakthroughs come from something which cannot be foreseen. This is always a problem with roadmapping exercises. The cluster has largely avoided the pitfall of prediction and has limited itself to identifying areas of need. Also the focus of the cluster is different in that it is multi-disciplinary.

5 The Key Areas

In the following, the main findings of the cluster are presented in terms of future research needs. The cluster identified five key areas for future work, based on an examination of the deficiencies in current technologies, these being :-

- Understanding humans
- Representation
- Enabling environment for collaboration and user interaction

- Two way knowledge capture
- Search and exploration

In addition to the 5 key areas, a large number of sub-classes were identified. These are also discussed below.

5.1 Understanding Humans

There was a discussion about whether or not this area should be included. This is a well established area of research in which many research teams are working. Hence, some people thought that it was outside the cluster's remit and that by including knowledge capture and enabling environments, human factors were sufficiently considered. However the majority argued that without understanding human needs, abilities and reactions to different developments, the proposed research would never fulfil its aims. It should be appreciated though that the cluster's suggestion is limited to the specific context of conceptual design assisted by computational support rather than a more global understanding of human behaviour.

The basic argument is that, computational tools have to fit in with human capabilities and needs. For example humans are very good at pattern matching and assimilating visual information, although from any image they typically only take in 30% of the information. Research is needed to better define human abilities, especially in relation to design. The design studies undertaken to date (e.g. [6]) have shown that designers have problems with cognitive overload and bias and tend to stick with their initial thoughts and decisions. One obvious area for research is to ensure that the sort of software environments that are envisaged, will help designers to avoid these problems. The other research need is that of communication between the user and the computer, not in the terms described in the knowledge capture section but more in the fundamental area of what sort of tools and interface strategies are best suited to transferring information. Finally the cluster unanimously agreed that any software should ideally be exciting and interesting to use. This is something which design software has so far largely failed to achieve.

5.2 Representation

The term representation caused the cluster problems because it means different things to different people. Some within the cluster argued against representation being a research area because they considered that it is a part of search and exploration. However once the cluster had fixed on a common definition, it was agreed that representation should be included. The cluster's definition of representation is that it includes all areas within the software where the properties and characteristics of the problem domain are described. If the specific example of genetic algorithms is considered, the genome and the coding strategy are a part, as is the fitness function. Also as Zhang & Miles [7] show, for certain classes of problems, crossover and mutation can affect the form of the final solution and so, some cases can be considered to be a part of the representation.

To date, much of the representation used, especially in genetic algorithms, has relied on the ability of the problem to be expressed as a series of parameters. As Zhang et al [8] show, for some classes of problems such as topological search, this can be limiting. Also, one of the forthcoming challenges for design software is for it to be able to tackle complex, multi-participant, multi-objective, highly constrained problems. These will require far more complex representation strategies than are currently used. The work of some cluster members on software design has shown that there are many areas for which the development of the relevant software techniques is still in its infancy. Even for the more mature domains, there are significant challenges in terms of representation techniques. For example, for topological search, there is yet to be an established a generic form of representation which can handle a multiplicity of highly complex shapes. Without this, true topological search is not possible.

Although representation has not been a significant limiting factor to date, as work progresses in other areas, the limitations of current strategies will start to hinder progress and the need for further work in this area will become more apparent.

5.3 Enabling Environment for Collaboration and User Interaction

The cluster looked at current technology and what is required if it is to be advanced to cope with the complexity of many common design problems. A lot of work has been done on creating techniques to find areas of high performance within design spaces and to present the results to the designer [4] but these methods have so far largely been applied to single designer or single discipline problems and the communication is largely in one direction, from the computer to the designer. Many design problems are multi-disciplinary and involve large design teams. These people are typically tackling complex design problems with massive, multi-dimensional search spaces which contain areas of non-linearity and discontinuities. Enabling designers to understand the form of search spaces is a necessity and a major challenge.

The complexity of these search spaces is such that any attempt to communicate the findings of a design search to the users is likely to lead to significant problems with cognitive overload. The obvious solution to this is for the design software to select what information the user sees but this runs the risk of the designer not being given sufficient information to understand the results. Additionally, this is straying into the area of the decision being made by the software rather than the designer. As previous experience with other design software, such as knowledge-based systems, has shown, this is bad practice. It deskills the design process and designers don't like this. Also computers lack world knowledge and so don't have the common sense to detect even the most basic of errors in their reasoning and so are not competent decision makers.

There is also the question of communication in the other direction, from the designer to the computer. Designers possess a wealth of knowledge, some of which is procedural and hence difficult to access but if it could somehow be made available to the computational search this would be very useful.

The need to protect Intellectual Property Rights (IPR) could mitigate against greater collaboration. In many industries such as construction, an organisation's main asset is its IPR. Therefore protecting this, while also enabling other members of the design team to access the resources that they need, is vital. The IPR can be expressed in a number of ways. For example it may be encapsulated within software or it may be the staff who possess it. Either way, if true multi-organisation collaborative design with software support is to be possible, ways have to be found of enabling design consortia to have access to the IPR in a manner which allows access to it to be controlled.

5.4 Two Way Knowledge Capture

If computational intelligence is to be able to support design undertaken by large multi-disciplinary teams, methods are required for capturing the design team's objectives and related constraints. Currently each designer or discipline tends largely to work in isolation in terms of setting the constraints for their part of the work. Objectives are defined by the client and the design team. The interaction between the constraints and the objectives is complex and when they are combined, nobody is able to fully predict what their impact will be. Anecdotal evidence from the UK defence industry on submarine design (Biddle per comm.) suggests that the impact can be substantial. Unfortunately because this has been work undertaken by the defence industry, it has never been published.

What is needed are methods for eliciting and modelling each discipline's constraints. These will come in a variety of forms and will need to be handled within the design software. This concept can be extended beyond constraints to all forms of knowledge relating to a design. Intuitively it would seem that the greater the degree of shared knowledge and understanding between the software and the designer(s), the better will be the outcome of the design process. Also this should help the system to "understand" the designers' objectives and provide better support. If the system truly does have an understanding of what the designer is trying to achieve, it could suggest new ideas. This is examined more in the following section.

5.5 Search and Exploration

Search and exploration are basic features of any viable conceptual design tool. The potential complexity of multi-discipline, multi-objective search spaces has already been discussed but what has yet to be covered is the difficulty of searching such spaces in a sensible manner. As computational support for design tackles ever more complex and obtuse domains then the search will become more difficult. With multi-objective search, there are techniques such as Pareto analysis for selecting areas of high performance but only for a limited number of objectives. Parmee & Abraham [4] present a method which avoids these limitations. However, there is still a concern that, with substantial numbers of objectives and constraints, trade offs in the search process will render the results meaningless. The implications of such searches need to be thoroughly investigated to either prove or assuage these fears.

The cluster spent some time looking at innovation and creativity. Undoubtedly the successful economies of the future will be those that are the most innovative and creative in terms of commercial products. Creativity typically arises from moments of inspiration, which are often the coalescing of random and previously unconnected thoughts. The cluster discussed whether it would be possible to assist with this process using computational support using, for example, a "nonsense" generator. This could be attractive but also could be extremely wearing if one had to spend hours considering random nonsense. The idea of "jump out" agents was considered, these being agents which somehow leave the current search space and look elsewhere for solutions [2]. Another idea was contradiction; going against the accepted wisdom.

Linked to the ideas discussed in Two Way Knowledge Capture is the concept that, if the system could understand what the designer is trying to achieve, then it could search for relevant ideas and information, very much in the way that the semantic web anticipate needs. This for example could be in the form used by Amazon: people who designed one of these also looked at….. or it could be more like a Google search.

6 Sub-classes

In addition to the above 5 key areas of work, a considerable amount of time was spent looking at how the areas could be broken down into sub-classes. At the end of workshop three, some 350 potential subjects for sub-classes were identified. These ranged from statements made by some of the guest speakers such as one designer saying he has a “butterfly mind” to categories such as “team integration”. Cluster members were asked to place each of the 350 potential sub-classes into one of the 5 key areas. Inevitably there was some divergence of opinion but the exercise made it possible to identify groupings within the potential sub-classes. The analysis was used at the start of workshop four to reduce the 350 down to 39 sub-classes.

An exercise was then undertaken to analyse these 39 sub-classes and determine how they relate to the five key areas in terms of importance. This was achieved by plotting two dimensional graphs with the graph axes being two of the key areas, giving in total ten graphs. The purpose of the exercise was to make the cluster members think about the relevance of the 39 categories in relation to each of the key areas and also to provide a visual aid to stimulate discussion. An example of a graph is shown in fig.1.

The exercise was useful because it stimulated discussion and it gives an indication of the potential difficulty of the research within each of the key areas. The amount of information obtained from this exercise is so large and complex that its analysis is incomplete but Parmee et al [5] have extracted the sub-classes that lie in the upper quartiles of the four graphs of each key area and identified the sub-classes that occur most often. These are shown in table 1. Note that the sub-classes are not exclusive to a given key area. This is an important finding and one which is still being analysed.

7 Discussion

The multi-disciplinary nature of the cluster was very beneficial and the interaction brought out some interesting concept and ideas. The body of information produced by the cluster is large and contains useful pointers as to the way forward. The cluster has identified that there is a huge amount of research yet to be undertaken before we can provide comprehensive software environments to support most areas of conceptual design. Some of the work to be done is fairly straight forward but much of it will require a substantial amount of fundamental research.. The cluster has focussed on areas where current approaches are lacking and identified the shortcomings. The workshops have produced a huge amount of information and this is still being analysed, especially with regard to the sub-classes. The work has been so rewarding and information rich that the members of the cluster have come together to form the Institute for People Centred Computation (www.ip-cc.org.uk). This will inherit the intellectual property of the cluster and continue its work both in looking at future research requirements but also in delivering the research.

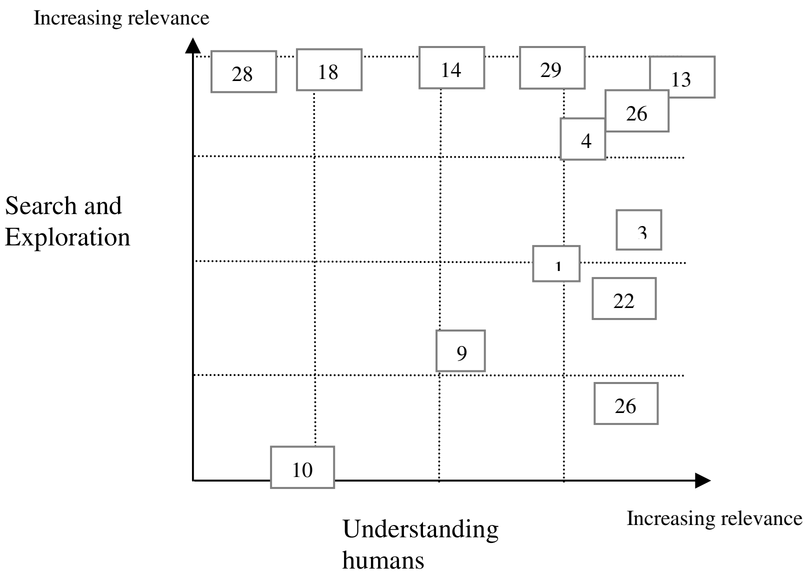

Fig. 1. An example of relating the 39 sub-classes to the key areas. (Some of the 39 categories have been omitted in the interests of clarity). [5]

Table 1. The more significant sub-classes in relation to the key areas

Two Way Knowledge Capture	**Search & Exploration**	**Enabling Environments**	**Representation**	**Understanding Humans**
Co-operation and collaboration; Capturing/ Extracting knowledge; Enabling Computational Technologies; Emergence; History and Traceability; Representation.	User support; Creativity and Innovation; Modelling; Emergence; History and Traceability; Capturing/ Extracting Knowledge; Data Issues.	User-centric Issues; Co-operation and Collaboration; Useability; Interface; Creativity and Innovation; Multi-users and Multi-user Interaction; Capturing / Extracting Knowledge.	Visualisation / Senses Stimulation; Form; Modelling; Capturing / Extracting Knowledge.	Usability; Visualisation / Senses Stimulation; User Interaction; Validation and Risk; Creativity and Innovation; Interface; User-centric Issues; User Support; End User Issues; Learning; Form; Co-operation and Collaboration.

8 Conclusions

A cluster consisting of people from diverse backgrounds has come together to look at the requirements for software support for conceptual design. The starting point of the cluster was that the work needed to be people centred and nothing that has arisen in the workshops has caused this assumption to be questioned. The cluster has identified five key areas in which further research is needed. Beneath these five areas are thirty nine sub-classes which relate to one or more of the key areas. The cluster has identified a significant body of research that needs to be undertaken to enhance the current technology of computational support for conceptual design.

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