INTERNATIONAL DESIGN CONFERENCE - DESIGN 2008
Dubrovnik - Croatia, May 19 - 22, 2008.

DESIGN 2008

THE ISSUES AND BENEFITS OF AN INTELLIGENT DESIGN OBSERVATORY

B.J. Hicks, H.C. McAlpine, P. Törlind, M. Štorga, A. Dong and E. Blanco

Keywords: design process, design teams, design performance, observational studies, experimental data, experimental methodology

1. Introduction

Central to improving and sustaining high levels of innovative design is the fundamental requirement to maximise and effectively manage design performance. Within the context of 21st century design - where the process is largely digital, knowledge-driven and highly distributed - this involves the creation of tailored design processes, the use of best-performing tool sets, technology mixes and complementary team structures. In order to investigate these aspects, there is a need to evaluate the practices and needs of industry; advance understanding and design science; create new tools, methods and processes; and assess the state-of-the-art technology and research output. However, effective investigation of these four areas can only be achieved through a fundamental understanding of today's complex, dynamic design environments. Such detailed understanding is presently unavailable or at least very difficult to obtain. This is largely because of a lack of capability for holistic investigation of the design process and an inability to perform controlled experiments, using reliable and meaningful metrics that generate complete high quality data.

The consequences of this are that many tools, methods or technologies that could benefit industry are not adopted, some are adopted without rigorous assessment and do not perform as anticipated, and many are developed on the basis of incomplete or limited data. For these reasons, there are a range of implications and potential limitations which may arise as a consequence of their use or misuse. It follows that there is growing concern that whilst certain developments have overcome a specific issue, more fundamental issues which are often less well understood have been introduced or exacerbated, or have been overlooked. In the context of design there are particular concerns about the impact of tools, techniques and technologies upon aspects of design performance, including but not limited to *creativity, innovation, fundamental understanding* and *productivity*.

For example, there are a wide a range of critical issues associated with aspects of information management, process improvement, integration and usage of computer-aided engineering (CAE) tools, composition of design teams and the use of supportive technologies, that require urgent investigation. More specific research questions might include:

- What information is needed during the design process, when should it be made available and how should it be presented?
- What are the benefits and risks of introducing new technologies or new tools to the design team and design process?
- If computing capabilities increased by 10^3 would the current design processes maximise the potential benefit of simulation? If not, how should the design process be altered and if it is altered what are the implications for the organisation?

- What tools and technologies should be acquired by an engineering organisation to support the design team and process and how would they best manage implementation and change?
- What is the optimum mix of technology or tools for different design activities or tasks? e.g. new design, variant design, product design or machine design
- What is the optimum composition of the design team?
- How do we best support innovation?

The lack of capability to investigate the aforementioned issues can be attributed to a number of factors including a lack of infrastructure, facilities and experimental methodology, and the limited resources and expertise of individual research organisations (including academic and industrial). These aspects are discussed in detail by Hicks *et al.* [2007]. A number of fundamental barriers are proposed to the creation of an 'intelligent' design observatory in which experiments can be conducted and fundamental data sets generated. More specifically, the environment would create a permanent data corpus that includes the capture of complexity that is impossible to record by simply observing the event. These datasets would provide researchers from across the design community the opportunity to interpret the data and perform collaborative multidisciplinary analysis to form an unbiased view of the events. The various barriers from Hicks *et al.* [2007] can be considered to represent five key dimensions:

1. Design of the environment – What would the physically space look like? How would it be configured? How many co-located and remote participants would it support?
2. Tools and technology for monitoring and recording experiments – What range of actors need to be monitored? What type and extent of data needs to be captured and how can this be done?
3. Tools and methods for data processing and analysis – What is the level and type of data analysis required? How can the large volume of data be organised and summarised?
4. Strategies for observation and measurement of design – What to measure? e.g. the process When to measure?
5. Experimental methodology – What experiments to conduct? How to setup experiments? How to control subjectivity?

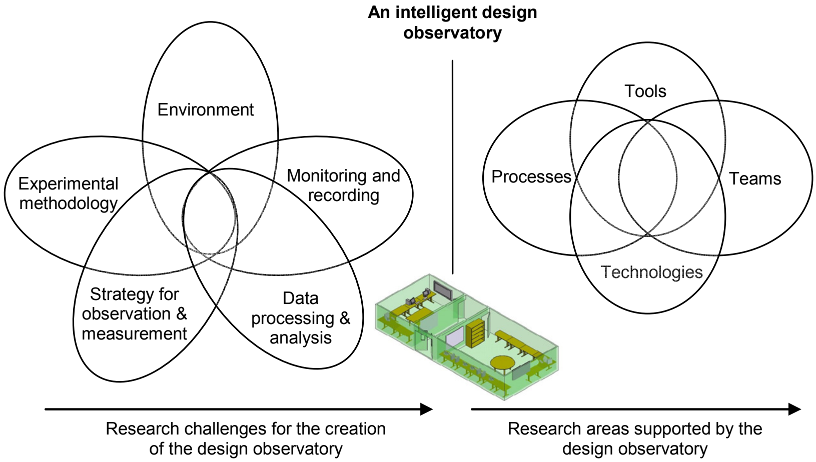

Figure 1. The five dimensions for the creation of an intelligent design observatory

The relationship between these five dimensions is shown in Figure 1, and it is argued that prior to the creation of an 'intelligent' design observatory a variety of research issues relating to each of these dimensions needs to be addressed. It follows that the contribution of this paper is to explore these five dimensions in more detail and present the research challenges within each area. The underlying argument of this paper is that these research issues require a community-wide collaborative effort in order to address them in a comprehensive manner. Where possible, existing strategies are discussed and possible solutions presented. The paper then concludes with an overview of the capability and benefits of an intelligent design observatory and how it might support the research activities of the entire design community.

2. Environment

The main feature required of the design observatory environment is a flexible facility that can be rearranged to suit different types of design and engineering scenarios, including co-located and distributed collaboration, meetings, brainstorming sessions and formal and informal work. At the same time, however, the environment must be robust enough for real users to be studied under realistic conditions. How this challenge may be met is discussed below, together with an example of an existing observational laboratory environment.

2.1 The need for flexibility

Whilst it is arguable that the need to monitor a design team demands a bespoke environment tailored to each team, this resulting flexibility also introduces complexity: An environment that is designed for only one task can be highly optimized for that task, whereas a general environment is more complex to design and maintain. Many of these restrictions can be overcome by the use of a suite of different observational facilities. However, there is still a great need for flexibility within each facility. Here flexibility is viewed as the users' capability to adapt the surrounding environment to new, different or changing needs. However, since the user can be a designer, a researcher or a learner, the notion of flexibility spans several modes of use and two distinct types of flexibility are identified here [from Larsson *et al.*, 2005]:

- **Researcher flexibility** - in terms of setting up the environment to fit a specific scenario or evaluating different types of environments, methods or technologies. Here, the researchers role is similar to that of a director: They set up the stage and decide what the environment should look like to fit the scenario or the 'real-world' design activity in question. As a researcher, they also choose which data that should be acquired. From the experience gained at Luleå, this research setup is time consuming.
- **User flexibility** - The user flexibility is seen from the users view (i.e. the designers being studied). In some cases the researcher can choose to limit the user flexibility (e.g. where the environment itself is part of the evaluation) but in other cases the environment should provide a user complete flexibility, so that they can rearrange the environment to suit their needs (move tables and chairs, to facilitate private and group work etc).

Figure 2, illustrates a number of possible environments that could provide this flexibility including the collaboratory at the University of Technology in Luleå, Sweden.
In this example, the large design observatories provide the core design environment, the pods are capable of being located in, for example, the parent organisation or a sub-contractors organisation, and the mobile monitor provides the capability to 'rove' and undertake practical trials or meetings at, for example, a customer premises. Common for all types of design observatories is that they must support real time acquisition of rich media (video, audio, interactions, etc). This is discussed in more detail in section 3.
The geographically distributed nature of the design team, both within a particular site and across an organisation/supply chain also creates a need to replicate co-located or globally distributed collaboration. When replicating globally distributed collaboration, the team could be located in one place but in different rooms. However, this approach does not take into account the language barriers and cultural differences that occur in truly global teams. Therefore there is a need for a global consortium where two or more design observatories can be interlinked to allow the issues of global collaboration to be studied under realistic conditions. This approach can also be used to run the same experiment with different groups of subjects (professional designers, students with different backgrounds and cultures etc). For example, one could run the same experiment with UK, Swedish and US students and compare the design approaches and results.

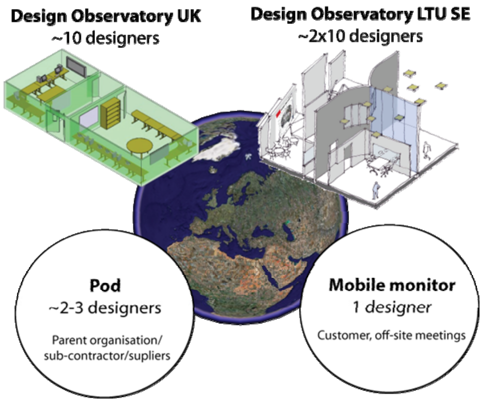

Figure 2. Different types of design observatories

2.2 The Faste Collaboratory

At the University of Technology in Luleå, Sweden, a design observatory (the Collaboratory) has been designed to support both local and distributed groups and can also be used to simulate geographic distance. The rational for the design of the Collaboratory is described in detail in Larsson *et al*. [2005] and the relevant design features are summarised below.

The studio is designed to support both informal and formal meeting spaces. The 'Greenroom' has been designed for informal communication, and here ambient technology is used, which is integrated in the building itself. The two design spaces illustrated in Figure 3, have a high level of researcher flexibility as the researcher can redesign the space (move walls, technical equipment, projectors etc) to suit the experiment. The two design spaces are actually part of one large room that is divisible into two separate spaces with a moveable sound-proof wall. Both spaces are also equipped with lighting trusses to enable flexible lighting design and a raised floor is used to encase all wiring, including the power and data distribution hubs users need to access.

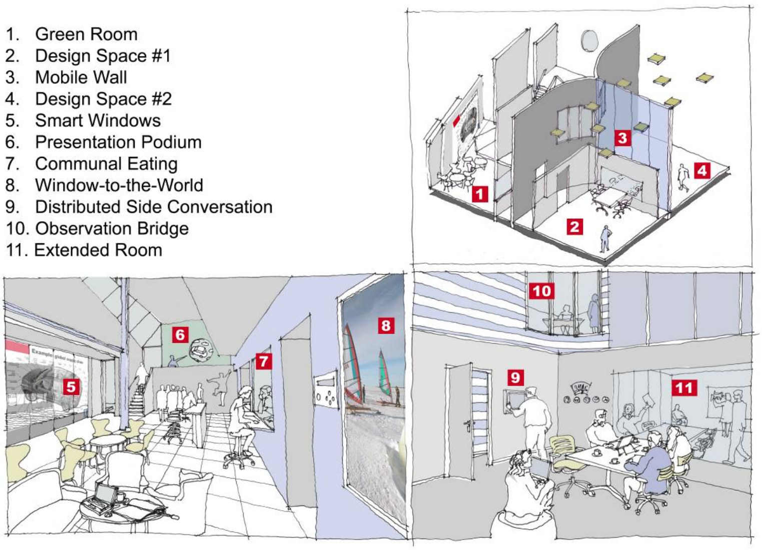

Figure 3. Concept design sketches of the design observatory at Luleå University of Technology, *courtesy of Hans Walloschke, Arkitekthuset Monarken*

The two lab spaces are also designed to simulate remote collaboration, where teams are placed in each design space and have to communicate using the collaboration technology. This enables the research team to replicate and observe remote collaboration and also retaining the capability to observe both the 'local' and 'remote' team.

The possibility for replicating remote collaboration has been received well from the industrial partners, because one has the possibility to test and evaluate new and promising technology within real industry projects, without the usual problems of implementing them at the industry partners in an efficient and secure manner.

3. Monitoring and recording

This section summaries existing approaches to the capture of design sessions and how these might be extended to capture the full range of interactions and transactions that occur between participants and a multitude of information sources, both physical and digital.

3.1 Video and audio capture

Traditionally, this type of design research has been documented by recording video and audio, often using several video streams and an in some cases even a unique audio channel per participant. The advantage with video is that it creates a permanent data corpus and can capture complex data that is impossible to note by simply observing the event at the time. Audio is also one of the most important parts of communication in design teams, and it is important to store more than purely ambient audio, because side conversation and private conversation is commonly used in engineering design sessions. The ideal solution is to store all individual audio streams (to improve transcription) as well as the ambient room audio and video. This is important to support reprocessability – i.e. all data can be re-examined or processed again, within the context of the whole design event.

Both video and audio recording can now be achieved relatively easily and discreetly with high definition video cameras, combined with radio microphones and a hard-disk recording solution. For distributed collaboration it is also important to store the video and audio received from the conferencing application in the remote location, although this is more challenging and creates more technical issues such as compression artefacts, delays, insufficient echo cancellation of the audio etc.

3.2 Extended capture

In addition to the obviously time consuming manual analysis of the resulting data, the video/audio approach has a more fundamental problem, namely that the modern design environment involves a large number of parallel interactions and transactions between designers using a multitude of different tools, such as various computer programs, tablet PC's, paper sources and physical artefacts [Hicks *et al*., 2007]. By only recording video data, the detail of many of these other interactions are lost. This has some parallels with Badke-Schaub and Frankenberger's [1999] differentiation between *direct* and *indirect* methods, where the direct method uses observation of design work (or analysis of video recording) and the indirect method consists of analysis of, diary sheets (papers with notes from problem solving) containing design rational etc. Badke-Schaub and Frankenberger conclude that this type of indirect data enriches and complements the data collected from the direct methods. The challenge for an intelligent observatory is to collect such data from the wide variety of sources both unobtrusively and automatically. For example, in the case of computers, it is possible to record and store what is happening on the screen. Screen recording can either be done by software (compressing to a video file) or hardware (full resolution or down converted). Hardware solutions that save full resolution are expensive and require large storage systems; hence, the software approach is the emerging approach used in design research. It is also important to store who is interacting with the computer, the nature of these interactions (typing, mouse movements etc) and crucially, the information transactions (what information is transferred and why). This type of context-adding metadata provides a much richer corpus and gives new possibilities for automatic analysis than the captured screen alone.

To identify who is interacting with a computer or other information source, an RFID (radio frequency identification) based solution is proposed [see Blackbay, 2007 for an example]. Such systems are cheap, discreet and lightweight and with the addition of readers on each station, allow the duration and frequency of interactions to be monitored automatically. They could also be used to trigger other source and content monitoring systems that monitor content such as text, audio, video and files that are exchanged electronically. These may be captured by a combination of screen capture and software that monitors user interaction and input/output devices. Examples of this include Raytown [2007] and Ciflex [Campbell *et al.*, 2005] which monitors what computer-based information sources are being used and why.

4. Data processing and analysis

The previous sections have alluded to some significant issues faced by the proposed design laboratory, including:

1. **Interaction** - The highly interactive (social) nature of many aspects of the design process.
2. **Information sources** - The wide variety and diversity of data and sources that need to be monitored in order to analyse all the interactions and activities undertaken by members of the team.
3. **Technology mix -** The need to monitor the use of a large number of new and emerging tools and technologies.
4. **Data processing and analysis** - Satisfying the data collection and analysis needs of the observing team in real time, as manual data processing is very time consuming.

Various technologies that can be used to capture a multitude of interactions and transactions, both direct and indirect have also been summarised in the previous section. However, this monitoring and recording represents only one half of the challenge, as the vast amount of data collected must be analysed in an efficient and meaningful way. Two of the main issues are organising and indexing of the data (to support both automatic and manual analysis) and automatic processing and analysis of the data itself.

4.1 Organising and indexing large amounts of data

Törlind [2007] notes that: *"The analysis of raw data is a tedious task and support tools are needed to synchronize the different media stored from a design session…Some systems from the HCI area that support analysis of multiple data types have emerged, such as d.tools* [Hartmann *et al.,* 2006] *that record video and other metadata to be later used for comparative analysis. These tools are normally designed to record information from only one user. When following a product development project over time, the amount of raw data soon becomes unmanageable; therefore, it is important that the tool also supports the retrieval and analysis of stored data."*

With the proposed laboratory providing for such comprehensive capture of video, audio and the interactions/transactions between designers and a multitude of sources, how to organise and index the resulting data therefore becomes even more critical. Törlind & Larsson [2006] describe three approaches to indexing captured information:

1. Active indexing done by the users, researchers or both,
2. Automatic indexing created by the system
3. Passive indexing, created automatically from the usage patterns of users who re-examine the information.

Clearly, for this 'intelligent' design laboratory, the vision would be to automatically index and analyse the data. Several state-of-the-art technologies which are capable of being used to support the processing and analysis of the data are thus summarised below.

4.2 Automatic analysis

For the design studio, it is suggested that the individuals are identified and tracked via the environment video stream using a system such as Crosscan [2007] that allows simultaneous tracking of multiple subjects and other advanced movement analysis tools. Using the existing video feeds in this way avoids the need for any additional obtrusive hardware.

Technologies such as SoftSound [2007] and Virage [2007] allow audio to be automatically transcribed and video to be indexed, searched and analysed in real time. Virage [2007] also provides automatically generated meta-data, alleviating the need for manual indexing. Automatic cross-referencing of the video stream with other forms of information is also possible, and an intelligent search engine allows retrieval via a multitude of criteria, such as keyword, speaker location and even concept, clustering and categorization of concepts and summarisation in real-time. Such technology could also be used to apply protocols to the data in near real-time for complete automatic analysis with little researcher intervention.

However, a significant challenge for automatically applying protocols involving more than the analysis of the transcribed audio involves the fusion of data from the transcribed audio, physical location of the designer and interactions/transactions with other designers and information sources, such as computer-based information sources monitored using Ciflex [Campbell *et al.*, 2005]. Whilst this a problem to be addressed during the development of the proposed laboratory, achieving it would open up the possibility of:

- A step change in our capability to analyse design activities and the influence on performance of tools, teams and technologies.
- Controlled, reliable and repeatable experiments.
- Reusable datasets – for an international consortium of researchers.
- The development of new methods and metrics for measuring design performance.

5. Strategy for observation and measurement

In order to overcome the fundamental lack of research methods for assessing the relationship between tools, teams and technologies, an "information perspective" of the design process and design activities has been proposed [Hicks *et al.,* 2007]. It is argued that by considering information as the primary subject of study, it is possible to monitor and explore the complex relationships between tools, teams and technologies in a manner which could not otherwise be achieved. The capacity of an information perspective for unifying design research has been emerging over the last decade, with a number of researchers adopting information-based approaches for analysing design rationale, shared understanding, managing documentation, collaboration and process management [Dong *et al.,* 2004; Kim *et al.,* 2005; Lowe *et al.,* 2000; Moreau & Back, 2000]. In fact, a number of authors have proposed that the design process can be considered to be an 'information transformation' process [Hubka, 1988; Ognjanovic, 1999]. Furthermore, it is widely accepted that the design process is highly dependent up on information [Moran, 1999] and in particular, obtaining and generating the right information at the right time. It therefore follows that the ability of the design team to optimise information use and hence process performance (time, quality and cost) is heavily dependent upon the efficacy of what are referred to here as information interactions and information transactions.

For the purpose of observation, an information interaction may be considered to represent a reciprocal action or influence involving data, information or knowledge between one or more systems or individuals. An information transaction may be considered to represent the results of an interaction, and in particular a successful interaction, where information is successfully exchanged between systems and/or individuals. For example, during information search and retrieval there are a large number of interactions which usually result in a small number of transactions when the most appropriate information is identified and then retrieved. It is therefore proposed that recording, measuring and analysing all these interactions and transactions are critical elements in analysing the design team, the process and ultimately performance. The relationship between tools, teams, technology and information is shown conceptually in figure 4:

In order to capture all the various interactions and transactions, it has been proposed that a wealth of data types will need to be recorded, including visual images, textual documents, audio and virtual and physical artefacts. The design knowledge potential that arises as a consequence of the integrated use of such multiple resources opens up design research to the field of multimodality [Kress & van Leeuwen, 2001]. Multimodal analysis considers the functions and meanings of individual semiotic resources and the functions and meanings of multiple semiotic resources arising from their integrated use. Some key methodological issues in multimodal analysis that apply to the study of designing in the proposed observatory include:

1. Unpacking of the multimodal resources to identify the units (interactions/transactions) within the multiple semiotic resources (information sources) that create meanings.
2. Analysis of how the units operate together to convey a meaning (Experiential function), maintain social relations (Interpersonal function), and produce a coherent whole (Textual function).
3. Analysis of what the units do to each other in conveying meaning, maintaining social relations and producing a coherent whole. There may exist overlaps, conflicts, inconsistencies and redundancies which are relevant to understanding the knowledge that is producible by the designers given their selection of units of information from the resources.
4. Characterisation of the context within which the semiotic resources are deployed and its effect on what the multimodal resources can mean, and how the resources themselves modify the meaning of the context.
5. The position and actions of the designers in utilising the resources, including how the designer recodes (i.e., re-interprets) resources, transfers a unit of one resource to another resource in order to move from one resource to another, introduces new units in order to make use of a resource, and the consequent shifts in meaning, social relations, and coherence of the resources.

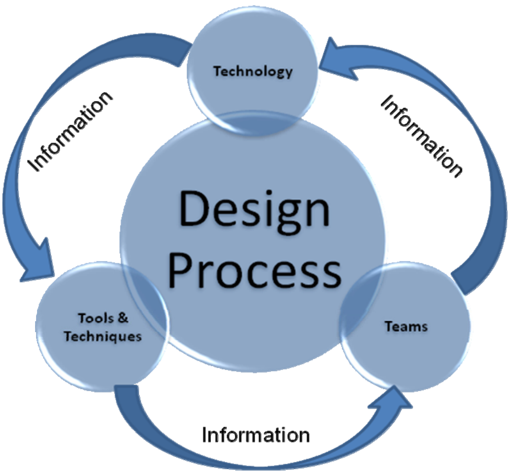

Figure 4. Relationship between tools, teams, technologies, information and the design process

What differentiates multimodal analysis methodology from how it is generally understood in linguistics (as a way to understand how language is part of a set of media used for communication) is the attention towards communication acts as ways to transform knowledge and ideas into a product. That is, in the context of design research, multimodal analysis entails the construction of new representations based on the meaning potentials of multimodal resources. While this is similar to the concept of intersemiosis (how semiotic resources interact with one another to give a new meaning) these new meanings represent choices in interpretations rather than new texts. In other words, design knowledge emerges through the interaction of multiple resources that are not necessarily bound by the resources themselves. Nonetheless, multimodal analysis within the proposed observatory is likely to increase the specificity from which design research is able to pinpoint which resources were foregrounded and what function (textual, interpersonal or experiential) the resource played as a generative force in producing new design knowledge.

6. Experimental methodology

The fifth consideration in the creation of an intelligent design observatory involves the development of the experimental methodology. The development of a robust methodology is essential if subjectivity, scalability, generality and validity are to be managed and assured.

Of particular importance is the definition of the design situation. According to Prudhomme *et al.* [2007] elements of the design situation are: the design task, the design actors, the design object or product and the constrained environment. The experimental methodology will therefore need to address the following considerations:

- What experiments to conduct? i.e. what type of design problem, what type of design activity and from what engineering domain?
- Who should participate? i.e. how large should the design team be, how should the design team be composed (novice, expert etc) and should the team have worked together before? For example, the role of hierarchy in the negotiation of the design solution is an important area to consider.
- How does the environment constraint the situation? This not only involves the tools and methods imposed but also how the goals of the design and the incentives influence the team. For example, the goals and incentives can induce tension and stress in the design activity. It is also the case that the number of design episodes (experiments) that can be conducted will be limited, if only because of time-constraints and limited resources. It is therefore likely that an entire programme of complementary experiments will need to be devised.
- How long should the experiments be? i.e. should the team be constrained by time or an activity? This point is very important a time is critical in the decision-making process.
- Where should the experiments be conducted? i.e. collocated or distributed? and if collocated, how familiar should participants be with the environment?

In addition to the aforementioned considerations it is important to explore the implications of conducting experiments at an academic institution or an industrial organisation. The main advantage of following a project at an academic site is that the environment can be controlled more easily, and methods, groupware and technology can easily be deployed. Further, the duration of university projects can be greater enabling several iterations of technology and tools to be implemented and evaluated. Also, the researcher has the advantage of close proximity to the group. Following teams in industry gives a more accurate view of an industry related problem, and also an introduction to a more complex environment. However, product development in industry is often done in large teams and can be very difficult to follow, even for a large research group. It is also difficult to instrument the team environment, and the use of video recording is often restricted due to company regulations and is thus limited to interviews, field notes, etc. It is also easier to conduct a descriptive study in industry rather than attempting to intervene and change the work process by introducing new methods. Even more difficult is the issue of implementing new software tools in strictly restricted environments, when the process of deploying a new tool in the existing environment of a large company often follows strict regulations and includes a process of conformance testing and security assessment.

The complexity of design situation in industry implies that isolating particular variables and using the hypothetico-deductive method of experimentation for validating a given hypothesis and generalizing its validity is a methodology that is not compatible with research on authentic design situations in the workplace. It is therefore arguable that the theoretical foundation of situated action and cognition are more appropriate. Here the objective is to understand how elements of the situation (tools resources task organisation) mediate interaction in a situation. In conclusion, the experiment methodology should certainly combine the different way of observations. Industrial situations can be used to both identify specific aspects of design to be focused on in experiments and to validate observations made during experiments.

7. Capabilities and benefits

The aim of the proposed observatory is to provide a core instrument for conducting research in the field of design theory and practice. Although any research could not have gone very far without the instruments which improve researcher contact with the research matter, they are not science itself. Therefore, the explicit goal of the proposed design observatory is to facilitate the data collection and analysis associated with observation of design practitioners, methods, tools and technology applied during the design process. It is expected that the observatory would provide a rich dataset about design practice that is complete, fully accessible and totally auditable. In addition to providing these unique datasets, it is anticipated that the intelligent observatory would also significantly decrease the amount of time that is spent in analysis of the empirical data, therefore enabling a greater number of experiments to be conducted.

In addition, of particular interest for the researchers in the design domain would be the ability to study creative and innovative processes related to the application of the different methods, tools and technology. These new or alternative methods, tools and technology could be observed using the observatory facilities in a controlled environment in order be tested and optimised before deployment in a working environment. It is expected that if used in this way, the observatory would increase the number of suggestions for methodology, tools and technology improvements, which promises to accelerate the design process itself. It is also expected that the facility will support focussed research to address fundamental industry needs in the areas of products, information, processes, tools, teams and technologies. The design observatory could be of particular importance and benefit for SME's that do not possess the resources necessary to adapt or test new approaches to improve their design processes.

It is intended that the proposed intelligent design observatory would be made available to the entire engineering design community (in both academia and industry) and its capabilities would enable the community to:

- Comprehensively validate existing tools, methods and approaches.
- Explore the complex relationships and influences of tools, teams and technologies on the design process and design performance.
- Investigate the capabilities and limitations of new tools, emerging technologies and design team structures within the context of design in the 21st century, thus driving innovation and creativity.
- Enable focussed research of the different factors influencing the design process from the multiple perspectives and viewpoints (such as multimodal analysis) by an international consortium.

The major benefits of such a laboratory are anticipated to include:

- A new body of knowledge about the engineering design process and related topics, captured from the engineers during observation and experiments, that will be available for applications that can lead to tangible benefits for industry and the research community.
- The entire learning community (industry and academia) could benefit from sharing experiences and working together on the real engineering problems by simultaneously using different tools, methods and technologies to solve the same problems.
- New tools, methods, and technologies – relating to both the design process itself and its measurement - will be developed and tested based on the experience and understanding generated through the use of the observatory.

8. Next steps

The dependency of design research on complete, high-quality experimental data has been highlighted and the fundamental requirement to study the practices and needs of designers within the context of design in the 21st century has been discussed. Central to achieving this is the need to undertake *in-situ* analysis and conduct controlled experiments. However, this is all but prevented by a lack of infrastructure, facilities and experimental methodologies and the limited resources and expertise of individual research organisations. In order to overcome this, an 'intelligent' design observatory is proposed in which experiments can be conducted and core data generated that would support the activities of almost the entire design community. It is therefore envisaged that the facility would be operated by an international consortium of research groups in order to conduct representative experiments and maximise the use the resulting datasets across the community.

Whilst the anticipated capability and benefits of an intelligent design observatory are both timely and wide ranging, the design of such a facility possess a number of significant challenges, which must first be addressed. These include the design of the environment, technology for monitoring and recording experiments, tools for data capture and analysis, strategies for observation and measurement of design and a robust experimental methodology. The challenges and opportunities within these five key areas have been elucidated in this paper, but will require considerable further research by members of the design research community. For these reasons, the work reported in this paper is to be elaborated through a series of international workshops.

References

Badke-Schaub, P. and Frankenberger, E. 1999. Analysis of design projects. Design Studies, 20, pp. 481-494.

Blackbay, Blackbay RFID systems. Available at: http://www.blackbay.com/products-rfid.html, last accessed December 2007

Campbell D.R., Culley S.J., McMahon C.A. and Coleman P. A methodology for profiling computer based design activities, International Conference on Engineering Design (ICED'05), Melbourne, Australia, August 2005.

Cross, N., Christiaans, H., and Dorst, K. (eds.) Analysing Design Activity, 1996 (John Wiley & Sons, Chichester).

Crosscan GmbH, Crossscan. Motion analysis software. Available at: http://www.crosscan.com/, last accessed December 2007.

Dong A., Hill A.W. and Agogino A.M. A document analysis method for characterising design team performance, Journal of Mechanical Design, Transactions of ASME, 2004, Vol. 126, No. 3, pp. 378-385.

Hartmann, B., Klemmer, S.R., Bernstein, M., Abdulla, L., Burr, B., Robinson-Mosher, A., Gee, J. Reflective physical prototyping through integrated design, test, and analysis. Proceedings of UIST 2006, October 2006.

Hicks BJ., Culley SJ., McAlpine HC. and McMahon CA. The Fundamentals of an Intelligent Design Laboratory for Researching the Impact of Tools, Teams and Technologies on Information use and Design Performance, International Conference on Engineering (ICED'07), Paris, France, 28-31 August 2007

Hubka, V. Practical Studies in Systematic Design, ButterWorth Scientific Co., UK, 1988.

Kim S., Bracewell R. and Wallace K. A framework for design rationale retrieval, International Conference on Engineering Design (ICED'05), Melbourne, Australia, 2005, pp. 252-253.

Kress, G., & van Leeuwen, T. (2001). Multimodal discourse: the modes and media of contemporary communication. London: Arnold

Larsson A., Törlind, P., Bergström M., Löfstrand, M., Karlsson L. Design for Versatility: The changing face of workspaces for collaborative design, International Conference on Engineering (ICED'05), Melbourne, Australia, 15-18th August 2005.

Lowe A., McMahon C.A., Shah T. and Culley S.J. An analysis of the content of technical information used by engineering designers, Proc. of the 2000 ASME Design Engineering Technical Conferences, 2000, DETC2000/DTM-14545.

Moreau K.A and Back W.E. Improving the design process with information management, Automation in Construction, 2000, Vol. 10, No. 1, pp 127-140.

Moran, N. Knowledge is the key, whatever your sector, The Financial Times Limited, UK, 1999.

Ognjanovic, M. Creativity in Design Incited by Knowledge Modelling, International Conference on Engineering Design, (ICED '99) 1999, pp. 1925-1928.

Prudhomme Guy, Franck Pourroy, Kristine Lund. An empirical study of engineering knowledge dynamics in a design situation J. of Design Research (JDR), Vol. 6, No. 3, 2007.

Raytown corp. Monitoring software. Available at: http://www.softsecurity.com/, last accessed December 2007.

SoftSound. Transcription software. Available at: http://www.softsound.com/, last accessed December 2007.

Törlind, P . A Framework for Data Collection of Collaborative Design Research, International Conference on Engineering (ICED'07), Paris, France, 28-31 August 2007

Törlind, P. and Larsson, A., Re-experiencing engineering meetings : knowledge reuse challenges from virtual meetings, Proceedings of Challenges in collaborative engineering, Prague, Czech Republic, 2006.

Virage Systems. Video analysis software. Available at: http://www.virage.com/, last accessed December 2007.

B. J. Hicks
Department of Mechanical Engineering,
University of Bath,
Bath, BA2 7AY,
United Kingdom
Tel.: +44 (0)1225 386881
Fax.: +44 (0)1225 386928
Email: b.j.hicks@bath.ac.uk
URL: http://www.bath.ac.uk/idmrc