INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

THE FUNDAMENTALS OF AN INTELLIGENT DESIGN OBSERVATORY FOR RESEARCHING THE IMPACT OF TOOLS, TEAMS AND TECHNOLOGIES ON INFORMATION USE AND DESIGN PERFORMANCE

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ABSTRACT

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 design in the 21st century, 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. Managing these important elements can only be achieved through a fundamental understanding of today's complex, dynamic design environments. However, such detailed understanding is presently unavailable or at least very difficult to obtain. This is due to the lack of research methods for analysing the relationships between tools, teams, technologies and design process performance, the lack of capability to undertake *in-situ* analysis of design teams, and the limitations imposed on data acquisition and processing. One approach for overcoming the lack of research methods, is to consider what can be thought of as the design information itself and in particular its generation, representation, communication and use. To address the issues of holistic *in-situ* analysis and data acquisition, an intelligent design observatory is proposed that is specifically focussed on supporting observation and real-time analysis of design teams. This paper describes the underlying information-based strategy to overcome the lack of existing research approaches and reviews the state-of-the-art technologies for data capture, analysis and real-time processing. The paper then sets out fundamental requirements of a design observatory from the designer's perspective and presents a possible laboratory configuration. Following this, the issues and barriers to designing experiments involving the observation of practising designers are discussed and the paper concludes with examples of possible experiments and how such a laboratory might be used to support a global research programme.

Keywords: Design information, teams, performance, observational studies, experimental data

1 INTRODUCTION

The relationship between design and manufacturing and its importance for industry is widely accepted. Since the early 1950s, considerable research has been undertaken with the aim of improving the processes associated with both product design and manufacture. This has involved researchers from a multitude of disciplines; engineering, psychology, operations management, information science and computer science. Collectively the various research programmes represent a considerable investment from both government and industry. Much of this research has led to the creation of new tools and techniques for visualising, analysing, developing and managing product development and also various aspects of engineering design including engineering teams and design processes and methodologies.

In general these tools, techniques and technologies have reduced time and eliminated many routine information tasks, and in particular, the representation, organisation and exchange of information between individuals, organisations, software tools and manufacturing systems. For these reasons alone, such tools and methods are generally considered to have been beneficial to industry *per se*. However, a fundamental requirement of design research is to evaluate the practices and needs of industry, assess the state-of-the-art and appraise research output. Further, this assessment needs to be performed using reliable and meaningful metrics within a truly representative environment. However, this assessment can rarely be undertaken in a holistic or scientific manner due to the complexity of measurement and detailed analysis required: data capture is often incomplete and subjective, and the subsequent analysis of even short design episodes can take months.

As a consequence, many tools which 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 also a range of implications and potential limitations which may arise as a consequence of the use or misuse of these tools. Because of this, 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 field of engineering design there are particular concerns about the impact of tools, techniques and technologies upon engineering on aspects of design performance, including but not limited to *creativity, innovation, fundamental understanding* and *productivity*. There is therefore a fundamental need to manage and optimise teams, tools and technologies to improve design performance as well as developing new tools and methods.

The subject of design performance has received some considerable attention over recent years [1-5]. Much of this work has focused on measuring the effectiveness and efficiency of a design, the management of design activities or overall performance measurement. However, design development is exemplified by novelty and non-repeatability, characteristics which provide particular challenges in the definition, measurement and management of performance with a view to improvement [1]. As a consequence, many of the metrics used are likely to be company specific, domain specific and or product specific. Notwithstanding this, recent work has examined the influence of resources on design performance such as IT and information access, the role of team structures, the time to reach a feasible or optimum solution and product quality [3-5]. However, these studies and the metrics developed are generally derived through consideration of particular perspective of performance in isolation. Furthermore, the underlying data upon which the findings are based rarely take into account the complex interrelationships of today's digital, knowledge-driven distributed design environment, which can seriously compromise the validity and applicability of the findings.

In addition, the modern design environment involves a large number of parallel interactions between designers and a multitude of different tools, both computational and non-computational. Further, such interactions can be undertaken by a variety of different technological means. These include discussions, emails, electronic documents, sketches, the Internet, video-conferencing and simulation tools. This wide variety of interactions, all contribute to the various aspects of design performance and as a consequence, there is a need to consider these complex dynamic aspects in a holistic manner. However, the ability of design researchers to undertake such analysis is not presently possible. This is due to a lack of research methods for analysing the relationships between tools, teams, technologies and design process performance, a lack of capability to undertake *in-situ* analysis of design teams, and the limitations imposed on data acquisition and processing with existing equipment.

2.0 DESIGN INFORMATION

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 is proposed. It is argued in this work 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, 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 [6-9]. In fact a number of authors have proposed that the design process can be considered to be an 'information transformation' process [10, 11].

Furthermore, it is widely accepted that the design process is highly dependent up on information [12] 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 is heavily dependent upon the efficacy of what are referred to as information interactions and information transactions.

For the purpose of this work, 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 these interactions and transactions are critical elements in analysing the design team, the process and ultimately performance. The relationship between tools, teams, technology, information and performance is shown conceptually in figure 1.

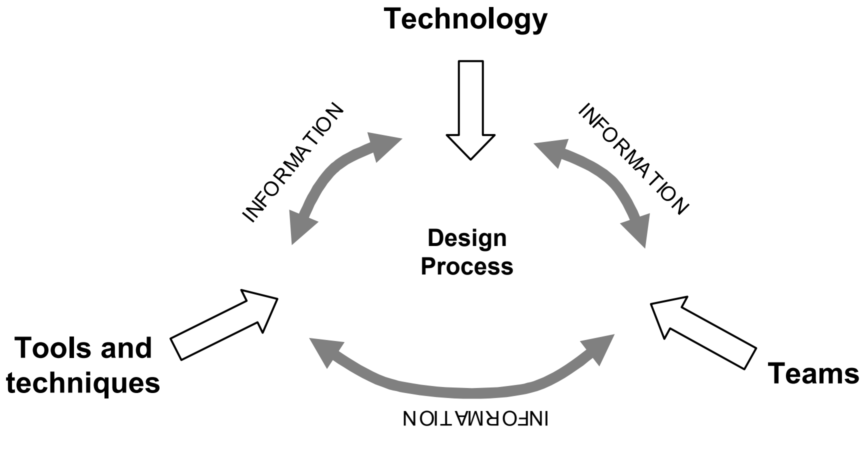

Figure 1. The relationship between tools, teams, technologies, information and the design process

2.1 Monitoring design teams and information use

As previously stated there are a wide variety of parallel interactions which need to be considered in order to effectively observe and analyse the design environment, design team and design process. Central to achieving this, is the ability to study design teams *in-situ* whilst using the various tools and technologies. However, the capacity to undertake such studies is all but prevented by a lack of capability, and in particular, an appropriate design environment, data acquisition equipment and processing resources. In addition to this, there are also a range of fundamental barriers to the *in-situ* observation of design teams. These include:

1. **Geographical location** - The geographically distributed nature of the design team, both within a particular site and across an organisation/supply chain.
2. **Resources** - The resources necessary to observe all team members whilst undertaking many parallel activities. This includes observers and data acquisition tools.
3. **Interaction** - The highly interactive (social) nature of many aspects of the design and manufacturing processes.
4. **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.
5. **Technology mix -** The need to monitor the use of a large number of new and emerging tools and technologies.
6. **Multi-disciplinary research** - The necessarily multi-disciplinary structure of the observing team. Including researchers from engineering, psychology, operations management, information science and computer science.
7. **Real-time processing** - Satisfying the data collection and analysis needs of the observing team in real time. Manual data processing can take many hours.
8. **In-situ analysis -** The lack of strategies for undertaking such holistic in-depth analysis of complex dynamic design teams.
9. **Confidentiality** – In today's highly competitive global markets intellectual property rights (IPR) and commercial confidentiality all but prevent access to real design teams working on commercial projects.
10. **Subjectivity** – Contrived scenarios, predefined environments and artificial teams can all influence the results of experiments.

In order to overcome these barriers an intelligent design observatory is proposed that:

- Builds on the capabilities of existing laboratories,
- Implements state-of-the-art data processing tools,
- Provides an unrestricted representative design environment ,
- Comprises real design problems using practising design teams.

These aspects are discussed further in the next sections.

3.0 OBSERVATIONAL LABORATORIES

In principle some of the aforementioned barriers and in particular those associated with geographical location (1) and data collection (2, 7) can be overcome by the use of an observational laboratory. However, there exist very few such facilities in the UK and Europe. Those which are available merely afford a room with a variety of audio and visual monitoring equipment, the output of which is analysed at a later date. In fact, all laboratories require a significant level of post-processing which can consume a significant amount of researcher time. A review of current observational laboratories across the UK, Europe, and USA is presented in Table 1.

Whilst it is difficult to explicitly determine the detailed capability of these existing laboratories an attempt has been made to assess their physical capability and level of data processing. From this preliminary assessment it is evident that there is no single laboratory that is capable of capturing the full range of information interactions and transactions between individuals, teams and tools across the complete spectrum of technologies (issues 3 and 5). Including for example, logbooks, Internet usage, Email, meetings/discussions, simulation tools, video conferencing and telephone calls. Notwithstanding this, iLoft (Stanford) [13] and NoteLook (Xerox) [14] both deal with a number of these elements.

Type		Existing Design Research Projects					Related Projects/Technologies		
Name of Project		Stanford Design Observatory	iLoft (Stanford)	BAE systems human factors work (COSITE, ACCESS GRID etc)	IBM User Centred Design - Electronically Linked Groups	IBM User Centred Design – Usability Test Lab	NoteLook – Multimedia Note Taking	MIT 'Intelligent Room'	Office of the Future
Source		Design 2002	ICED '03, Milne & Winograd	BAE Systems	IBM UCD Website	IBM UCD Website	Xerox PARC	MIT Website	NSF Sci-Tech Centre
Physical	Layout	approx 3.5x2.5m	approx. 6x4m	NA	unknown	unknown	unknown	NA	flexible
	Participants	Up to 6	Up to 20	Multiple, unknown	Up to 20	unknown	Multiple, unknown	Multiple, unknown	Multiple, unknown
Capture capabilities	Audio	yes, group	unknown	unknown	yes	yes	yes, individual	unknown	Yes
	Video	yes	yes	yes, no details	yes	yes	yes	yes	yes
	Movement/ location tracking	Video only	Video only	unknown	unknown	unknown	yes	yes	Video only
	Computing	no	yes, records all interactions	yes, no details	yes, groupware	yes, no details	unknown	no	Yes, notebook computers used
	Other	Electronic whiteboard	Electronic whiteboard, interactive displays, video-conferencing	unknown	unknown	unknown	Electronic whiteboard, Speech and gesture recognition	unknown	whiteboard
Processing/Analysis		Automatic indexing by time of audio and video only	Automatic recording and structuring of interactions with technology	unknown	Stored in database, manual analysis	unknown	NA	NA	NA
Notes			Based in part on the earlier Design Observatory, also at Stanford.				Designed to support multimedia note taking, not design research	Designed to support activities, not for design research	Designed to support collaboration non co-located workers, not design research

Table 1. Existing observational laboratories

In order to overcome these barriers it is necessary to record, measure and analyse a wealth of information interactions and transactions. As previously stated, within the context of the design team, interactions may be considered to represent a reciprocal action or influence involving data, information or knowledge between one or more systems, individuals or a combination thereof. A large number of interactions may occur with a range of actors throughout design and manufacturing activities. A transaction may be considered to represent the results of an interaction, and in particular a successful interaction. In general a successful interaction will result in an exchange between the interacting parties, which is usually in the form of information. For the purpose of evaluating transactions it is the *content* of this information exchange that is important, and also the *amount*, *format* and *type* of information exchanged. Furthermore, these interactions and transactions can occur both internally (within the engineering team and confines of the laboratory) and externally (involving people, processes and systems that are beyond the laboratory and engineering team). The theoretical space over which interactions and transactions can occur is shown in figure 2. To illustrate the extent of the space a number of common examples are classified.

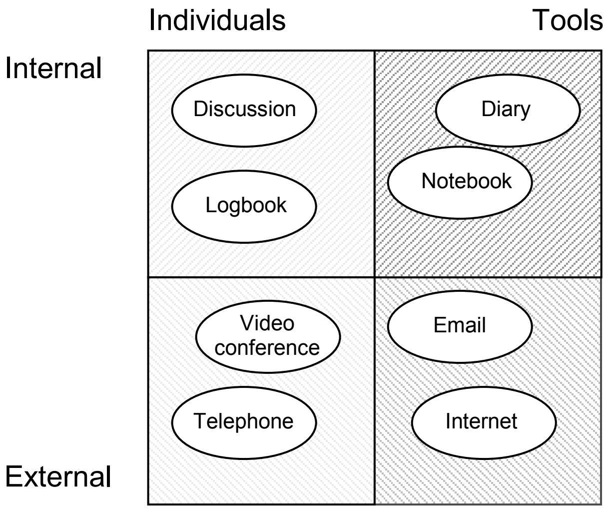

Figure 2. Theoretical space of information interactions and transactions

Whilst it is arguable that a transaction may only occur as a result of a successful interaction, there may be many interactions that led to the final transaction. These 'unsuccessful' interactions are also important as they provide important history of success and failure which are also fundamental aspects of performance. It is therefore necessary to monitor all interactions and actors as well as transactions. To enable such extensive, detailed, real-time *in-situ* analysis there is a need for automated recording and data analysis. This intelligent dimension is discussed in detail in the next section.

4.0 AN INTELLIGENT DESIGN OBSERVATORY

In this section a possible configuration for an intelligent design observatory is proposed. In addition to real-time analysis a further limitation of existing laboratories is that teams (participants) are frequently isolated or at best only able to communicate by virtue of specific technologies (e.g. video conferencing). Furthermore, participants are often limited to specific tool sets and are unable to access those information sources or tools that they are familiar with. Whilst it is arguable that the need to monitor the design team demands a bespoke environment, some of these restrictions can be overcome by the use of a suite of observational facilities. This suite might include a design studio, a pod and a mobile monitor. This is shown conceptually in figure 3. The design studio provides the core design environment. The pods are capable of being collocated in, for example, the parent organisation or a sub-contractors organisation, whilst the mobile monitor provides the capability to 'rove' and undertake practical trials or meetings at a customers premises.

In order to capture information interactions, transactions and the various actors five key areas need to be monitored:

1. **Environment** – Continuous video and audio recording of studio and pods.
2. **Stations** –All stations are individually identified including but not limited to electronic logbooks (tablet PCs), PDAs, PCs, Video conferencing, Skype, Whiteboards, meeting tables and telephones.
3. **Individuals** – All individuals are individually identified and their location tracked using GPS.
4. **Sources** – The use of all sources including the Internet, Email and software applications.
5. **Content** – All images, video, text and audio that is exchanged.

The suite of design spaces and the monitoring of these five areas are necessary to provide an environment capable of providing for the holistic *in-situ* observation of complex, dynamic, distributed, knowledge-intensive design teams. The state-of-the-art technology that would enable such detailed data capture and analysis is now summarised.

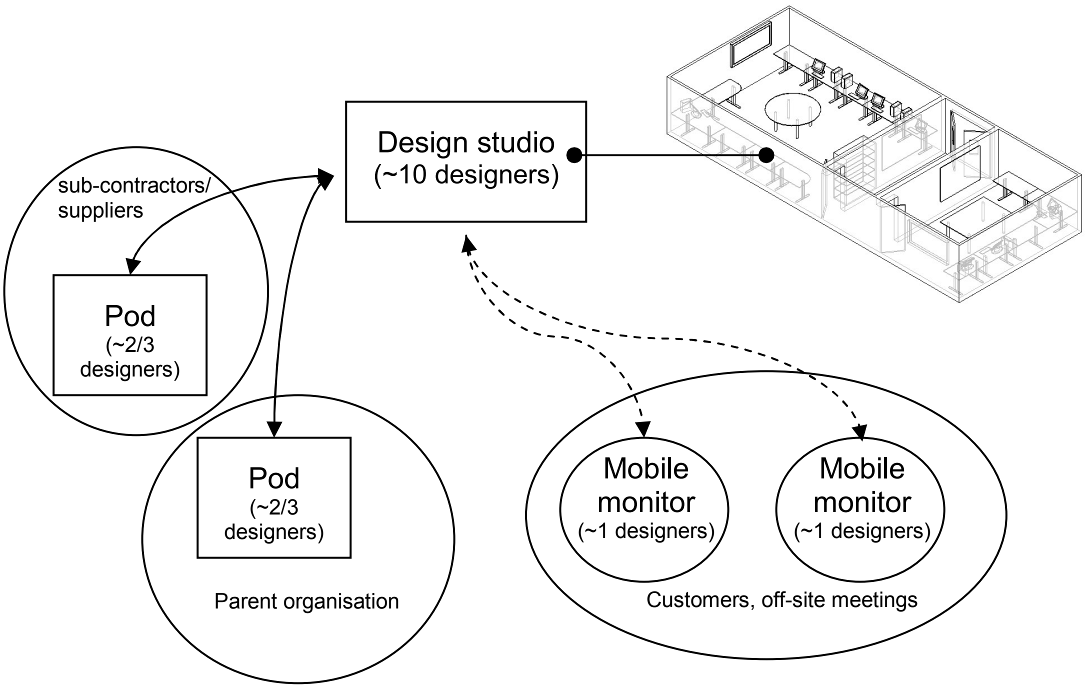

Figure 3. The design observatory

4.1 Real-time analysis

The state-of-the-art systems and technologies which are capable of supporting the intelligent monitoring of the five key areas previously defined are summarised.

4.1.1 Environment

Video and audio recording of the 'whole environment' is necessary to provide a master record and a reference. This could be achieved easily and discreetly in the design studio with cameras such as a 360° camera [15], combined with microphones and a hard-disk recording solution to allow large amounts of footage to be stored.

4.1.2 Individuals and Stations

For the design studio, it is suggested that the individuals are identified and tracked using the environment video stream using a system such as Crosscan [16] or Virage [17] that allow simultaneous tracking of multiple subjects and advanced movement analysis tools. Using the existing video feed in this way avoids the need for any additional hardware.

In addition, each designer can be individually monitored with a radio microphone system. Technologies such as SoftSound [18] allow audio to be indexed, searched and analysed in real time. To show that individuals 'docked' and interacting with a particular station, such as a computer, whiteboard, telephone etc, an RFID based solution to uniquely identify each designer and station is proposed [19]. 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 can also be used to trigger the source and content monitoring systems (see below). Global Positioning Systems (GPS) will be used for geographical location of the mobile units.

4.1.3 Sources & Content

The use of computer-based information sources may be monitored using software such as Ciflex [20] which records what source was used and why. RFID tags may be used for physical sources. Although they will not capture the richness of information, it is thought that there will not be a large number of such sources and the information about their use could be obtained by asking the designer to describe how they are using it.

Other content such as text, audio, video and files that are exchanged electronically may be captured by a combination of the video or audio system and software that monitors user interaction and input / output devices (See [21] for an example of capability).

4.2 designing effective experiments

The proposed configuration for an intelligent design observatory overcomes many of the barriers previously identified in section 2. However, to overcome issues concerning confidentiality and subjectivity an experimental programme that complements the physical laboratory is necessary. It is arguable that the detail of such a programme can only be fully determined through the initial use of such a facility. Notwithstanding this, it is proposed that many of the issues surrounding confidentiality and also subjectivity can be overcome by investing in a design team comprised of consultants and small independent design practices who are brought together to work on a real design problem set by the research team and external customers - who are once again brought in from external organisations but also employed for the duration of the project. In this manner, the design team is configured from individuals that used to working in unfamiliar environments. Furthermore the content of all interactions and transactions is owned by the research team (collaborating institutions) which enables the capture of a complete dataset. The latter of which has not previously been possible.

In addition to the aforementioned considerations it is ultimately the case that the number of design episodes (experiments) that can be monitored will be limited, if only because of time-constraints and limited resources. It is therefore necessary to develop a framework for designing a series of robust experiments that

- enables subjectivity to managed,
- external influences to be assessed and quantified,
- ensures the results can be used to infer generic findings.

It is arguable that addressing these issues poses a research challenge in its own right and as a consequence it is argued that these issues will need to be further investigated during a commissioning phase of such a laboratory.

5.0 A CORE INSTRUMENT FOR GLOBAL RESEARCH

The need for a design observatory with an ‘intelligent’ component has been previously discussed. In particular, it is the aim of the laboratory to provide a rich dataset that is complete, fully accessible and totally auditable. Such a rich source of data describing design episodes is arguably fundamental for the design research community and the facility and the datasets would provide a unique and fundamental instrument for research into design practices in the 21st century. For these reasons it is proposed that the datasets would be made available to the entire design research community and would support the community to:

- Validate current 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 team structures within the context of design in the 21st century.

- Research new tools and methods for analysing and supporting design within the context of the 21st century and the individual designer.

More specifically it is envisaged that the facility will support focussed research to address fundamental industry needs in the areas of information, processes, tools, teams and technologies. A variety of non-exhaustive research topics arising from gaps in existing literature and proposed by a number of industrial collaborators are summarised in Table 2.

Area	Research Question
Information	• What information is needed during the design process and when should it be made available? • How much information should be made available at different stages of the design process and how should it be presented?
Process	• What are the benefits and risks of introducing new technologies or tools on the team and design process? • If analysis capabilities increased by 10^3 would the current design processes maximise the potential benefit? If not, how should the design process be altered and if it is altered what are the implications for the organisation?
Tools	• What tools should be acquired and how to 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 or sector aerospace, product design or machine design
Technologies	• What technologies should be acquired and how to best manage implementation and change?
Teams	• What is the optimum mix of technology or tools to support the design team?

Table 2. Example research topics

The areas identified in Table 2 represent only a fraction of the scope of possible areas that could be investigated by virtue of the proposed observatory. Furthermore, it is arguable that due to the high quality, complete and detailed data sets, each study (experiment) has the potential to support a wide variety of studies across each of the aforementioned areas. For these reasons, such rich data has the potential to support a global consortium of researchers each dealing with different aspects of information, processes, tools, teams and technologies. It is therefore, proposed that such a laboratory and the corresponding experimental programme be operated by an international consortium. With the experimental programme agreed in advance and the processed results made available to all partners. Furthermore, given that the underlying premise of this work focuses on design information, it is envisaged that the consortium would provide the initial membership for a Special Interest Group for the Design Society in the area of design information.

6.0 CONCLUSIONS

The fundamental requirement of the design research community to study the practices and needs of designers within the context of design in the 21st century, where the process is largely digital, knowledge-driven and highly distributed, is discussed. Central to achieving this is the need to undertake *in-situ* analysis. However, such analysis is all but prevented by three barriers: the lack of research methods for holistic analysis of tools, teams, technologies and design process performance, the lack of capability to undertake *in-situ* analysis of design teams, and the limitations imposed on data acquisition and processing. In order to overcome the lack of methods for holistic analysis, a strategy that considers the design information itself, and in particular what are defined as information interactions and transactions, is

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proposed. To address the issues concerning *in-situ* analysis and data processing an 'intelligent' design observatory is proposed. The intelligent dimension refers to the automated monitoring of all information interactions and transactions, and the real-time analysis of data. To achieve this intelligent dimension a possible configuration for the design studio has been outlined and the state-of-the-art technologies capable of supporting an intelligent observatory are summarised.

In addition to discussing the configuration and technology of an intelligent design observatory a variety of important research topics are defined. It is also proposed that a research facility, such as the 'intelligent' observatory be made available to the wider design research community. More specifically, it is envisaged that the laboratory would be operated by an international consortium of research groups in order to design appropriate experiments and maximise the use the datasets. It is arguable that such a group may also form the founding members of a Special Interest Group focussing on design information and knowledge.

Acknowledgements

The work reported in this paper has been undertaken as part of the EPSRC Innovative Design and Manufacturing Research Centre at the University of Bath (grant reference GR/R67507/0) and supported by a number of industrial companies. The authors gratefully acknowledge this support and express their thanks for the advice and support of all concerned.

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