The spiral of applied research: A methodological view on integrated design research

Conference or Workshop Item

INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 03 STOCKHOLM, AUGUST 19-21, 2003

THE SPIRAL OF APPLIED RESEARCH: A METHODOLOGICAL VIEW ON INTEGRATED DESIGN RESEARCH

C M Eckert, P J Clarkson and M K Stacey

Abstract

Design covers a wide range of human activities. It is inherently multi-facetted, multi-layered and complex. Design research serves the dual purpose of understanding the phenomenon of design and improving particular aspects of design. Understanding design requires multi-disciplinary research drawing on such diverse fields as psychology, sociology and computer science. This paper proposes a framework with in which design research can be carried out in big research teams. It contains eight major stages. Four fundamental research efforts drawing on different domains (Empirical studies of design behaviour, Development of theory, Development of tools and procedures, Introduction of tools and procedures) and emphasis the important of separate evaluation after each stage. Individual projects can contain any number of these stages, provided the researchers are aware of the bigger picture. The paper concludes with a comparison with DRM.

Keywords: research methodology, empirical study, process

1 Introduction

In the design research community everybody agrees that design is a highly complex and extremely multifaceted endeavour. There is much less consensus about how one should go about studying design and what the aim of any such study should be. But design research has two dominating characteristics: it is inherently multi-disciplinary, and it is driven by the twin goals of understanding designing and improving it – two goals that require very different research methods. As developing effective tools and methods requires not just understanding but understanding at the different levels investigated by different disciplines, design researchers need to see the big picture.

The methodological challenge of design research lies in finding ways to integrate a large number of small-scale research problems activities to make cumulative progress. This paper discusses the methodological approaches needed for design researchers to build the big picture by co-ordinating different types of design research.

We begin by discussing how the nature of designing as a complex human activity makes design research multi-disciplinary, and considering what, if anything, makes design research a distinctive discipline. We describe the eight distinct types of design research – the eightfold path – which form a logical spiral; and outline how individual research projects should be integrated into larger agendas. We contrast this perspective to DRM [1, 2, 3, see section 6], a design research methodology with which it has much in common but also significant differences.

2 Integrating design research across disciplines

Researchers struggle to find a common understanding of the nature of design. Research is fragmented. First, because everybody is looking at different instances of design, that form their view of design and therefore their interpretation of other design situations. Different types of designing proceed in radically different ways, though they often have interesting characteristics in common [4]. Second because researchers' and designers' varied intellectual training and cultural bias and background leads them to interpret the world they see in different terms. Most practising engineers look at design processes as sequences of activities to generate solutions to newly identified needs; sociologists look at design as a socially negotiated process; psychologists as the sum of individual mental processes. However we all know that design is really all of these things at once.

2.1 Taking multidisciplinarity seriously

Design phenomena are inherently multi-causal. Cognitive, social and cultural processes interact. This is often pointed out, but rarely applied to understanding why designing happens the way it does. Many design projects are complex social processes involving multidisciplinary teams of people with very diverse knowledge and thinking styles, embedded in an organisation, developing products combining several technologies. We need to look at aspects of design described at several scales of both organisation and time, from designers' perceptual categorisation processes to the effects of business models on patterns of communication in organisations. Different scales require different research methods. And we need to integrate these different analyses into a coherent whole, so that the relationships between different aspects are understood. This requires a multidisciplinary approach to research – as is well recognised by the originators of DRM, among others [1, 2, 3].

Across the entire scholarly community cumulative knowledge is pushed forward through a mechanism of publishing papers and citing other people's work. But researchers are often trapped in isolated specialisms busily developing explanations of their own sets of phenomena, and do not engage in debates with other groups of researchers. A few design researchers have contrasted different approaches to making sense of design [see 5 for a survey of research on processes; 6 for a comparison of cognitive and sociological research; 7 for a comparison of models based on the ideas of Herbert Simon and Donald Schön]. Textbook writers have integrated problem-solving psychology into process-level descriptions of engineering design [8]. But attempts to develop cross-level accounts of design phenomena spanning cognition, human interaction, process and culture [such as 9] are very rare.

Taking multidisciplinarity and the diversity of design seriously requires two things. Ways to map the causal relationships between phenomena operating at different levels, described in different terms, to produce multi-causal explanations for multi-causal phenomena. We put forward some ideas for this elsewhere [4, 10, 11]. And organising design research to foster multidisciplinary understanding, which is the subject of this paper.

2.2 Design research as a discipline

Design researchers frequently lament that design research is not scientific and that a methodology needs to be created to put design research on a scientific footing. But most design research is – or should be – grounded in the techniques and methodological rigour of one of several academic disciplines that treat design as another human activity. These disciplines, including cognitive psychology, artificial intelligence, complexity science, and various flavours of sociology, have very sophisticated views of what are effective research procedures, what constitutes adequate methodological rigour, and what is the epistemological status of their findings. While cognitive psychology is certainly science, a lot of valid design research doesn't fit most philosophers' definitions of science.

Design research has no unique features besides its subject matter, but it has two defining characteristics that differentiate it from these contributory disciplines. It is concerned with a complex heterogeneous human activity; and it is concerned with finding practical ways to improve human performance in complex tasks. Each of these characteristics has parallels in other fields. Philosophers have examined the practice of science from social and cognitive perspectives, and social studies of science is a distinct if controversial branch of sociology. Ethnography and soft systems methodology [12] have been extensively applied to requirements analysis for software systems; and human computer interaction and computer supported co-operative work are disciplines concerned with both understanding and enhancing complex human behaviour.

We do not call the framework we present in this paper a methodology partly because we do not presume to tell design researchers within the various contributory disciplines what should or should not be design research, though we have put forward methodologies for particular kinds of research ourselves [10, 11, 13, 14].

3 The practical challenges of design research

Research in design, which should both advance knowledge and bring practical benefits to designers, is subject to tensions between conflicting needs and goals:

- between the need for valid, well-grounded research results, and the need for industry-supported research to have immediate practical applications;
- between the academic need to produce reportable results quickly from projects with limited resources, and the industrial need for powerful, reliable, validated tools and techniques;
- between the need for large research groups to exploit their resources to make major advances, and the need to allow isolated researchers to make effective contributions;
- between the need for students to achieve intellectual independence in their own research, and research leaders to achieve larger-scale, longer-term results;
- between the need for students to develop skills in different aspects of applied research and their need to focus to achieve results in a reasonable time.

The crucial problem in applied design research is that achieving the usable results we aim for requires more effort than a single doctoral student can contribute or a single research grant will pay for. In the next section we present a view of what applied design research involves, that supports a view of how to integrate individual research projects into long-term research agendas and how to co-ordinate the activities of large research groups such as our own.

4 The spiral of applied research

Design research has the dual goal of providing understanding of designing as a phenomenon and to improve to process that it is studying. The research community spans the spectrum from researchers who are primarily interested in describing design to those that claim that design research always needs to aim at improving processes [for example 1, 2]. While we reject this extreme view, we regard scholarly and practical research as organically connected, as trying to improve design requires understanding, and spawns research questions.

Research that delivers tools and procedures into industrial use encompasses activities addressing four fundamentally different questions: (1) How does design happen in concrete situations we can study, in particular within process we would like to improve? (2) How can we understand the cognitive, social and cultural mechanisms that underlie the phenomena we observe, by building theories? (3) What computer tools, pencil-and-paper techniques or design methods might be useful, and how can we develop them? (4) How can we introduce these tools or methods into industrial use, and what happens when we do? These types are very similar to those identified by Cantamessa [15] and Blessing and Chakrabarti [1, 2, 3].

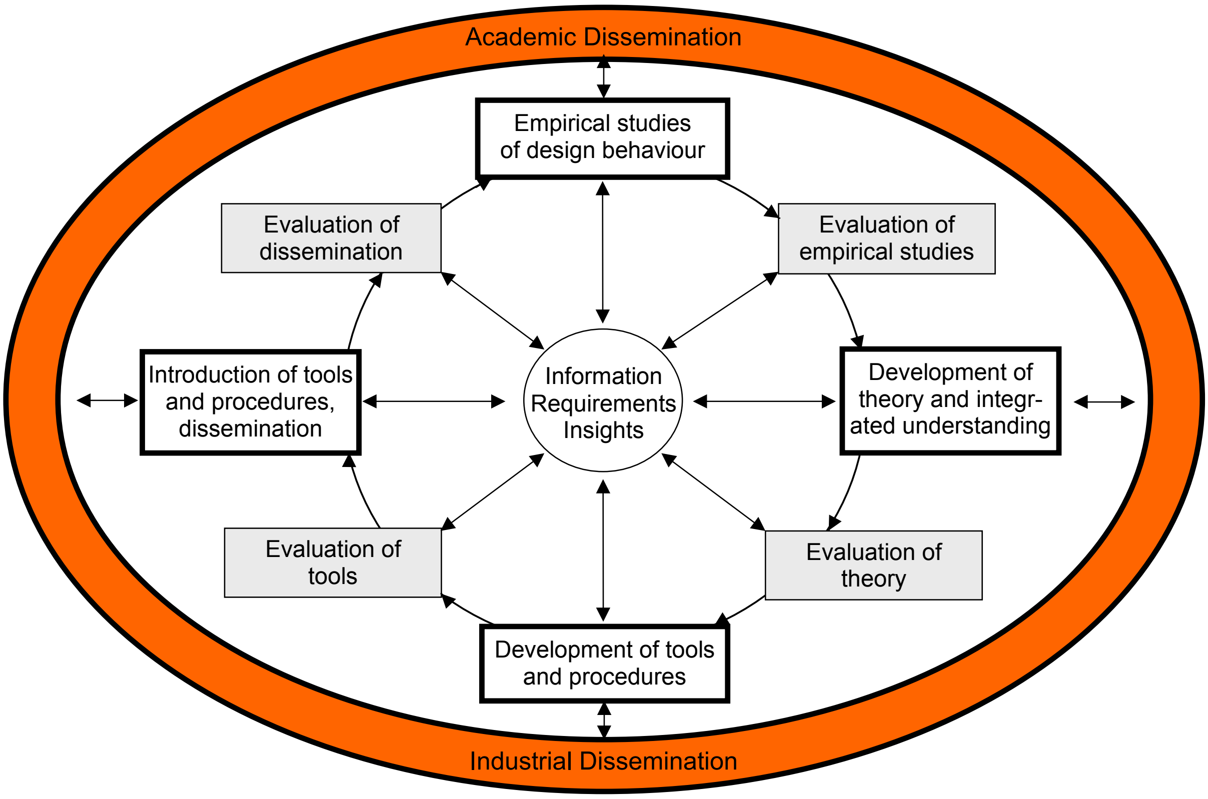

Figure 1. The eight fold model of design research

4.1 Evaluating research results

During and after each of these activities, it is important to evaluate what one has found – we stress this by treating the evaluation of empirical findings, theory, tools and methods, and industrial trials as separate primary themes for research. What happens in design is determined by a variety of interacting factors, so that it is difficult if not impossible to predict or relate the consequences of introducing tools and methods in industry to the findings of studies of the industry. So the validity of research findings needs to be queried at each stage, to assess what sort of foundation the research gives for work that depends on it. Evaluation can draw on the approaches of different disciplines – this is crucial for the iterative refinement of computer tools and procedures. Evaluation is also important in DRM, which takes a different view on how to evaluate design research [1, 2, 3, see section 6].

4.2 The Eightfold Path

The eight types of research form a logical circle – with forward progress this is a spiral:

- *Empirical studies of design behaviour*. These can include case studies employing different observational methods, such as ethnography and soft systems methodology, and a range of analytical approaches, as well as cross-process comparisons and experimental studies of individual design activities, including protocol analysis studies of thinking processes. The direct results of such studies are findings about how exactly design proceeds in certain conditions.
- *Evaluation of empirical studies*. This includes assessing the validity of the research results, how far the results can be generalised, how they relate to other studies and how they fit or conflict with theories of design behaviour.
- *Development of theory*. Empirical research should lead to the development of our understanding of design practice, whether this takes the form of theories of aspects of design, mathematical models of processes, theories in contributing disciplines such as psychology, or more local analyses of particular types of designing.
- *Evaluation of theory*. Theoretical analyses should be compared with existing empirical data, and assessed both in terms of their philosophical and methodological assumptions and their grounding in more general theoretical frameworks, and their relationship to analyses grounded in different conceptual frameworks.
- *Development of tools and procedures*. These are design activities that depend on the developers' objectives. As design researchers and software engineers well know, understanding people's real needs for procedures and software support is very difficult. Computer tools for designers, and techniques such as design methodologies, thinking techniques and management procedures, will only be effective if they are grounded in a good understanding of the thinking processes and work practices of their users.
- *Evaluation of tools and procedures*. As is now well recognised in software engineering, the development of tools and procedures is only be effective if it is an iterative activity interlaced with evaluation of interim products, as users' and developers' understanding of the real requirements change when the users get to test prototypes. And a lot of usability testing is needed to identify and correct glitches and situations where the users do not interact with the system in the anticipated ways. The same principles apply to formal procedures and techniques that designers are expected to learn and apply. The discipline of human computer interaction provides a range of useful analytical techniques.
- *Introduction of tools and procedures*. Successful tools and procedures should be tested in serious industrial use. This is dissemination of research. It is also an opportunity to conduct useful research on design practice and the process of introduction as well as the tool itself. In the social sciences studying the consequences of changing how an organisation works is called *action research*. Soft systems methodology is essentially a procedure for thinking in systems terms about how the participants in a work culture might achieve their goals more effectively and then effecting changes to that culture [12].
- *Evaluation of dissemination*. The results of studying the introduction of a tool and its subsequent use can be assessed for validity and for how they fit into our general understanding of design practice.

All of these activities generate information and insights that can be used to formulate the requirements and hypotheses that guide the design of research within any other step. Research at each stage needs to draw on both knowledge of design and of contributory analytical disciplines such as psychology and sociology – it should meet these disciplines' standards for methodological rigour. Although ideally applied research will form a clockwise cycle, researchers may pursue several of these activities in parallel, and may need to backtrack if the failure of a tool shows the inadequacy of the theory it was founded on. In healthy research groups research on tool building and tool introduction leads to new research questions. All good design research raises as many questions as it answers – we should accept this as a positive force. In practice the temptation seems to be very big to move on to the next interesting research question, before a tool is tested in industry. As Cantamessa [15] points out, the bulk of research publications (at least at ICED) are on new methods and tools, and far fewer focus on the introduction of research results into industry.

While the primary interest of academia lies in theory and tool building, and of industry in usable tools, both groups have an interest in all aspects. For example engineers in industry often find reflections on their design behaviour extremely helpful. By academics providing new insights and stating the obvious companies can often be brought to solve their own problems without requiring methods or tools from academia. Both groups would greatly benefit from learning about the failures of our research just as much as its successes, but this is alien to academic research culture.

5 Integrating design research across projects

The Eightfold Path is a research strategy for a large group that carries on research over many years. At the EDC in Cambridge, our research is driven by large overarching questions that give us a long term agenda, such as "how do people plan?" and "how can we improve planning", or "how does complexity affect design?" and "how can we reduce complexity?" Our view – and our aim for our own work – is that large research groups pursuing co-ordinated super-projects should include all these types of research in their agendas, articulate these agendas, and develop a considered view of how their different research activities are connected. We would like to encourage groups with large-scale agendas to facilitate collaboration with other researchers by making their agendas and research needs explicit as well as their results.

Within the agenda driven framework, individual projects and PhD studies need to be undertaken. Individual students and projects will seldom do more than two or three of the eight types of applied research. We think it is a mistake to prescribe which types of activity students should be required to do for a doctorate, or a project should do to be worthy of a grant, or to value some of the eight types of research higher than others. But it is imperative that students and researchers have a clear understanding of how their work fits into the broader context of applied research and what research findings it should draw on. It is extremely important that researchers and in particular students are aware of the assumptions they are making and their origins. They must consciously select the methods that they are employing and reflect over how their research can be evaluated. Critical thought is far more important then following any set of pre-defined steps.

In our framework a project does not have to start with empirical research of industrial practice; it could also start with an experienced researcher's hunch or an *a priori* analysis of the problem at hand. Radically different approaches can often only be developed if one steps away from industrial practice to look at the real structure of a problem, and does not engage with the more mundane concern of people in processes. Fundamental research, removed from industrial practice and industrial needs, can provide new insights. Some exceptional examples of radical research reframe our way of thinking about design, long before the research is applied in practise. For example shape grammars challenged established assumption and brought new concepts into design research, long before industry-relevant applications have been built [for instance 16].

6 Relationship to the DRM

Many in the design research community have recognised the need for a more rigorous approach to design research, that provides a multidisciplinary framework for undertaking empirical research, and developing, validating and introducing tools and methods [17]. This poses the question whether design research needs its own methodology, as a distinct activity; or a framework in which multidisciplinary methodological approaches are facilitated. Our approach is in the later category; the Design Research Methodology (DRM) developed by Luciënne Blessing and Amaresh Chakrabarti, is closer to the former [1,2, 3].

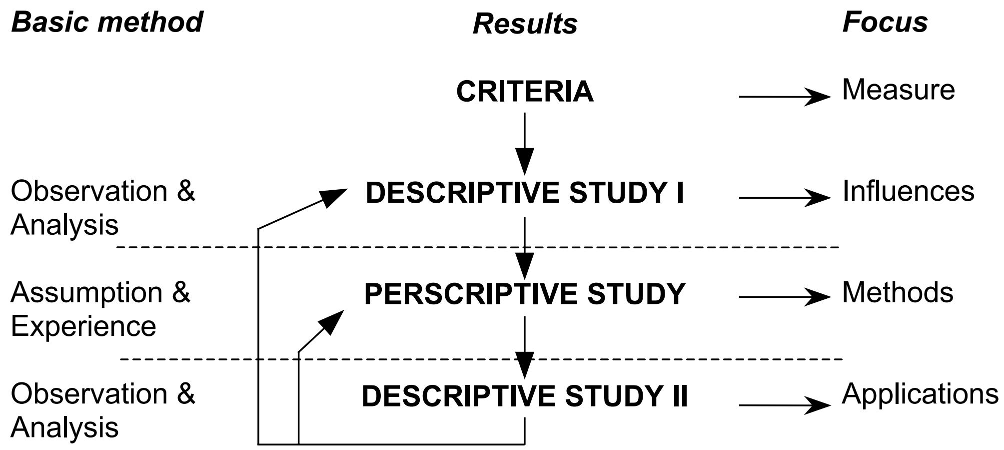

Figure 2. The DRM framework

DRM is also concerned with taking research through from empirical studies of designing to the introduction of new methods, but it divides research up rather differently, as shown in Figure 2. Our approach is agenda driven, while DRM stresses the prior specification of practical success criteria. Empirical study and theory building are covered by 'Descriptive Study I', tool building and method development by 'Prescriptive Study', and tool evaluation and introduction into industry by 'Descriptive Study II'. We approve of DRM's objective of connecting different types of design research and primary concern with action research to test tools and methods in industry. We are more sceptical of DRM's insistence on carrying individual projects through to practical outcomes, and use of criteria – though DRM allows for a variety of types of study [2]. We wanted to place a stronger emphasis on the role of larger agendas, on allowing any research sufficiently well grounded in an understanding of design, on the distinction between empirical research and theorising, and on the iterative nature of both design research and tool building.

We were to some extent provoked into articulating our methodological position more formally by seeing DRM invoked in a more rigid and naïve form than Blessing or Chakrabarti would use. DRM is a response to too much research that is undertaken without a clear goal and methods and tools that are produced as solutions to problems that do not exist [3, 15]. Researcher from other fields, such as computer science, sometimes use design as an example with only the vaguest understanding of what design involves, and no contact to designing practice. These endeavours could be grounded in reality by applying DRM, and especially the focussed use of criteria. The target audience of DRM is primarily PhD projects and isolated projects, which need to follow the outlined stages to produce well-rounded results. Our methodological approach is for large groups, which are in a position to pursue long term research agendas and tackle fundamental questions, therefore our criticism of DRM focuses on its limitations for mature research, rather than demeaning its merits for researchers with little methodological interest.

6.1 Criteria

According to DRM, research should begin with clearly defined criteria for success. In the published examples, these criteria are quite general but entirely practical, e.g. "reduce time to market" [1] and can be translated into a practical measure of success. We fully agree that individual research projects need to have specific questions that they are trying to answer, and ways to evaluate their success. However, the concept of criterion is very rigid in DRM, and in our opinion too restrictive. Empirical studies engaging with industrial practice need to be opportunistic. As researchers we can have agendas, questions or criteria, but we have to respond to the company we work with and the knowledge that is available within this company. Issues emerge through the study. Early fixation on measurable criteria can lead the researcher to miss the real issues by selecting over-specific methods. As industrial engineers find continually, measures are meaningless or even misleading until the problems they address are well understood. We see criteria for the success of tools and methods as desired results of an empirical study, rather than a starting point. In our experience of industrial studies it takes a holistic analysis of the processes in an organisation to establish whether any of our research hypotheses are valid and understand what tools or procedures the organisation would need. For example we recently undertook a case study with the original aim of investigating the effects of bad planning on communication, and found ourselves in a company where personality issues played such an important role that they overpowered all other factors that we hypothesised would influence communication.

The strong emphasis on criteria also comes from the stated goal of DSM to improve industrial practice. However design research has the dual objective of supporting industry and understanding design as a human activity. The later ultimately needs to be curiosity driven and free to latch on to interesting questions and problems, even if they do not fulfil the original criteria. Many good PhD theses have delivered something totally different from what was intended at the beginning of the research.

6.2 Descriptive Study I – Prescriptive Study – Descriptive Study II

In DRM Descriptive Study I covers both empirical studies and their analysis to form new hypotheses. In our framework this is split into 4 separate stages, namely empirical studies, evaluation of empirical studies, development of theory and integrated understanding, and evaluation of theory. We have divided the empirical studies and theory formation, because they often require a completely different set of methodological approaches and can span very different fields. For example an ethnographic study feed into an artificial intelligence analysis of decision points and heuristics [18]. The some empirical study can afford many different analysis and lead to a number of different theories [see 19]. The results from empirical studies can be reanalysed in the light of later findings. Similarity theories need to be formulated and evaluated before a method is developed. We realise that in practice this is a much less clear-cut process: as we observe phenomena we form hypotheses, without hypotheses we miss points, because we do not recognise them as significant. Similarly in recognising problems and forming hypotheses about them we often immediately see a cure.

Again we employ three categories for the varieties of research covered by 'Descriptive Study II', partly to draw attention to the different research methods and evaluation techniques that are required for each activity. This most crucial for computer support tools, which need to be thoroughly evaluated before they are introduced in industry. It is impossible to test a system or method in anger, if it is not possible to differentiate between the effects due to in adequacies in underlying theory, flaws in the implementation of the tools and the idiosyncrasies of the situation where it is used in industry.

7 Key conclusions

Design is multi-layered, multi-faceted and multi-disciplinary. Real process in design research that recognises this can only be made by pursuing an integrated research agenda encompassing many projects. Successful applied design research encompasses eight different types of research activity, forming a spiral. Individual pieces of design research need only include two or three types of research activity, but should be clearly grounded in the findings and needs of other types of research.

Acknowledgements
This research has been supported by the EPSRC block grant GR/R64100/01 to the Cambridge University Engineering Design Centre.

References

[1] Blessing L.T.M., Chakrabarti A. and Wallace K.M., "An Overview of Descriptive Studies in Relation to a General Design Research Methodology", in E. Frankenberger and P. Badke-Schaub (eds.), Designers – The Key to Successful Product Development, Springer-Verlag, Berlin, 1998, pp. 56-70.

[2] Blessing L.T.M. and Chakrabarti A., "DRM: A Design Research Methodology", Proceedings of Les Sciences de la Conception, INSA de Lyon, Lyon, France, 2002.

[3] Blessing L.T.M., "What is this thing called Design Research", Annals of the 2002 International CIRP Design Seminar, Hong Kong, 2002.

[4] Stacey M.K., Eckert C.M., Earl C.F., Bucciarelli L.L. and Clarkson P.J., "A Comparative Programme for Design Research", Proceedings of the Design Research Society 2002 International Conference: Common Ground, Brunel University, London, 2000.

[5] Blessing L.T.M., "A Process-Based Approach to Computer Supported Engineering Design", PhD thesis, Universiteit Twente, Black Bear Press, Cambridge, UK, 1994.

[6] Minneman S.L., "The Social Construction of a Technical Reality: Empirical Studies of Group Engineering Design Practice", PhD Thesis, Department of Mechanical Engineering, Stanford University, Stanford, CA, 1991. Xerox PARC report SSL-91-22.

[7] Dorst C.H., "Describing Design – A Comparison of Paradigms", PhD thesis, Delft University of Technology.

[8] Ehrlenspiel K., "Integrierte Produktentwicklung", Carl Hanser Verlag, München, Germany, 1995.

[9] Eckert C.M. and Stacey M.K., "Designing in the Context of Fashion – Designing the Fashion Context", in P. Lloyd and H.H.C.M. Christiaans (eds.), Designing in Context:

Proceedings of Design Thinking Research Symposium 5, Delft University Press, Delft, Netherlands, 2001, pp.113-129.

[10] Eckert C.M., Earl C.F., Stacey M.K. and O'Donovan B., "Patterns of Designing for Understanding Communication", Cambridge Engineering Design Centre Technical Report CUED/C-EDC/TR-122, 2003.

[11] Stacey M.K., Earl C.F., Eckert C.M. and O'Donovan B., "A Methodology for Comparing Design Processes", submitted to ICED'03.

[12] Checkland P.B., "Systems Thinking, Systems Practice", Wiley, Chichester, UK, 1981.

[13] Bracewell R.H., Shea K., Langdon P.M., Blessing L.T.M., and Clarkson P.J., "A methodology for computational design tool research", Proceedings of the 13th International Conference on Engineering Design: Design Research – Theories, Methodologies and Product Modelling, 2001, pp.181-188.

[14] Langdon P.M., Bracewell R.H., Blessing L.T.M., Wallace K.M. and Clarkson P.J., "A practical methodology for integrating software development and empirical techniques in design", Proceedings of the 13th International Conference on Engineering Design: Design Research – Theories, Methodologies and Product Modelling, 2001, pp.557-564.

[15] Cantamessa M., "Design research in perspective – a meta-research on ICED 97 and ICED 99", Proceedings of the 13th International Conference on Engineering Design: Design Research – Theories, Methodologies and Product Modelling, 2001, pp.29-36.

[16] Knight T.W., "Transformations in Design: A Formal Approach to Stylistic Change and Innovation in the Visual Arts", Cambridge University Press, Cambridge, UK, 1994.

[17] Culley S.J., "Future Issues in Design Research (FIDR) Report", EPRSC/DTI, Bath, 1999.

[18] Stacey M.K. and Eckert C.M., "An Ethnographic Methodology for Design Process Analysis", Proceedings of the 12th International Conference on Engineering Design, Technical University of Munich, Munich, vol. 3, 1999, pp.1565-1570.

[19] Cross N.G., Christiaans H.H.C.M., and Dorst C.H. (eds.), "Analysing Design Activity", Wiley, Chichester, UK, 1996.

Claudia Eckert
Engineering Design Centre
University of Cambridge
Trumpington Street
Cambridge CB2 1PZ
United Kingdom
Tel. Int +44 1223 766 957
Fax. Int +44 1223 766 963
E-mail: cme26@eng.cam.ac.uk
URL: http://www-edc.eng.cam.ac.uk/people/cme26.html

Martin Stacey
School of Computing
De Montfort University
The Gateway
Leicester LE1 9BH
United Kingdom
Tel. Int +44 116 250 6256
E-mail: mstacey@dmu.ac.uk
URL: http://www.cse.dmu.ac.uk/~mstacey