# Design Inquiry: An Introduction

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In the not too distant past there occurred a subtle, but highly important, transition from design methods to design studies (Cross, 1992). The thrust of first generation methods such as efforts to formalize global models of design processes and to develop more objective design methods began to undergo an important evolution in the early Seventies. From a current perspective it is appealing to characterize this paradigm shift as a new orientation to the significance of *design inquiry*. It is only in recent decades that the study of the activity of designing has developed as a research field. There has been a steadily growing interest in the significance of the cognitive activity of the designer. Today one of the central areas of work in design studies is research into the cognitive aspects of design in order to study and model such phenomena as analogical reasoning and creativity. *Design thinking* has emerged as a central emphasis of design studies.

Though many have contributed to the development of contemporary approaches in design research, it is clear that there have been certain milestones in the emergence of the two dominant contemporary research directions which have emerged; studies of design cognition and computational models. While a first generation concentrated on developing systematic approaches and methods in design, a subsequent generation focused upon the study of design processes in order to model cognitive processes in design and structures of knowledge. Certain early works in design thinking developed under the influence of Information Processing Theory and the work of Newell and Simon (1972) with notable domain applications soon following in Eastman (1970) and, later, in Akin (1986). Information Processing Theory as an attempt to model the cognitive processes underlying problem solving and design, contributed much of the conceptual framework in which design research and computational design research is undertaken today. The introduction of key descriptive terminology to the study and formal description of problem solving processes such as problem space, state space, symbolic representation, generative processes, operations, and task environments were part of the theoretical patrimony of these researchers. They pioneered the use of Protocol Analysis as an observation technique employing verbal descriptions of design thinking. Eastman's pioneering work on the first application of protocol analysis to design (Eastman, 1970) contributed more than simply an application in the field of architectural design. In his employment of the term 'intuitive' he laid emphasis upon the explication through research of the internal representations and processes of design cognition, and upon cognitive activities during design. He also demonstrated the significance of the knowledge and manipulation of representations as a cognitive capability in design.

Gradually 'design inquiry', or the scientific study of design as a complex human activity, developed in new directions. Other researchers began to emphasize inquiry into the cognition of design, with less importance placed upon the modeling and formalization which characterized the computational connection of the pioneers. Akin is part of the shift from IPT to design cognition. Schön, Porter, and the MIT Design Theory and Methods Group were also very significant in this shift of interest. Their studies on the thinking of design professionals as 'reflection in action' helped to build the modern research field of design inquiry. Wittgenstein appears to be an important philosophical source, and their work, particularly that of Schön, is involved with meaning, communication, and verbal transactions in design communication and teaching. The group has done much research employing design games and protocols in the study of designer's behavior. This enables the modeling of design reasoning in the transactions taking place in games. Much of this work is also influenced by the research of John Habraken at MIT, particularly on the formalization of representations (Habraken, 1983), the study of heuristics and conventions in design thinking (Habraken, 1985), and on design games (Habraken and Gross, 1987).

There is considerable recent work in the field including comprehensive studies of design thinking (Lawson, 1980, Rowe, 1987), work in protocol analysis (Eckersley, 1988; Gallé and Kovacs, 1992), and research in cognitive function in design tasks, with work on questions such as the influence of examples on 'design fixation', and the influence of problem statement, etc. Others have done considerable work on visual reasoning (Arnheim, 1969), and visual reasoning in the sketch (Mc Kim, 1980; Hewitt, 1985).

A related, and frequently integrated, field is that of computational models of design. Computational cognitive modeling in design is frequently employed as a basis for experimental research through the study of systems behavior. Beyond this instrumental aspect, an objective is building of the theoretical foundations of design cognition through computational modeling of design processes and reasoning. Generally work in the field links theoretical, experimental and computational research. Some examples of researchers are Domeshek and Kolodner (1992) on case-based design aid; Hua et alia (1992) on case-based adaptive reasoning in design; Tzonis (1990) on modeling analogical reasoning in architectural design, and Oxman (1990) and Oxman and Oxman (1993) on prior knowledge in design; and Oxman and Oxman (1992) on models of design reasoning. Much of this work is interdisciplinary.

Currently an awareness has developed among design researchers regarding the research potential of integrated work in design cognition and computational modeling. In this development, recent work in computational modeling has provided both conceptual and research tools, and computational models of cognitive processes are becoming one of the fundamental tools and conceptual environments for design research. Artificial Intelligence (AI) is among the important fields in the large body of diverse work of research, modeling and understanding of mental processes in design. Gero's work in computational design research has contributed in recent years to the foundation of one of the most important design research fields, AI in Design (AID).

Simultaneous with these research developments, there is a growing pragmatic interest in the construction of Design Support Systems (DSS) which utilize knowledge about design which has been generated by foundational research. This latter body of work addresses aspects of human-computer interaction in the performance of design tasks which exploit knowledge and reasoning, such as reasoning from prior knowledge of design situations (Case-Based Reasoning).

## 1. STRUCTURING THE FIELD OF DESIGN RESEARCH

It appears possible to propose a general structure which reflects the crystallization of the field through these developments of the past two decades. At the center of such a schema are the diverse *fields of design activity*. These are probably schematically sub divisible into the broad areas of Engineering Design and Design. Engineering Design contains the technological engineering fields such as Mechanical, Structural, and Civil Engineering. Beyond this are other design fields such as Graphic Design which are less technological in orientation. However, the distinction is not always clear, and making such an analysis of characteristic distinctions in design domains seems necessary. Some activities such as Architectural and Industrial Design share attributes of both classes. Certain general phenomena which are studied by design researchers, creativity for example, may apply equally to all types of design.

Beyond this core of design fields are *subject areas*, each having its own research tradition: the Social Sciences (in the case of design research, particularly Psychology); Philosophy and Theory; Cognitive Sciences and Computer Sciences (particularly, AI). The interaction of people from the core design areas and the additional discipline areas are formative in design research. These interactions have begun to be recognized in recent years by emerging terminology which we might consider the *field categories* of design research. These are: Design Psychology (or Design Cognition), Design History and Theory, Design Computation and AI in Design. The fields utilize four dominant contemporary *research streams*: Empirical

and Theoretical Studies, Theoretical and Cognitive Models, Computational and Cognitive Models, and Design Support Systems. Specific *research subjects* such as creativity may combine various research streams.

A summary of the elements of a possible model of the design research field are listed below:

- *disciplines*
  - design fields
  - education and social sciences
  - philosophy and theory
  - cognitive sciences
  - computer sciences
- *research methods streams*
  - empirical and theoretical studies
  - theoretical and cognitive models
  - computational and cognitive models
  - design systems
- *research fields*
  - design education
  - design psychology/design cognition
  - design history and theories/design methods
  - design computation/AI in Design
  - design support systems
- *research subjects*

The interdisciplinary activity of design research clearly emerged in the presentations of the symposium. Research is frequently the result of multi-disciplinary interactions between members of design disciplines and related subject areas. Research projects may also share multiple research method streams.

## 2. DESIGN RESEARCH AND DESIGN STUDIES

The submissions represent a horizontally broad coverage of the major research approaches and sub-fields of contemporary design research. Research centered in facul-ties of the design disciplines, particularly Architecture and Industrial Design, accounts for more than fifty per-cent of the submissions. This probably has a historical explana-tion connected with the sources of modern design research in the Design Methods Move-ment which was strongly centered in these two fields. In the Netherlands, the Stichting Architecten Research (SAR) and the associated Design Methods Group (Groep Ontwerp Methoden - GOM) appears to have been among the earliest foci of design research.

To this day, design research is predominantly associated with the technical universities. However, due primarily to the development of the cognitive psychological and computational approaches, several interesting phenomena can now be observed. The first, and perhaps most significant of these, is the interdisciplinary nature of design research. Much of the research described is the result of *multi-disciplinary teams* from several universities. Many of the research groups themselves have become multi-disciplinary, representing some mix of the design methodological and theoretical, the psychological, and the computational. Another observation is that the technical universities, representing the largest concentration of design-related fields have a tremendous potential interest in the practical implications of design research for two important areas: *design systems development* and *improvements in design education*. Cutting across disciplinary (technological) lines, design appears to be a common denominator with the potential to build communication between the technological disciplines. An example of this can be see in the remarkable 'Doctor of Design' program of the TUE. The general relevance of design research also appears to have expanded beyond the traditional core of conventional design disciplines and related research fields to include a broad spectrum (software design, educational design, drug design, etc.) of fields. Thus *design has become one of the important foci for multi-disciplinary scientific research and development.*

There appears to be much relevance in the emerging theoretical foundations of design research, in the taxonomic contributions, in the research techniques and findings for a broad range of human activities. The growth of general interest in, and use of, computers in activities of design, particularly in design and decision support in a partnership relationship with human agents has also become a ubiquitous and potentially unifying factor.

## 3. DESIGN RESEARCH IN THE NETHERLANDS

The presentations demonstrate significant indications of both the more traditional and the emerging phenomena of *design studies*. In the following section, we briefly introduce the papers. Most of the papers present a clear exposition of the research orientation and interests of the group, the composition, completed work, publications, etc. The purpose of our review is not to survey this material. We present a 'critical introduction' which considers the groups, their work and composition as a reflection of current developments in design research and some indication of future potential.

The papers have been organized into five groups. Since many of the groups work in multiple sub-fields and employ various research techniques, the classification of the work of certain groups is difficult. However, this attempt at classification appears to facilitate comparison. It also appears to clarify certain general orientations within design studies. The proposed classification is as follows:

- design education, design philosophy, the social sciences;
- design psychology / design cognition;
- design history, design theory, design knowledge;
- artificial intelligence in design (AID);
- design systems and design tools.

## 4. DESIGN EDUCATION, DESIGN PHILOSOPHY, THE SOCIAL SCIENCES

In this first group, Trum's paper describes the highly successful Doctor of Technological Design program of the TUE which provides a vehicle for undertaking advanced design studies in the various fields of technology. In many respects his report focuses certain of the issues implicit in other presentations. Underlying the school are several postulates which relate significantly to issues of design research and education. First of all, is the foundational issue that the exploratory nature of the design activity itself can improve understanding and generate knowledge. Thus the design activity under certain conditions that we might describe as systematic, rigorous, integrated, or inter-disciplinary might function as a medium of study as well as of technological development.

Design development as such may be construed as a form of experimental research. This may provide a broader understanding of leading edge problems in the fields of technological development. A challenge for the school is to make a concomitant contribution to design research as well as to design development. The idea of a *core design program of design methods and theories* which would be a common body of studies for all students is one of the challenges which might potentially help the *design program evolve into a 'design school'*. A further challenge is the potential for the establishment of a*n associated center for design research and design systems development*. The research center could be a complement to the core program of design studies and thus might constitute a *university-wide, interdisciplinary locus for the communality of the design discipline*. It could provide some university-wide focus for currently decentralized departmental activities, for example, design systems development in the various faculties. In fact, we shall see that many of the characteristics of *an academically-based design discipline* (theoretical foundations, comprehensive educational program, research activity, developmental program) are currently present in embryo within several of the existing integrated research groups.

The idea of an *inter-departmental graduate design school alongside a university-wide design research and development center* would crystallize much of the potential of the current generation of design studies. It would potentially provide a new focus for design education, design research, education in design research, computational design research and design systems development.

The Sarlemijn and de Vries paper continues the broad-based orientation to technological design as a social and historical phenomenon. Their work again associates research with education in advanced degree programs; in this case, the TUE M.Sc. program in Science, Technology and Society. The work of the group is relatively unique among the presentations in the philosophical and theoretical orientation, the emphasis upon technology and society relationships, and the use of a comparative historical approach in order to establish 'different types of technologies'. Their view of different classes of technologies contributes some broad distinctions on requisite design knowledge relative to classes of technologies (or classes of design problems).

The final presentation of this group (Visscher-Voerman, de Diana, Visscher, and Rip) deals with design research related to various aspects of the social sciences. Here design is considered to encompass the wide range of activities in the social sciences. The multi-disciplinary research program reported upon deals with, among other things, a critical assessment of existing design methodology and an approach to the definition of relevant design methodology for the social sciences through the 'reconstruction of design practices'. It would include such diverse design problems as design of curricula, educational courseware, design of IT for management and production, design of legal systems as well as the procedural and theoretical aspects

of design, such as 'design conceptions'.

## 5. DESIGN PSYCHOLOGY / DESIGN COGNITION

The second group of papers falls into the broad, but relatively well defined, sub-field of the psychological study of designer's behavior. The field is variously designated design psychology, or design cognition. Among the influences in the emergence of the field has been Simon and Newell's studies of cognitive phenomena, the development of protocol analysis as a research method, Akin's (1986) consistent contributions to, and building of, the field. Much of the work in this area is the result of the fruitful research interaction between psychologists and design researchers working in teams to undertake empirical research of designer's behavior. There are many classical research problems which have emerged with the growth of the international body of researchers in the past decade including the perceptual and psychological significance of design media such as the sketch, visual reasoning, creativity, fixation, and modes of reasoning including analogical and precedent-based reasoning. Since many of these research issues, e.g. creativity, are significant beyond design, there are also many psychological researchers whose work overlaps with, and has relevance for, design research.

The first of this group of papers, by van Andel, introduces another of the current focal areas of interest of design psychology: information usage by designers. He reports on a broad range of research activity on the influence of types of information and types of presentation of information in various design situations and contexts. Among their studies has been involvement with the influence upon design of the form of communicating design requirements. They have also done work on visual and graphic information. This work obviously has direct implications for computer-based information systems for designers. The implications on the design process of the provision of visual information in the form of design precedents - the phenomena referred to as 'fixation', has also been the subject of joint work between with the Design Methodology Group of the Faculty of Industrial Design Engineering at Delft. Beyond the particular psychological research emphases of these researches, this group has also been engaged in complementary research activities related to the development of and experimentation with formalization techniques for the transmission of design guidelines (design knowledge and information) to designers. Thus their work represents a constellation of research subjects related to design knowledge and information presentation, usage, and implications upon design.

Hamel's work deals with empirical research for the construction of psychological models of the architectural design process. It introduces many of the classical research issues of design psychology. These include the study of cognitive processes of experienced designers, and in general, the development of understanding of the constituents and processes of design intelligence and the nature of expertise in design. Among research issues in this work are the characterization of the processes of conceptual design and the development of knowledge of the design problem during the design process. This process of 'search and understanding', or evolving a structure for the design problem through design heuristics is a characteristic and significant phenomena of the architectural design process. The nature of this phenomenon differs significantly between experienced and novice designers. Therefor, the psychological mechanisms of problem formulation and structuring in early design is a key area of research in design psychology having connections to other important factors such as learning and knowledge formation in design. Hamel's work has also been involved with other important research areas of design psychology. Among these are short and long-term memory and the exploration of 'task specificity' in design. An additional area of work is visual reasoning, and he has done research on sketching and visual imagery in the design process.

The Design Methodology Group of the Faculty of Industrial Engineering, TU Delft is one of the oldest and largest of the design research groups in the Netherlands. As with many of the other research groups in this collection, they are diverse in their research orientation including empirical research in design psychology (Christiaans, Cross and Dorst, theoretical formulations of design knowledge (Roozenburg) and computational modeling for design support (Kruger). Two members of the group have produced well known and widely used texts on design methods (Cross and Roozenburg). In recent years, the group has held two symposia-workshops which have resulted in the production of important publications, *Research in Design Thinking* (Cross, Doorst, Roozenburg, eds., 1992) and a forthcoming work on protocol analysis in design, *Analyzing Design Activity*. This latter work is of some significance, since it reports on a workshop which provided an opportunity to compare approaches and methods in protocol analysis. Though the group is also well known for design methodology, I have chosen to include them under the category of design psychology due to the current emphasis in their research approach and subjects. Their members have done research on a broad range of subjects including fixation, creativity, design knowledge, design paradigms, expertise, and discursive processes in design reasoning.

## 6. DESIGN HISTORY, DESIGN THEORY, DESIGN KNOWLEDGE

Two of the groups of researchers have in common a strong emphasis on the formulation of domain knowledge in architectural design. These are the Design Knowledge Systems group of the Faculty of Architecture, T.U. Delft and the Design Methods Group, of the Faculty of Architecture, Building and Planning, T.U. Eindhoven. Both have their origins in design methods. Both have a theoretical rather than empirical or experimental research orientation. Both are committed to developing models of design process and design reasoning. Both groups are oriented to the interaction with design computation as a medium for design research.

The Design Knowledge Systems (DKS) group was founded by Professor Alexander Tzonis ten years ago. It is unique among the research groups in the Netherlands for its architectural theoretical and historical orientation. Among work of the past decade they have employed historical research as a medium of analysis of design behaviors and the modeling of cognitive processes in design. Their studies of analogical reasoning, precedents in design and creativity are well known. Historical analysis as a medium of design modeling is complemented by the second stream of their work in computational modeling and the construction of computational design systems. Given their pivotal position in exploiting the complementary aspects of a historical-theoretical approach and a computational modeling approach through formalization of models of design knowledge, it is natural that they have been involved in various interdisciplinary research programs, including work with colleagues in AI and other disciplines. Like the DMG of Industrial Design Engineering, not the least of their achievements has been the convening of symposia in recent years such as ABCD (Automation-Based Creative Design), 1992 and PRECEDENTS, 1994.

The Design Methods Group (Groep Ontwerp Methoden-GOM) of the Faculty of Architecture, Building and Planning, TU Eindhoven is also one of the oldest design research groups in the Netherlands. It has been closely associated with the Stichting Architecten Research (SAR). One emphasis of the group in the past has been in concepts and representations of environmental structure and the relationship of urban and architectural structuring formalisms to design process. The group is internationally noted for theoretical works on housing form, structure and design process; as well as the relationship of structured formalisms for flexibility and housing systems design. Their publications on the SAR design method, flexibility in design, core housing, and housing types are well known, and they are currently working on a history of SAR. Among the theoretical work of the group have been studies of structured rule-based design. The group is also involved in work on computational design information systems (particularly employing the 'pattern language'). Currently they are involved in theoretical work on design education

(particularly the possibilities for knowledge-based design didactics), the formalization of computational design processes, studies in typological and generic design and design systems, precedent-based design and other models of design reasoning, including visual reasoning. They have developed a cycle of courses at the TUE in design studies.

## 7. ARTIFICIAL INTELLIGENCE IN DESIGN (AID)

In the past decade design has become one of the sub-fields of artificial intelligence. Design as one of the most complex of human behaviors provides a range of unique questions for AI researchers. In addition to research in design knowledge representation and models of design reasoning, AID researchers often work in applications in Intelligent CAD, Knowledge-Based Systems, and Design Aid (or Design Support) Systems. Many of these developments have their origins in interest in the mid-Eighties in so-called, 'expert systems' applications in the design domains. There is currently a large international body of researchers in the field, and great interest has developed in recent years sub-fields in AID such as Case-Based Reasoning in Design (CBRD) and Design Support Systems (DSS).

The Knowledge-Based Systems Group, Department of Computer Sciences of the University of Twente has researched models of the design process as a basis for the development of models and techniques to support Engineering Design. They are also working in the area of shareable, reusable knowledge bases for design. This includes modeling engineering design knowledge based upon a specific 'ontology' which specifies a taxonomy of concepts relevant for multiple engineering domains. Certain of these research projects have and are being undertaken in collaboration with engineering faculties and/or industry. The group is also working in the area of Case-Based Design including indices systems for case retrieval, adaptation, or re-fitting, of cases, and redesign knowledge through diagnosis and respecification.

The Knowledge-Based Systems Group, Faculty of Technical Mathematics and Informatics, Technical University, Delft has done work on a variety of approaches to the recognition and generation of architectural floor plans. Among this research on floor plans has been experimentation with neural nets and genetic algorithms. Work on conceptual design, a particularly complex problem of modeling, is currently a subject of research employing constraint-based and case-based reasoning.

Design research in the Artificial Intelligence Group, Department of Mathematics and Computer Science, Free University Amsterdam combines three perspectives: empirical (task analysis, task and agent analysis, study of design strategies, cooperation and interaction between designers, etc.) foundational (modeling design knowledge and reasoning) and developmental (modular design of design support systems with meta-level architectures, formal specifications for DSS, tools and techniques for generic task models), with the latter having emphasis upon the design and development of design support systems.

## 8. DESIGN SYSTEMS: FROM DESIGN RESEARCH TO DESIGN TOOLS

We have attempted to classify work into the five broad categories of design education and philosophy, design psychology, design history and theory, AI in design, and design systems. The core three fields (psychology, history and theory, and AI) are clearly defined by their research methods. Many of the groups are also working in areas of development as well as research, and are producing computational systems, such as DSS for design. Four of the groups represented are doing design research in order to produce computational design tools.

The IDEATE research projects, Industrial Design Engineering, Delft under the direction of Professor Jim Hennessey are focused upon conceptual design. They study idea and form generation in conceptual design and knowledge and tool usage in early design. The long-term objective is the development of electronic environments and tools for the "creation of innovative form". This effort has involved empirical and theoretical research (sketching and mental images in sketching, design typologies, precedents, shared designing) as well as a variety of innovative tools. The group is interdisciplinary including members from mechanical engineering, electrical engineering, art and design history, psychology as well as industrial design.

The DESYS research group, Department of Engineering Design Faculty of Industrial Design Engineering, Delft is under the direction of Professor P. de Ruwe and the coordination of Ir. Aad Bremer and Dr. Joris Vergeest. It emphasizes information handling in the design process and IT tools to support design. They are part of a larger modular research program collectively called Technical Product Information (TPI) having some 23 staff members. Research of DESYS has included empirical and experimental research work on information usage in the industrial design process, and on empirical research in design processes of diverse designers.

The Computer-Aided Design and Building Informatics Group of the Faculty of Architecture, Housing and Urban Design, Delft is under the research coordination of Assistant Professor Peter van Loon and includes among its research staff Professor Alexander Tzonis and Professor Alan Bridges. Its current research is in the areas of CAD, and team and collaborative design and decision making systems.

The Design Morphology Group of the Department of Architecture, Building and Planning, TU Eindhoven is under the direction of Roel Daru and with the participation of Professor Jean Leering. They have done work in the development of computational tools for design generation, on form perception and form description, and on design styles/strategies. Currently they are working on tools for form generation in the sketch design phase, and principles of formal description and representation. They are an interdisciplinary group with members from Psychology as well as from design fields; they have also done research in participation with other research groups from Delft, Nijmegen and Tilburg.

## 9. **CONCLUSIONS**

What are the profiles of the different universities? Delft with two groups from Architecture, three from Industrial Design Engineering, and one from Technical Mathematics and Informatics represents a broad spectrum of design research approaches and methods. Eindhoven with two groups from Architecture, one from Philosophy and Methodology of Technology, one from Philosophy and Social Sciences, one from the School for Technological Design represents an equally broad, but different, profile from that of Delft. Twente was represented by two groups while other universities had single groups.

How comprehensive is the selection of papers, how representative the sampling at the symposium? In addition to the groups which presented, we know of active design research in several groups of the TNO Delft, in Civil Engineering of TU Delft, in the Building Informatics Section and Calibre Institute of TU Eindhoven, and in the Department of Psychology, in Tilburg. Thus there are more than twenty groups in the core fields of design inquiry at educational and research institutes in the Netherlands.

What does the current situation of design research as a multi-disciplinary activity suggest for the future? As a result of the past generation of design activity it is now possible to define the 'science of design' as the scientific study and understanding of design. To fulfill this vision requires the clarity and rigor in design research which can help us to achieve a 'design discipline'. That is, once we derive knowledge from the scientific study of design, it may potentially add rigor to the activities of design. This is the meaning underlying the idea of a design discipline.

If these are the objectives of design science and the design discipline how do we get there from here? We need a collective agenda of field objectives and a better understanding of what we expect to achieve through inter-disciplinary research activity. We require empirical studies of our theoretical models, including more interaction and mutual understanding between designers and researchers. The establishment of the theoretical foundations of a design discipline should be considered an objective of both design practitioners and design researchers.

A majority of design researchers are academics. As such, many of them are also involved in design pedagogy. Perhaps the common challenge of improving the teaching of design, of achieving a knowledge-based design, may provide such a general field objective for the next generation.

There were many areas of potential interaction and some areas of correspondence of research activity as indicated by the presentations. On the whole, the symposium indicated a very lively and productive state of the art in the Netherlands. There appears to be much potential for collaboration, not the least of which might be the continuation of such symposia on a yearly basis.

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