Design research in the Netherlands

DESIGN RESEARCH IN THE NETHERLANDS

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Oxman Bax Achten editors

Groep Ontwerp Methoden
Bouwinformatica

Department of Architecture, Planning and Building Science
Eindhoven University of Technology

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A Symposium on the State of the Art

Design Methods Group (GOM) + Building Informatics (BI)
Technical University Eindhoven

Preface to the Symposium Pre-prints

The objective of the symposium as described in the first announcement was to provide a forum within which the participants might present their research activities and interests to a diverse group of researchers in the field. As an initial goal, we considered this a unique opportunity to gauge the breadth of activity in the Netherlands. After consultation we assembled a list of researchers and groups which appeared to us to be comprehensive, and sent out the first announcement. In most cases, the response was positive and immediate. Design research appeared to be ubiquitous. Cutting across disciplinary lines, the symposium would provide a locus for discussion among an intellectually heterogeneous audience sharing a common interest in design research.

Beyond the initial objectives of communication and information exchange, there is a significant underlying agenda. From a historical point of view the field appears to have reached a plateau. It is well-founded, diverse and active. There are venues for international meetings as well as for scientific publication. Among these, Design Studies, and Nigel Cross have to be singled out as one of the contributing factors in the self-awareness of the research field as well as in its growing definition and maturity.

What now appears to be necessary is the development of overall objectives for design research. The term 'design science' seems to hover in the background to imply the emergence of a rigorous design discipline. What are the next steps towards a science of design? How can the multi-disciplinary state currently characteristic of the field contribute to its realization? Will the new initiatives of the Graduate Schools of Design currently in stages of inception at both Eindhoven and Delft provide new incentives. Can we now enter a cycle of 'knowledge-based design education' in which what we are learning about design through research can be applied to teaching? Might the Netherlands play a unique role both in research and design pedagogy?

The symposium may provide an initial step. We will attempt to re-publish the contents of the pre-prints in a book format. The authors will be given an opportunity to re-write and to incorporate their reactions to the issues raised in the symposium. If the symposium is successful, and interest exists, we will plan a future meeting.

Robert Oxman, Thijs Bax, Henri Achten January, 1995

Design Inquiry: An Introduction

Robert M. Oxman
Eindhoven University of Technology
Faculty of Architecture, Building and Planning
P.O. Box 513 5600 MB Eindhoven NL

Phone:(+31) 40-472088/47341 Fax:(+31) 40-452432
E-mail: bwrmoxm@bwk.tue.nl

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 process 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 a cognitive approach in design studies, 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 the cognitive processes in design and the 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) and domain applications in Eastman (1970) and 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 architectural design. In his employment of the term 'intuitive' he laid emphasis upon the explication through research of the internal representations and processes of 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 other 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 work 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 (Rowe, 1987, Lawson, 1980), work in protocol analysis (Eckersley, 1988; Gallé and Kovacs, 1992), and research in cognitive function in design tasks, working 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 often integrated, field is that of computational models of design cognition. 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 multi-disciplinary. In is interesting that in attempting even a brief review of theoretical and empirical work in design reasoning, it is impossible not to refer to simultaneous developments in other fields such as AI. Artificial Intelligence is among the important fields in the large body of diverse work of research, modeling and understanding of mental processes in design. 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. 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) and which utilize this knowledge. 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.

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 is 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 design domain characteristics 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, probably apply equally, to all types of design.

Beyond this core of design fields are four interacting *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 four additional discipline areas produces 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, Design Methods and Theories, Design Cognition, Design Computation and Design Systems. Interactions between the fields produce the four dominant contemporary *research streams*: Empirical and Theoretical Studies, Theoretical and Cognitive Models, Computational and Cognitive Models, 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.

- *fields of design activity and related subject areas*
  - design fields
  - social sciences
  - philosophy and theory
  - cognitive sciences
  - computer sciences
- *research field categories*
  - design psychology
  - design methods and theories
  - design cognition
  - design computation
  - design systems
- *research streams*
  - empirical and theoretical studies
  - theoretical and cognitive models
  - computational and cognitive models
  - design support systems
- *research subjects*

Research field categories and research streams are frequently the result of multi-disciplinary interactions between members of design disciplines and related subject areas. Research projects may also share multiple research traditions and methods.

From Here to Design Science

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.

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FROM IDEOLOGY TO METHODOLOGY
The Theoretical Evolution of the Design Methods Group

M.F.Th.Bax Professor of Architectural Design
Faculty of Architecture and Building Science
Technical University Eindhoven

Introduction

Design research has never been a popular subject in the Netherlands. Developments in the Anglo-Saxon world were noticed, but not considered relevant for design and building practice. However, design work was done on a comparatively high level. Architects, like many of their professional colleagues in other design areas have little concern about methods and theory.

Even when the designer actually is using *methods* and employs a *theoretical* framework, he is not inclined to mention these techniques in explaining the *structural* and *procedural* aspects of the building he created. This would dissipate the aura of *creativity* and *originality* which are supposed to be the trademark of designers, also in other areas than building. This is partly explainable as a strategy to keep control over the design and building process by making their *territory* inaccessible for other participants in the design process, but mainly, I believe, by the absence of an operational *body of knowledge* which enables them to communicate and share responsibilities with other parties involved.

In the Sixties there were certain socio-economic developments, together with technological developments, which opened the door of the professional world to external control and *participation*, just for a moment as it seems. The Design Methods Group (GOM) of the Faculty of Architecture and Building Science, Eindhoven University of Technology, played an important role in this respect since 1967, when John Habraken founded the faculty and occupied the Chair of Architectural Design.

My intention is to give a short description of the development of the scientific work of the group in three episodes. I will indicate these three episodes as *Ideology, Theory and Methodology.* Of course all three aspects are present in each period, but my point of view is that they are dominated by one specific concept. At the same time they indicate a *development in phases* of a theoretical framework which is perhaps only visible in retrospect. This historical development maintained its consistency during a relatively long period of time. More important even is that because of its origin in architecture and building, it has a certain *autonomy*, so that it doesn't depend on general theories but, on the contrary, can determine its own reference to them.

Each period, or phase, is characterized by a specific *relation* between the theoretical framework and society, the great theories and empirical reality. Respectively these relations are termed here as the *natural relation*, the *cultural relation* and the *structural relation*.

1. IDEOLOGY: 1965-1975 - John Habraken
The core of the philosophy of Habraken is the so-called "natural relation" between people and their environment. He takes the point of view that this relation has a *dynamic* nature and that only by an active involvement can the 'massafication' of the environment be avoided. Three pairs of groups determine this relation:

-the relation between *individuals and community*, a primarily *social* definition of the field of architecture;

-the relation between *consumers and producers*, a primarily *economic* definition of the field of architecture, which is considered to be a market;

-the relation between *short and a long term*, a primarily *physical* definition of the field of architecture, in which the two first mentioned classifications are summed up, determining support and infill components in relation with social groups and economic conditions in terms of time and process.

The three types of relations define together the so-called scale *concept of planning*, which connects the level of architectural *design* with the higher level of architectural *planning*. It connects, at the same time, architecture with the wider field of urban design and planning. This is through the notions of process and time because of its inherent *explicit* and *public* character which has always played an important role. Physical elements in this ideology only make sense when social and economic *attributes* in the form of the *parties* involved, are defining them, thus providing the basic conditions for a decision making *process*. This *dynamic* definition of architecture in terms of a process provides us with the conceptual tools to think about our environment in terms of *ecology*.

These conceptual tools were made operational by the definition of a set of *representations* in order to make it possible for designers to design supports and infill components. Zones and margins, sectors and sector groups, modular co-ordination in the form of the well known 10-20cm band grid, and basic variants determined the operational tools in *SAR-methodology*. The same type of representations was used to define urban tissues and building nodes, in addition to Supports, as different *scale levels* of design and decision making. *Coherence* of a building was considered as *harmony*. between designs on these various levels.

The influence of SAR thought can be noticed in the so-called *NEN-norm 6000* for modular co-ordination giving a priority to position above exact measurement, the so-called *Bouwbesluit* in which buildings actually are defined as supports and which opens the building and design process for the various parties involved. In the near future it will make a connection possible with the *ISO-norm 9000* which emphasizes the procedural aspect of architecture. When these standards are implemented in architectural design the three dimensions of architecture, *Form, Function and Process* are dealt with in a consistent way.

This type of redefinition of the field of architecture is actually what is happening in *post modernism* and *deconstructivism.* The relations between these philosophies and architecture are more basic in SAR thinking than can be found in the fashion of cult architecture with its use of citations and the play with architectural syntax.

However, many methods, techniques and computer programs like the first really form generating computer program, SAR 70, were developed between 1965 and 1975. This period has to be characterized by its *ideological* drive and, in the sense that Peirce used that notion , its *pragmatical* nature.

2. THEORY: 1975-1995 - Thijs Bax

The following period is characterized by connecting the theoretical framework of SAR thought with other fields of theory building, technology and science in an international European context. That is the reason why I want to refer to that period as the *cultural relation*, the embodiment in a wider intellectual environment. The period is referred to as *Theory* for other reasons. In spite of the name of the Design Methods Group, not much work was done in the field of methodology.

a. The Cultural Context and the General Theories

Referring to Bill Hillier's famous paper "Systems, Structures and Transformations", these three fields of theory building were found to be relevant for SAR thinking. *General Systems Theory* provided the three dimensions of "architectural space in transition" by defining *hierarchy, aspect ,and phase systems. Form, Function and Process* determined the anatomy of the so-called ,*GOM-Model.* A new definition and articulation of space, objects and events, respectively, was required in formal (*level-* bound), functional (*domain-* bound), and temporal, or procedural (*phase-* bound) systems. The GOM-Model was elaborated in two modalities: a *static* and a *dynamic* one, the latter defining categories of processes in architectural thinking. These are level-bound *ordonnance* processes, domain-bound *integration* processes and phase-bound *differentiation* processes, depending on their direction in the model.

French Structuralism provided the working model of structure. The definition of structure contained the three dimensions of form, function and process, by emphasizing the notion that a structure is what *variants* have in common. *Actual* reality and *structural* reality, connected by processes of *induction* and *deduction*, provided a mechanism for the definition of *levels*, and linked modern process oriented thinking with more functional and form oriented thinking in previous stages of *developments in western philosophy.*

Evolution theory provided the notion of *generation* (of variants) and *selection* (by context), and the notion of "relucter pour mieux sauter" which is characteristic for evolutionary process, connecting *ontogenese* and *phylogenese* in one concept. *Transformations* of the Site is the title of the book John Habraken wrote about processes of adaptation and adjustment of the built environment as a living configuration.

It must be clear that it is not possible to deduce the implications for architectural design from these great theories. Only in a reverse process is it possible to make a connection contemplating the similarities which become visible.

Three theses were written in that period in which each dealt with a specific dimension of architectural space:

-Thijs Bax dealt with the concept of levels, based on the notion of structure, in a so-called *generic grid.*

-Henk Trum dealt with the notion of norms and functions, in which he together with Thijs Bax defined the functional domains and orders which became the core of so-called *Domain Theory.*

-Jan Thijs Boekholt dealt with the notion of phases, and ,more specifically, connected the notion of levels with phases in the *process-states*: of analysis, synthesis and evaluation.

Together these dimensions form the core of the *GOM-Model* as a basis for the definition of *categories* of design thinking and the notion of *concept..*

Following these three works, the dynamics of architectural form became the subject of a thesis by Matthijs Prins on the costs of flexibility.

b. European Context: the Taxonomy of Concepts

Developments in Domain Theory and GOM-Model made it possible to comment adequately on the European Directive of 1985 and more specifically on article 3, enumerating the requirements for architectural *formation* and, at the, same time of architectural *design..* The list of 12 components of art.3, describing the content of an architectural project, could be represented on a more consistent way by referring to a number of architectural *phenomena*, which in a later stage of development were termed "Concepts of Architecture", and were organized in a *taxonomy.* The taxonomy, by identifying and defining *fields of design* is considered to be a useful tool for the description of the *profile* of any designed object.

c. The Technological Context: Design Science
General acceptance of the taxonomy by the various European member states, assembled in the Advisory Committee of the European Commission, made a wider acceptation of GOM theory easier. The descriptive theory proved to be applicable in other fields of technological design, like mechanical engineering, electrical engineering , etc. The long neglected possibility in Dutch law to make a *doctoral thesis*, based on design, could now be materialized because of an adequate description of the requirements of such a design.

However, this episode is theory dominated. There still is the ideological content of designing by *participation*. The international Design Participation Conference of 1985, just half way through the period, testified to the belief that design in collaboration is not only associated with the Seventies, but that this is a modern, even post modern notion which provides us with the basis for both social and scientific development in design theory.

3. METHODOLOGY: 1995-2000 - Robert Oxman
This period is indicated as Methodology based on theory and given a motivating spirit by ideology. This period is not pragmatic any longer, not directed to adjacent theories, but seeking the content of designerly thinking. It employs the results and methods of *cognitive psychology* in a quest to discover the very fundaments of design. That is the reason I have characterized this period as the *structural relation*, based on the observation of the designer at work. Perhaps the body of theory is will be substantial enough to deal with the empirical world on a scientific way.

So we now enter the field of *Design Science*, the field of the homo inveniendus, and the field of *knowledge systems* which support design activities. There are three topics which seems to be of interest.
The implementation of the formal, functional, and procedural have defined *Concepts* supported by the philosophy of Peirce. Currently, the exploration of the field of *generic representation*; is the areas in which Henri Achten is writing his thesis on the design of generic grids based on the use of typology. Beside design itself and design theory and cognition, it becomes clear that a more profound knowledge of design thinking provides the means for *design management* and *design didactics*.

Already from the very beginning of SAR and GOM the activities of these groups were supported and stimulated by the use of *computers*. Based on the theory already developed, a concept of design activity is imaginable in which the computer is considered to be an *intelligent* *medium*, which not only conveys messages, but brings some order and quality in them which is close to the structure of human design.

Epilogue

This overview from ideology via theory to methodology is mainly historical. The objective is that it provides us with an insight into the evolution of our thinking and work, and opens a perspective on the activities of a group which has been working for already three decades in the field of architectural design theory and methodology. The content of our work always was determined by the content of architecture itself, and was always given a direction by our belief that architectural design will have to be carried out by the *participation* of all parties involved. We hope that our work will provide the *professional world* with the tools they need to adjust their attitude, as mentioned in the beginning, in order to deal with the growing complexity of design.

Symposium 'Design Research in the Netherlands'
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Design Methodology in the Context of the Eindhoven University of Technology 'Technology and Society Program'

Andries Sarlemijn and Marc de Vries

0. Structure of the paper

In this paper we will first describe the general nature of our research activities, as they are related to the context in which we work (paragraph 1 and 2). Next we will deal with the content of our research and the approach we have developed (paragraph 3, 4 and 5). Finally the disciplines that are represented in our group, and thereby the body of knowledge from which we seek inspiration, will be discussed (paragraph 6). A list of publications is added to these sections.

1. Socially oriented design research

In general two types of design methodological research can be distinguished:
(1) research that came forth from the practical needs of designers to get more structure into their design activities;
(2) research that studies the broader context in which design activities take place (influence of the company's policy, developments in the market, in lawgiving).
One could phrase these two types as the two 'cultures in design methodology [De Vries, 1993]. Thereby one should realise that here the use of C.P. Snow's terminology only refers to the idea of two separate groups of researchers, each with their own approach, jargon, methods, and not to his distinction between literary and natural scientists.
The first approach - the first to use the term 'design methodology' - resulted in the search for step models that would guide the designer in his/her activities. These models are based on reflection on practice and not on the application of logic (as in the second approach). Generally speaking these models are based on two assumptions:
(1) such models can be developed in a technology independant way;
(2) design processes follow the order 'analysis - synthesis - evaluation'.
The first assumption becomes evident from the fact that all 'classic' design method handbooks do not use any specific technological context to describe these models. The second assumption can be restated in other terms, like 'determining the list of requirements - concept and detail design - comparison with requirements'. Observation of what real design processes look like have raised doubts about the validity of both assumptions. In the first place design processes are not all alike, but differ from product to product. In the second place analysis, synthesis and evaluation do not necessarily take place in that order, but rather pervade the whole process.
The second approach, that is primarily taken by philosophers, historians, and sociologists (often under the heading of 'technology dynamics'), at first sight may look less practical than the first. This, however, is a false impression. One of the most serious

problems modern business corporation are faced with is the need to tune the products to the social requirements and constraints. More and more 'the voice of the customer' is looked for. More and more product development is influenced by political influences (this becomes clear in the case of e.g. High Definition TeleVision or the rapidly emerging many new environmental laws). The integration of technical possibilities and social requirements and constraints is the main focus of the second approach in design methodology. The research that is described in this paper must be located in this second approach. Our main aim is to get more insight into the way designs can be developed in such a way that they fit better with the situation in society, in other words what we look for is 'socially oriented design'.

2. The role of design research in the 'Technology and Society' program

The faculty of 'Philosophy and Social Sciences' since 1984 has a M.Sc. program entitled 'technology and Society'. Internationally such programs are known as 'STS' programs (Science, Technology, Society). In particular in the USA several universities have STS programs (e.g. Penn State, Virginia Tech, Stanford, MIT, Rensselaer). But there are also European institutes with STS programs operating already (e.g. in Manchester, UK and Linköping, Sweden) or in preparation (in some Eastern European countries). These programs are either
(1) social science oriented with a special focus on technology, or
(2) engineering oriented with a special focus on social and human factors.
The Eindhoven University of Technology (EUT) STS program leads to the title of 'engineer' and therefore is of the second type.
In this program our design methodology activities takes place and this to a certain extent determines the content of our research. The general aim of the program is to educate people for doing studies that can support decision making in technological developments. In terms of design this means decision making with respect to the directions into which the design and development of a product or group of products should be guided. In practice this can be the task of a product manager in a large company or the management team of a small company. Usually the results of our studies are not directly usable by designers. Therefore our research belongs to the 'second culture' in design methodology, as described under paragraph 1.

3. Design research and the need to distinguish types of technologies

The 'STS' nature of our research has been elaborated in the following way:
- by analysing the S-T relationship of the S-T-S complex we identify the need to distinguish three types of technologies when studying the way designs are developed: experience based technologies, macrotechnologies and microtechnologies,
- next we look at the T-S relationship of the S-T-S complex to find out how social factors play a different role in the different types of technologies we have distinguished,
- finally we offer an approach for design strategies that integrates S, T and S: the so-called STeMPJE approach. STeMPJE is the acronym for the initials of the main

factors that are included in the approach: Scientific, Technological, Market, Political, Juridical and (A)Esthetical factors.
The three types of technologies can be described as follows:
(1) the scientific knowledge that is involved experience based technologies has been derived from engineering practice rather directly. One could caracterise this knowledge as 'tabelised experience'. Because this knowledge is so practical and concrete its use in design mostly is not so complicated (e.g. looking up the relevant table of material properties and reading the necessary data). At the same time, the various bits and pieces of knowledge all deal with very specific phenomena. Hence the difference with
(2) macrotechnologies, where the scientific laws and concepts involved are (i) the result of a mathemetical deduction from basic equations and (ii) concerned with a much broader range of phenomena. This means that the designer has to bridge a gap between the idealised theory and the practice that deals with reality in all its complexity. Sometimes the engineer tries to realise the ideal sitaution, in other cases he deliberately uses the disturbing factors to reach his goal. Newton's mechanics is a good example of such scientific knowledge. The role of scientific knowledge in macrotechnology is that of accelerating the development of a technology. An example: steam engines already before (classical) thermodynamics was developed and this theory helped improving the steam engines, which proces would probably have taken much more time without scientific knowledge of the behaviour of the steam in the machine.
(3) In microtechnologies the scientific theories that are involved become even more abstract, as they deal with microscopic structures we can not see. Even when we think we can imagine their nature (regard electrons as little balls) the theory disturbs this picture (electrons are solutions of wave function equations). The development of such theories mostly precedes their application in design. This application is difficult because of the very abstract nature of these theories and therefore often analogies with macro-situations are looked for when designing. At the same time, microtechnologies would never have been developed without such theories. An example: television would still be in its (Nipkov disc) infancy without fundamental knowledge about electrons.
The distinction between these levels is relevant for the development of products, because of the preliminary closure of a certain level at a certain stage of the development (e.g. in the design of microprocessors one does not any more question the microtechnological basis behind the design, but one takes it for granted).

4. The STeMPJE approach

So far our studies into the development of several technical devices have given us the strong impression that the role of social factors in design differs between the three types of technologies.
In the development of the Brabantia corkscrew we see that scientific knowledge only plays a marginal role. It is the experience of the designer that determines the use of material and shape properties. From the beginning of the development market factors are present and play a vital role.

Almost the opposite is the case in the development of the transistor in the Bell Labs. Here we see a strong emphasis on the use of solid state physics in the beginning of the development, that is certainly not driven by a concrete market, and only later on the product was further elaborated to fit into a certain market. Practical experience with diode and triode tubes rather hampered the process than helped it. In the development of the Plumbicon (a television camera pickup tube, that has been developed by Philips) we see the same essential role of solid state physics: the crucial step from its precessor (the RCA Vidicon) to the Plumbicon could be taken thanks to intensive research into photoconducting and semiconducting properties of materials.
The case of the Stirling hot air engine shows an example of a macrotechnology as a kind of intermediate type of technology: Robert Stirling invented this machine before Carnot wrote his 'Reflexions', but the use of thermodynamics, theories about heat transfer and friction in gas flows helped Philips to improve both power and efficiency substantially in just a few years. During all developments market considerations palyed a role, in particular price, safety and efficiency.
Knowing these differences is useful for contemporary business corporations when considering their design strategies. When the product to be developed is likely to be a microtechnology, it seems best to choose a microtechnological development approach. Neglecting this can cause serious barriers in the design process, as has been shown in the case of liquid crystal displays (LCD's) with Flat Panel Displays (a daughter corporation of Philips). Only in a very late stage of the development the Philips Research Lab was involved to study the behaviour of the crystals in the display, which helped solve the problem of rubbing the glass, which with the designers had been struggling in an experience based way for a long time already.
Several students have been guided by us when making STeMPJE analyses for business corporations. Some examples of this are:
- ISDN based telephone equipment. A small company in the southern part of the Netherlands wondered what the consequences of the introduction of ISDN (Integrated Digital Network Services) for the development of their telephone equipment. A student in the context of his M.Sc. thesis analyses the various STeMPJE factors: the state-of-the-art in ISDN and IC's for digital telephone equipment, the respons of customers to the new possibilities of ISDN based services like call-in line identification, the expected emergence of Dutch and European norms for ISDN, and legal issues with respect to privacy of phone calls. Based on this analysis he delivered a set of requirements for the new telephonbe equipment;
- in a similar way another M.Sc. student made a STeMPJE analysis with respect to the new possibilities for Stirling cycle based refrigerating equipment: the technical state-of-the-art in Stirling engine and cooling machine design, the market sectors and their requirements in terms of temperature range and power, the expected development of national and international laws for stopping all CFC production, and political (financial) support for the development of alternative cooling machines. With this analysis as a basis the student came up with a strategy for developing Stirling cooling machines.

5. Tools for design decision making

In the context of the 'first culture' in design methodology (see paragraph 1), a number of practical design tools have been developed. Usually these tools take the shape of seemingly easy-to-use prescriptions for activities in the design process. The validity and reliability of the outcomes of such tools seldomly are studied. As long as the tools seem to work, there is no worry about what is seen as typically academic questions that have no practical relevance to the designer.
In the 'second culture' though, the philosopical-methodological basis for such tools is studied. Insight into the nature of the tools, the (often hidden) assuptions for their use, and the nature of the outcomes often leads to certain 'caveats' in their application.
An example of such a tool, that caught our interest, is Quality Function Deployment. As this is a tool that pretends to enable a conversion of customers' wishes into engineering features of the product, it fits quite well in our research field, that focuses on technology-society relationships. The current literature merely describes the procedure of QFD as a practical tool. No distinction is made between different types of technology, which, as we have seen before, is more or less typical for the 'first culture' in design methodology.
The procedure for QFD is the following: first the customer's needs (the rows) have to be identified, with priorities that can determine weight factors, next the main features of the product have to be stated (the columns), then the correlations between the customer's needs and the technical features are put into the cells of the matrix, usually in the form of symbols representing weak or strong relationships, then a benchmarking of the company's own product and its competitors is carried out and added to the matrix, and finally technical target values for the relevant features are set. The 'House of Quality' as this matrix is often phrased, is completed by the 'roof': the mutual relationships between the technical features (in fact here the conflicts between different design requirements can be found).
From a methodological point of view this procedure raises several questions, like:
- how is the customer identified: it is the user, or the buyer, or the yet another relevant person,
- what is the nature of the so-called correlations in the cells of the matrix,
- how are they determined
- what type of scale is used for these correlations,
- how is the reliability of these correlations established,
- can the method be applied irrespective of the technology that is involved?
The answers to such questions may leed to guidelines for the prerequisites for the use of QFD as well as for the status that is given to the outcomes in the further design process.
The broader context of QFD is the total quality management idea. Quality should be assured throughout the process of designing, producing and using products (and services). For designers the message is to consider all phases of the product life cycle when designing the product. In practice this leads to terms like: design for production, design for assembly (DFA), failure mode and effect analysis (FMEA), design for maintainance.
A parallel trend in design is: ecodesign or design for sustainability. Here too the whole life cycle of a product has to be taken into account. A tool for this way of designing is: Life Cycle Analysis (LCA). Such analyses prevent a too narrow focus on one phase (e.g. non-degradability after disposal) while forgetting another (e.g. low

energy production process). Ecodesign and its tools are studied in our group from the perspective of the STeMPJE approach: how can designs be made succesfull by integrating knowledge of materials and production processes, desired functions, perception of 'greenness' of the product with the customer, environmental government policy and laws, appearence of the product.

6. Disciplines represented in our group

Before describing the disciplines from which we draw, it is neccessary to come back to the nature of our design methodology activities.
The broadest context for studying the nature of technology and design is the philosphy of technology. When this philosophy becomes more empirical and/or more exact through the application of logic, we speak about the methodology of technology and design. Because of the relationships between science and technology, our study of design methodology also makes use of knowledge from natural sciences and the philosophy and methodology of science. As design methodology is part of the curriculum of our STS program, the didactics of technology and design to a modest extent functions as a background for our teaching.
Now the composition of our group can be understood to be appropriate for our field of research:
- prof.dr. Andries Sarlemijn studied philosophy and logic, and specialised in the historical relationships between science and technology and in the philosphy of design,
- dr.ir. Peter A. Kroes studied technical physics, specialised in the philosphy of sciences and took a special interest in the philosophy of technology,
- dr. Marc J. de Vries studied physics, specialised in studying the practical ways in which designs are developed in industries, and has a particular interest in the didactics of technology.

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A. Sarlemijn:

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Between Science and Technology, [Delta Series] Amsterdam / Oxford, New York / Tokyo: North-Holland, Elseviers Science Publishers B.V., 1990; ISBN 0 444 88659 1. Essays on fundamental research being relevant for industrial technology.

Editor in chief i.c.w. P.A. Kroes; contributors: L. van Hove [CERN], J.S. Bell [CERN], G. 't Hooft [Utrecht], M.F.H. Schuurmans [Delft, Philips Labs], J. Demuth [Watson Research Centre IBM, New York], H. Haken [Stuttgart], M. Eigen [Heidelberg Univ, Nobel Price 1967], L. Hoddeson [Illinois University].

Het ontwerp, spil van de techniek-kultuur Inaugural Lecture, Eindhoven University of Technology: 1990.

Series of 4 books on the philosophy of technology, probably published by Reidel-Kluwer during the periode 1994-7 (negotiations are going on)

- *Philosophy of Science Based Technologies:*
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  Business Philosophy, Business Ethics and R&D-Manamgement (studies in aansluiting op Sarlemijn, A., Tussen akademie en industrie, Casimirs visie op wetenschap en researchmanagement, Amsterdam: Meulenhoff, 1984 en op onderstaande III.3)

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Environment-behavior studies and design research.

Dr. Joost van Andel
Department of Philosophy and Social Sciences, DG 0.11; TUE

1. Description of the research group

Environment-behavior studies has been one of the main topics in research and teaching at the Department of Philosophy and Social Sciences, TUE, from about 1980. We are mainly interested in the interaction between users and their built or natural environment. Interest in design processes comes therefore through the fact that most environments are designed by architects or environmental planners. More specifically we have always been interested in communicating with designers about the results of environment-behavior research. Hamel has started the first substantial researchproject on this subject, which eventually has led to his dissertation in 1990 about a cognitive psychological description of the architectural design process (Hamel, 1990). Using protocol analysis of design activities of a number of practicing architects, Hamel was able to test empirically his model of the architectural design process.

From then on essentially two lines of research were followed:

On the one hand the use of Alexander's patterns as a form of communicating research results to architects in a number of practical studies by staff members and/or MA-students, such as on nursing homes (van Wagenberg, Dellaert, Waalwijk, 1989), the role of doorsteps in housing (van Andel, Bruls, Jaartsveld, 1990), environments for users with cognitive disfunctions (van Vree, van Andel, Venselaar, 1992), houses for the elderly (Christmas, 1994), environments for visually impaired elderly (de Kort, 1993), and offices (van Dorst, 1992). Most of these studies were done in cooperation with colleagues from Bax's Design Methods Group at the Department of Architecture, TUE, especially with Boekholt and Dinjens, who maintains a growing database of Alexander-type patterns on a variety of issues and environments. At present this database contains about 1900 different patterns from about 50 different sources.

On the other hand we have focused on the role of both visual and graphical information, and on the role of computer support in transferring information from research to designers, culminating in the use of hypermedia systems. A major study on this subject is the recently completed PhD work of de Vries (1994) on the cognitive aspects of designing as problem solving and the role of external information with different structures. The goal of the designer in using the information system happened to be important, esp. distinguishing browsing (for new information) and searching (for specific answers). The structure of the information was als studied, comparing hierarchical, network, and mixed structures. (See also: de Vries, 1993; de Vries, van Andel, de Jong, 1992[a] and 1992[b]; and de Vries, de Jong & van Andel, in press). Related to this subject two MA-theses were finished, one of which was about hypertext-based information on the environmental impact of different materials and procedures in the design of consumer products (Bor, 1992). The other MA-project studied the role of image-based information, using mainly pictures with minimal textual information, in communicating with architectural designers of children's playgrounds (Burger, 1993; Burger & van Andel, in press).

In the meantime, collaboration with the Department of Industrial Design, TU Delft resulted in a study of the role of user-centered design information in rela design projects at the department. Here again the role of visually presented information was studied together with the phenomenon of "design-fixation" (Christiaans & van Andel, 1993). Recently, the results of a study in cooperation with the Department of Architecture, UC Berkeley have been published (van Andel, 1994). In this study the effects of three types of presnetation of a behavior mapping study were compared. Students completed the task of redesigning a school playground with the use of research data either in graphical, or in a table, or n a combined form. Finally, the combination and interaction of researching and designing were studied introspectively by a MA student. His analysis shows clearly both the differences and the mutual reinforcement of these two activities (Boer, 1994; Boer & van Andel, in press).

2. Objectives and interests

To summarize the main objective of our group in design research:
To study the use of a specific type of information (user related knowledge) and the role of the form of presentation (through patterns; using graphical information and visual images; computer supported through hypermedia) in a specific design context (environmental, architectural, and product design).

3. Activities

Some of our current and planned activities are:

* Staff- and MA-students' research on environment-behavior concepts that are relevant and useful for architectural designers such as affordances and patterns.
* Joint research project with Dept. of Product Design, TUDelft on the function of adaptable knowledge bases for designers.
* Possible joint research project with Design Methods Group, Dept. of Architecture, TUE, on the actual use by designers, and the effects of pattern language on the design process and the design product.
* Possible evaluation study in cooperation with Calibre, TUE, on the effects of various computer-based presentations techniques in design practice such as virtual reality; hypermedia, and the WorldWideWeb.

4. Publications

Andel, J.van (1994). Behaviour mapping and urban design: Graphic versus non-graphic information about environ- ment-behaviour relations. In: S.J. Neary, M.S. Symes, F.E. Brown (Eds.). **The urban experience. A people-environment perspective. Proceedings IAPS 13.** London: E & FN Spon.

Andel, J. van (1988). Expert systems in environmental psychology. In: H. van Hoogdalem, N.L. Prak, T.J.M. v.d. Voordt, H.B.R. v. Wegen (Eds.). **Looking back to the future. Proceedings IAPS 10.** Delft: Delft University Press.

Andel, J. van; Bruls, P.W.M.; Jaartsveld, R.F.M. (1990). **Functie en constructie van drempels in de woning. (Function and construction of doorsteps in houses).** Amsterdam: Stichting Consument en Veiligheid.

Boer, F. (1994). **Speelplaats voor onbevangenen. Een onderzoek naar exploratiemogelijkheden in de Dommelzone in het centrum vassn Eindhoven. (Playground for open-minded people. A study on possibilities for exploration).** MA Thesis. Eindhoven: TUE/TEMA.

Boer, F.; van Andel, J.van (in press). Thinking in an integrated design and research process: A non-linear approach. **Design Studies.**

Bor, A. (1992). **Recyclingwijzer voor produktontwerpers. De ont wikkeling van een informatiesysteem voor recyclinggericht produktontwerpen. (The development of an informationsystem for recycling in product design).** MA Thesis. Eindhoven: TUE/TEMA.

Burger, J. (1993). **Computer onderstuende inspiratie. Overdracht van informatie aan ontwerpers door middel van realistische beelden. (Information transfer to designers by realistic images).** MA Thesis. Eindhoven: TUE/TEMA.

Andel, J. van & Burger, J. (in press). The tranfer of information to designers using an image bank. **Design Studies.**

Christiaans, H. & Andel, J. van (1993). The effects of examples on the use of knowledge in a student design activity: the case of the Flying Dutchman. **Design Studies**, 14, 58-74

Christmas, D.A.E. (1994). **Methodisch programmeren van eisen voor ouderenhuisvesting. (Programming housing for elderly people).** MA Thesis. Eindhoven: TUE/TEMA.

Dorst, M. van (1992). **Op weg naar de optimale kantoorwerkplek. Patterns for optimal offices.** MA Thesis. Eindhoven: TUE.

Hamel, R. (1990). **Over het denken van de architect (On designing by architects).** PhD Dissertation UvA. Amsterdam: AHA Books.

Kort, Y. de (1993). **Onderzoek naar en patronen voor bejaardenoorden voor visueel gehandicapten. Patterns for nursing homes for visually impaired elderly).** MA Thesis. Eindhoven: TUE/TEMA.

Vree, F. van; Andel, J. van; Venselaar, K. (1992). De gebouwde omge ving voor mensen met cognitieve functiestoornissen. **Tijdschrift voor Ergonomie**, 17, 9-13.

Vries, E. de (1994). **Structuring information for design problem solving.** PhD Dissertation. Eindhoven: TUE.

Vries, E. de; Andel, J. van; Jong, T. de (1992[a]). **Computer-aided transfer of information on environment and behavior: Network versus hierarchical structures.** Paper EDRA 23 Conference. March 1992, Boulder.

Vries, E. de; Andel, J. van; Jong, T. de (1992[b]). **Effects of different structures of knowledge on computer-aided transfer of information on environment and behavior.** Paper DDSS-conference, July 1992, Mierlo.

Vries, E. de (1993). The role of case based reasoning in architectural design: Stretching the design problem space. In: W. Visser (Ed.) **Proceedings of the Workshop on Re-use of Designs of the 13th International Joint Conference on Artificial Intelligence** (pp. 28-40). Chambéry: France.

Vries, E. de; Jong, T. de; Andel, J. van (in press). Exploiting informati on systems for design problem solving: The influence of task characteristics and information structure. **Man-Computer Studies.**

Wagenberg, A.F. van; Dellaert, B.G.C.; Waalwijk, W.R.G. (1989). **Het gebruik van omgevingstechnologische patronen bij het ontwikkelen van programma's van eisen voor verpleegafdelingen van verpleeghuizen (Patterns for programming nursing homes).** Eindhoven/Utrecht: TUE/NZI.

DESYS Research Group: Development of Tools and Methods to improve the output of Product Creation Processes

Willem G. Knoop, Ernest van Breemen,
Joris Vergeest, Tjamme Wiegers

Delft University of Technology
Faculty of Industrial Design Engineering
Jaffalaan 9, 2628 BX Delft, The Netherlands
Phone: +31-15-784546/3034
Fax: +31-15-787316
E-mail: W.G.Knoop@io.tudelft.NL

Abstract

This paper discusses the research that is carried out in the DESYS research project. DESYS is part of a larger research structure, the TPI-programme, that is performed in the department of Engineering Design in the faculty of Industrial Design Engineering. The relation with the greater research structure is explained. DESYS itself was initiated due to the lack of efficiency of current IT-systems that promise to support and optimize the product creation process. The research objectives and strategy are discussed. The objectives are focused on the information handling in the design process as a mean to determine requirements for tools and methods to support it. It is justified why this kind of research is of major importance for the industry. An overview is presented of the work that was done so far and the directions for the future are indicated as well. The chapters on staffing and publications complete this article.

1. Introduction

The faculty of Industrial Design Engineering has a long tradition in education and research in the field of computer support systems in the product creation process. This was built up due to the enthusiasm of professor Schierbeek, one of the founders of our faculty. Over the years a lot of CAD/CAM tools have become available in industry. Most of them support a specialized part of the design process, for instance optimization tasks through finite element analysis. However, the need to assist the total process grew, and it was seen that a single tool was not available that supported all the different tasks in the design process. Along with this need there was still little support given in the early design phases. These circumstances were the initiators that defined the DESYS research project.

Initially DESYS, an abbreviation for Design Environment SYStem, aimed at the development of a software shell around existing programs. It was thought that this approach could lead to a better understandable information environment for the designer at work. Making current programs transparent through an umbrella tool would protect the designer from all the specialized operations of the different tools. However the integrated functionality would support the design process more than the separated pieces together. This should lead to an improvement of the process itself in terms of throughput time and design quality, including the very early stages. During the early stages of the project it became more clear that the research had to focus on the information aspects first before defining any requirements for a tool. After all if one wants to study the impact of an information system, one has to start with the basic entity, that is the information processed in the design process by designers. A literature survey showed a lot of research already undertaken in the field of design. The drawback however was that this research was carried out on a high-level of abstraction, not showing the detailed information needs in the design process. These needs will become clear when research is done on the micro-level. DESYS will therefore investigate the information handling on the micro-level in the design process including the early phases of design.

The DESYS project is part of a larger research structure in the Engineering Design department in our faculty. The Technical Product Information (TPI) programme, which is presented in figure

1, covers a span of research activities in the fields of:

- Fast Shape Prototyping
- Product Information Management
- Product Model Definition and Applications

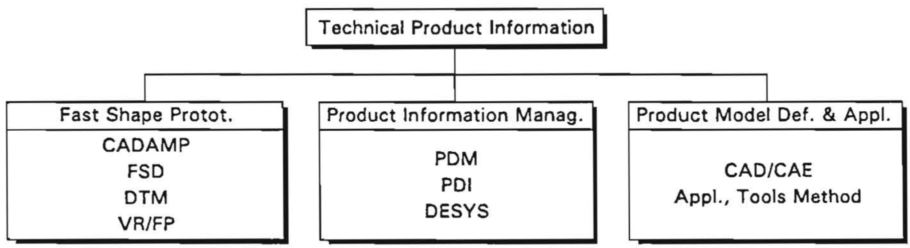


Figure 1. *The position of DESYS within the TPI project.*

The different abbreviations indicate the individual research projects and have the following meaning:

CADAMP	Computer Aided Design And Model Production
FSD	Fast Shape Designer
DTM	Desk Top Manufacturing
VR/FP	Virtual Reality/Fast Prototyping
PDM	Product Data Management
PDI	Product Data Interchange
DESYS	Design Environment SYStem
CAD/CAE	Computer Aided Design and -Engineering

The TPI-programme is carried out by 23 staff members. On a yearly base they produce on average 15 scientific and 25 other publications as well as one PhD thesis. There are worldwide contacts with leading research institutes in the field of CAD/CAM and there is a close work relation with the Product Centre TNO in the Netherlands.

Within the TPI-programme DESYS can be seen as a pivot project. Integrating the results from other, specialized projects into one environment.

2. Research objectives and strategy

In principle the research objectives of DESYS are driven from the fact that only limited achievements were reached in industry in the product development process, in spite of the major investments in information technology systems. The literature described this phenomena often as the productivity or Solow paradox. A greater understanding of the role of information in product design will give a better insight into the process and lead to recommendations about tools and organization around it. The management of information is the central element. From this perspective a three step problem definition was defined as follows:

PB1: When using information technology, how can the product development process be supported to obtain a product definition which leads to a future product with required characteristics?

The product definition is the information as it comes out of the product development process. The optimal product characteristics are achieved when the mix of price, time-to-market and performance fits the market demands.

PB2: How is the product definition characterized, or what is the meaning and impact of the information elements in this?

PB3: What does the use and need of information of a product designer or design team look like, and how does it relate to the product definition?

These general problem descriptions were translated into a research strategy. It is expected that insight in the role of information on a micro-level (PB3) leads to the identification of bottlenecks in the design process. The next most challenging topic is to verify that the removal of bottlenecks can be actually measured. A resolution of the bottlenecks will be translated to the second problem level (PB2). Hereafter recommendations can be formulated that contribute to the overall problem definition (PB1). Recommendations will be in the field of tools or organizational options. These recommendations can be tested later on in laboratory and/or field experiments. In the area of tools this research distinguished itself in the way that requirements are set from the inside out. The design process drives the design of tools and not the other way around as often seen in commercial vendor environments. Summarized we formulated the research strategy:

1. Gain insight into the "information landscape" of the product design process. This activity takes place on the level of one designer or a design team, so the micro level of designing.
2. Discover and indicate the bottlenecks that come out of the analysis of the data gathered in the first stage.
3. Develop recommendations for methods to remove the bottlenecks.
4. Verify the recommendations by laboratory and field testing.
5. Formulate models and theories which make the acquired knowledge more generally applicable in multiple domains.

Based on this strategy the DESYS team formulated detailed research questions. The first task of the team was then to develop a research method which explicitly shows the role of information in the process. An overview of the research work until now is given in chapter 4.

3. Relevance of research

This research has some important relevance in several fields. Besides the educational relevance we distinguish two further major fields of relevance: scientific and industrial

3.1. Scientific relevance

From a large number of conferences it has been seen that scientific research towards an optimized product creation process is performed by numerous institutions around the world. Our research is supplementary to that. Furthermore, the research will lead to a better insight into the complex structures of information used in the (conceptual) design process. The results will be relevant also for the field of cognition and methodology. A literature survey showed that detailed research into the information structure in design has hardly been done. There has been done much information analysis of design processes on a high-level of abstraction (SADT, IDEF, etc.) but the main question of how to solve designer bottlenecks has not been answered.

3.2. Industrial relevance

Companies that are able to create new and innovative products are very important for the health of an economy. They are at the start of the value chain and can not rely on the innovativeness of their suppliers. Therefore it is necessary that the product development process, which forms the first prime activity in the chain, is controlled and managed in the optimum way. The importance is confirmed by Seitz in his book on the German industry where he declares to improve the product development processes to keep in pace with the increasing level of global competitiveness.

A lot of companies invested enormous amounts of money in IT-systems. The opportunities which are incorporated in these systems are however only partly used. In-depth insight into the design process as an information driven process, the aim of this research, will result into a more effective and more efficient application of these IT-systems. This will lead to an industry which is constantly on the frontiers of new markets and keeps distinguishing itself in the rapidly changing world of today.

4. Status of DESYS research

In the following paragraphs the separate research activities that are carried out or planned to be carried out are listed. The actual start of the activities was in 1993.

4.1. Finished work

- Exploratory research of a real-life industrial design process (D0-experiment). This research was performed to gain insight in the information structures that might occur during the design process. The retrospective research leads to a set of recommendations on the experiments that were planned in a later stage in the DESYS project.
- Literature survey of the state-of-the-art in design research. Supplementary to the D0-experiment, this survey listed the commonly used methods in design research. Special attention was given on the study of information aspects in previous research.
- Recruitment of a pool of testees. To supply the experiments with enough qualified subjects a recruitment procedure was carried out. This leads to a pool of over 60 available persons for our experiments. The subjects are upper level faculty students.
- Development of an observation and data structuring method. This method serves the experiments that had to be carried out. It makes it possible to visualize the design process as a set of activities with their information elements attached to it. As a result a design process can be visualized in an "infogram". The infogram shows the design activities, information input and output items and information links.
- The set-up of a design experiment that reflects the complexity of an industrial design assignment but was as compact to be performed in multiple experimental sessions.
- Observations of the design processes of 10 designers. This D1-experiment was accomplished to get experienced with the previously described method to present the information structure in the design process.

4.2. Current work

- Analysis of the D1-experiment. Focusing on the defined information links and detecting bottlenecks in certain activities that were observed. The analysis will eventually lead to a conclusive overview of the D1-experiment, helping to provide guidance in future experiments.

- Description of the research method. Due to the experiences in D1 the proposed method will be fine-tuned and described in detail to provide a non-ambiguous procedure to process design observations.
- Definition of follow-on experiments to prove that bottlenecks can be removed.

4.3. Future work

- Experiment sets to study the detectability and removability of bottlenecks.
- List of constraints for design environment definition.

5. Staffing

The research project is carried out under the responsibility of prof.ir. P. de Ruwe. He is in charge of the department of Engineering Design. Prof. de Ruwe holds a master degree in Mechanical Engineering and was involved in many automation projects especially in the electronics industry. His practical knowledge is a major driving force in the project. The project itself is staffed by two coordinators and three researchers. On average the researchers are available for 75% of their time to support the project. Their background and experience can be summarized as follows:

Coordination:

Ir. Aad P. Bremer, associate professor. Holds a master degree in Aeronautical Engineering and worked for over 20 years as a university staff member. He is the overall project coordinator of the TPI-project and as such managing the position of DESYS in relation with the other projects that are carried out.

Dr. Joris Vergeest, assistant professor. Holds a PhD in physics, worked as a university staff member at several universities in the Netherlands. He has a broad experience in the setup and management of scientific research projects, and serves as the scientific gatekeeper in the DESYS project.

Research:

Ir. Ernest J.J. van Breemen, assistant professor. Holds a master degree in Industrial Design Engineering and worked for 3 years in an industrial design agency.

Ir. Willem G. Knoop RB, assistant professor. Holds a masters degree in Mechanical Engineering and a MBA degree. He worked for 10 years as a CAD/CAM Consultant in several fields of the industry.

Ing. Tjamme Wiegers, assistant. Holds a bachelor degree in electrical engineering. He worked for many years in a variety of software development companies, programming complex industrial systems.

Besides the permanent staff students carry out scientific training programs or graduation projects.

6. Publications

Hereafter follows a list of the publications in relation with the DESYS project, including internal memorandums and lectures.

- Breemen, E.J.J. van, Characterisation of information in product development processes, Internal memo K311, University of Technology Delft, faculty of Industrial Design Engineering, Delft, august, 1994.

- Breemen, E.J.J. van, Ontwerpen is met informatie omgaan of niet soms? (Design is coping with information, isn't it?), Produkt 06/94, p.6-7, Uitgeverij Wyt, Rotterdam, october, 1994 (in Dutch).

- Breemen, E.J.J. van, A chronological analysis of high-volume data on actual product engineering processes, to be published in the proceedings of ICED 95, Prague, 1995.

- Bremer, A.P., Projectvoorstel Technische ProduktInformatie TPI (Project proposal Technical ProductInformation), Internal memo K275, University of Technology Delft, faculty of Industrial Design Engineering, Delft, march, 1993 (in Dutch).

- Broek, J.J., et al., TPI Annual Report 1993, Internal memo K312, University of Technology Delft, faculty of Industrial Design Engineering, Delft, 15 june, 1993.

- Knoop, W.G., DESYS Projectbeschrijving 1993/1994 (DESYS Project description 1993/1994), Internal memo K286, University of Technology Delft, faculty of Industrial Design Engineering, Delft, september, 1993 (in Dutch).

- Knoop, W.G., Lean design, een multidisciplinaire uitdaging (Lean design, a multidisciplinary challenge), Produkt 02/94, p.11, Uitgeverij Wyt, Rotterdam, february, 1994 (in Dutch).

- Knoop, W.G., Vision on Advanced Product Development: Tools, lecture on the seminar Vision on Advanced Product Development, by the Royal Society of Engineers, march 11, 1994.

- Knoop,W.G., Empirical research in design: a literature survey of the state-of-the-art, Internal memo K310, University of Technology Delft, faculty of Industrial Design Engineering, Delft, may, 1994.

- Knoop, W.G., Information analysis as a mean to successful implementation of information technology in the design process, proceedings of the East-West Conference on Information Technology in Design (EWITD94), Moscow, Russia, september 5-9, 1994.

- Knoop, W.G., Munnich, P., Lessons from industry towards the application of complex information tools to support the automotive design process, 2nd International Symposium on Engineering Education, Limerick, Ireland, october 28-31, 1994.

- Knoop, W.G., Advanced Product Development in de Verenigde Staten (Advanced Product Development in the United States of America), Produkt, Uitgeverij Wyt, Rotterdam, november, 1994 (in Dutch).

- Knoop, W.G., Breemen, E.J.J. van, Vergeest, J.S.M., Wiegers, T., DESYS Research Group: Development of Tools and Methods to improve the output of Product Creation Processes, to be published in the proceedings of the symposium on Design Research in the Netherlands, Eindhoven University of Technolgy, Eindhoven, january 3, 1995.

- Knoop, W.G., Wiegers, T., A method for visualizing information in the design process, to be published in internal memo K309, University of Technology Delft, faculty of Industrial Design Engineering, Delft, 1994.

- Schierbeek, B.B., Produktontwikkeling ondersteund met een Design Environment System (DESYS) (Product development supported with a Design Environment System (DESYS)), Project proposal to the Research Council of the Faculty of Industrial Design Engineering, Delft, 1992 (in Dutch).

- Vergeest, J.S.M., Breemen, E.J.J. van, Knoop, W.G., Wiegers, T., An effective method to analyze chronological information aspects in actual engineering processes, to be published in the proceedings of the 5th International Conference on Computer Applications in Production and Engineering, CAPE'95. Beijing, 16-18 may, 1995.

The IDEATE Research Projects

Industrial Design Engineering
Delft University of Technology

1.0 Research Objective

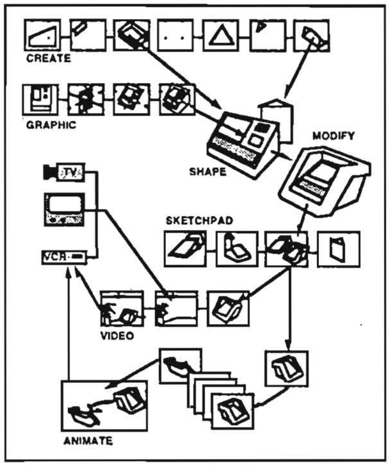
The objective of the IDEATE research is:

To analyse the conceptualising phase of the industrial design process and to research ways in which this activity can be supported through tools, systems and techniques for designers.

Since this research is concerned with the conceptualizing phase of the Industrial Design process, we are interested to know how ideas are generated, how designers create form, and what kinds of tools designers use for this process. One of the goals of our research is the application of these investigations toward the development of new and better tools for the process; tools for creative thinking and visualizing. By focusing on the specific area of Industrial Design, we hope to develop an organized set of multi-nodal tools that can assist the designer in the creation of innovative form by offering extensive visual databases, methodologies, form-giving strategies and organizational capabilities. These results should be implementable in an advanced electronic "environment" which supports the designer in the development of innovative and creative product form.

2.0 History

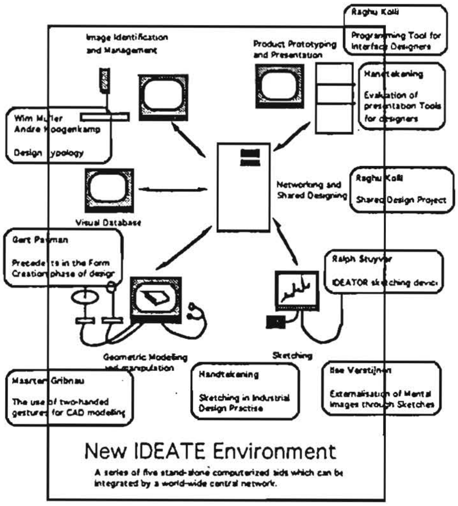
The IDEATE Research has been derived from a project done in 1987 called "The Designer's Toolkit". The Toolkit was intended to be a single computer program with a series of modules which allowed 3D object definition during the early phases of design. The most interesting attribute of the Toolkit was its attempt to bridge the gap between 2D representations and actual 3D objects. It did this by allowing the designer to quickly generate 3D extruded shapes which could then be frozen as a bit-map and sketched upon. In this way the designer could add details and refinements to the 3D object by using it as an "underlay" drawing.



3.0 The IDEATE Environment

When the IDEATE Research began in 1991, studies of the work environment of both creative people as well as designers were made. Observations from these studies showed that the all-in-one-box solution of the Toolkit was no longer valid and that the designer would be better supported by a series of ubiquitous, computer-intelligent devices. Six areas of design activity were identified

1. Image retrieval, classification and manipulation
2. Visual databases
3. Geometric modelling with two- hands
4. Sketching
5. Networking and shared designing over distances
6. Product prototyping and presentation



IDEATE currently supports projects in each of these areas.

4.0 Personnel and Projects

Jim Hennessey is a professor in industrial design engineering and directs the IDEATE research group. As an American educator and researcher, he has been active in industrial design in three countries over the last 24 years.

4.1 Computerized Tools Research

4.1.1 "Interactive tgeneration and manipulation of computerised objects in 3D using two-handed input", M. W.Gribnau, AIO, J. M. Hennessey, Prof.

The emphasis of this project is the development of new strategies for intuitive hardware and software including the implications of sketching, gestures and input devices. Work will especially focus on two-handed input for geometric modelling. M. W. Gribnau is currently doing a literature search and project analysis. Additionally, he has directed the development of testing software (with R. Dickhout and D. DeVries, Hogeschool, West Brabant) for the Turntable and Grabber input devices. Also, R. Stuyver is currently working on an improved version of the Turntable.

Maarten Gribnau is a Graduate Assistant (AIO) with a background in Electrical Engineering (Electrotechniek).
He began his work in IDEATE on 1, January, 1994.

4.1.2 "Development of a New Prototyping Tool for Interaction Designers", R. Kolli, UD, Promotor R. Den Buurman, Prof.,Co-promotor J.M.Hennessey, Prof.

The Doctoral work of Raghu Kolli is just beginning. It will focus on the development of a new prototyping tool for interaction designers. A unique strategy for the basis of this tool has already been formulated and corporate partners are now being sought for the purpose of assisting in software development. Raghu is also developing research on CSCW and Shared Designing over networks.

Raghu Kolli is a researcher from India who works on projects in both the vakgroep Vormgeving and the vakgroep Produktergonomie. He has a background in Product and Graphic Design and specialises in Interface Design.

4.2 Sketch-related research

These two projects both focus on the sketching activities in the design process.

4.2.1 "IDEATOR ", R. Kolli ,UD, R. Stuyver, OBP, M.W.Gribnau, AIO, J. M. Hennessey, Prof.

The first conclusions for this project were finished on 1 September, 1993, and a definitive report was written (see Scientific Publications). High quality, ray-traced (ElectroGig) images of the product were created by R. Stuyver. M.W.Gribnau implemented parts of the IDEATOR interface in a Macintosh-based program which will be used for testing and demonstration. R. Kolli has ended his work on this project in order to develop his Doctoral thesis (see above). We are currently seeking corporate partners for the development of a working prototype of this device for user testing and evaluation.

In addition to doing research in IDEATE, **Ralph Stuyver** is responsible for teaching the course IO78a, Computer Visualisation.

4.2.2 "The importance of paper and pencil sketching to visual imagery and how it can be improved by a sketch tablet", I. Verstijnen, AIO, C. van Leeuwen, UD-UvA, W. Muller, UD, J. M. Hennessey, Prof.

Sketching is seen as an extension to visual imagery; in many ways it adds to visual imagery what visual imagery, itself, cannot. By researching the ineffectiveness of visual imagery and what is subsequently added to it through paper and pencil sketching we can extract the remaining needs in order to define functions for the sketch tablet of the IDEATOR and other pen-based systems.

Ilse Verstijnen's background is in Psychology at the University of Amsterdam. She has been a Graduate Assistant (AIO) in the IDEATE project since 1 April, 1992.

4.3 Typology-related research

These four projects are all related to the concept of typology in design.

4.3.1 "Typology and design methods", W. Muller UD , A. Hogenkamp, UD J. M. Hennessey Prof.

This project is a definitive research into form-types. The goal of the research is to determine the role of form-types in design by identifying and classifying form-types which can then play a part in the design process. The computer implications of form-types will be applied in the research project of G. Pasman.

Willem Muller is an Assistant Professor (UD) and has been researching and teaching in the faculty of industrial design engineering since its beginning in 1969. He is well-known for his book: "VORMGEVEN: Ordening en Betekenisgeving", uitgeverij Lemma, Utrecht, 1990, ISBN 90-5189-039-7.

Andre Hogenkamp is an Assistant Professor (UD) with a background in industrial design engineering. He began his research work in IDEATE on 1 September, 1992.

4.3.2 "The Organisation of Design Knowledge in Precedent-based Design;", G. Pasman, UD, W. Muller, UD, J. M. Hennessey, Prof.

This research has both a theoretical and a practical side. The theoretical goal is to derive an understanding of the actions and strategies industrial designers use in acquiring design knowledge from existing design situations and, later, applying this design knowledge to new design situations.

The results from theory will be used in the development of an image database, which makes use of visual representations of existing form concepts, in order to create a domain-specific knowledge base from which the industrial designer can acquire and apply design knowledge in order to aid the generation and development of new form concepts. The domain of this research is limited to the form-creation process in industrial design.

Thus far, in collaboration with the "Typology and design methods" research, a typological model has been developed for the description and organisation of the design knowledge that can be extracted from existing form concepts. This model will provide a framework for the structure of the image database. In order to verify the model a study has been conducted with 17 subjects performing a design task.

Gert Pasman began his work as a graduate assistant (AIO) in December, 1991 and in 1994 he was named Assistant Professor (UD). His background is in Mechanical Engineering with a specialisation in Methodology.

4.3.3 "Type-concepts in the History of Design Education" J. B.L. van den Heuvel, UD

Jeroen v. d. Heuvel is an Assistant Professor (UD) and is responsible for developing and teaching courses in Art and Design History.

The research for this project is particulary directed to the existence and development of type-concepts in the history of design education. When a designer decides to become a teacher he often feels the need to express his ideas on design in writing, so there is a large number of texts by designers for educational purposes. Analysis of these texts revealed more often then not type-concepts to legitimize choices in the design process and in educational programmes. On the other hand there exists a collection of student work which will be analysed on the consequences of the use of a specific type-concept.

4.3.4 "History of Form-concepts in Electric Domestic Appliances" T.R.A. de Rijk, AIO

This historical project asks what form-concepts were used in the industries for domestic appliances in the period 1930-1970, especially in the Netherlands. One of the main research topics is the development of product-types in these industries. What was the contribution of the designer and what role played the principal consumer-acceptance and technical limitations in the arising of these types. The project gives good opportunities to find the actual development of product-types and shall in this way be of great interest to the other typology-research in the IDEATE-project.

Timo de Rijk is a graduate assistant with a background in Art History. He began his work in April, 1992.

5.0 Interrelationships

The projects of J.B.L. v.d. Heuvel en T.R.A. de Rijk are closely related to the "Typology and design methods" project of W. Muller and A. Hogenkamp. All three projects provide valuable material for the research of G. Pasman in collecting and classifying existing form concepts as input for the image database. A cross-project "Image Database Group" has been formed in order to establish co-operation between these research projects.

6.0 Recent Publications

Kolli, R., Pasman, G., Hennessey, J.M., "Some Considerations for Designing a User Environment for Creative Ideation", Proceedings of INTERFACE 93, Raleigh, NC., USA, May 5-8, Published by the Human Factors & Ergonomics Society, Santa Monica, 1993, pp. 112-117.

Kolli R., Pasman G., Hennessey, J.M., "Deriving the Functional Requirements for a Sketching Device: A Case Study", Proceedings HCI Conference 93, Vienna, Austria, Springer-Verlag, 1993, pp. 184-195.

Kolli, R., "Using Video Scenarios for Presenting Consumer Product Interfaces", Adjunct Proceedings INTERCHI 93, ACM

Conference on Human Factors in Computing Systems, Amsterdam, 24-29 April, 1993, p. 61.

Verstijnen, I., Leeuwen, C. van (UvA), Hennessey, J.M., "Paper and Pencil Sketching to Reveal Implicit Information from Images", Lecture, Tagung Experimental Arbeitende Psychologen und Psychologinnen (TEAPP-Congress), Munich, Germany, 28-31 March, 1994.

Hennessey, J.M., "Exploring Computer Enhancements for Conceptualizing", Automation Based Creative Design: Current Issues in Computers and Architecture, Edited by T.White and A.Tzonis, Elsevier Publishers, April,1994.

Kolli, R., Stuyver, R., Hennessey, J.M., "A Conceptual Sketching Device for the Early Phase of Design", Design and Decision Support Systems (DDSS) Conference, Vaals, Netherlands, June, 1994

Hennessey, Christopher J.,Stuyver, R., Hennessey, J.M., "CAD and Design", Internal Stage Research Report, Sektie Vormgevings-methodieken, vakgroep vormgeving, TUDelft, 15 Augustus, 1994.

Dickhout, R., De Vries, D., Gribnau, M.W., Hennessey, J.M., "IDEATE-G", Internal Stage Research Report, Sektie Vormgevings-methodieken, vakgroep vormgeving, TUDelft, September, 1994

The design methodology group
at the faculty of Industrial Design Engineering
TU Delft

presented by Kees Dorst

Introduction

The Delft faculty of Industrial Design Engineering has a five-person group working on Design Methodology. Organizationally this group is linked to the department of New Product Development, section innovation management.
This research group has been internationally active for quite some time - it must be one of the oldest and biggest in Holland. The development of and reflection on design methods is seen as one of the key areas of research in our faculty. We are also very much involved in developing and monitoring the design teaching.

The key scientific events of the last few years were the organizing of two workshops on Research in Design Thinking. A theoretical workshop was held in 1991 and a special workshop on protocol analysis in 1994. The faculty has co-organized the ICED '93 conference in Den Haag, with our methodology group as a main contributor .
Two widely used textbooks for design methodology teaching (in industrial design and in engineering) have been written by members of our group, Norbert Roozenburg and Nigel Cross.

1. Spanning Design Methodology

But this five person group seems small when you compare it with the task before us: our mission is to span (or at least keep track of) the whole width and depth of Design Methodology. The growth in design methodology is clearly outrunning the growth in our group.
But currently, our activities do run from empirical studies in design psychology (Christiaans, Cross and Dorst), theoretical formulation of design knowledge (Roozenburg) and computational models of design (Kruger) to the development of design support systems (Ackers).
The research projects in these fields have at least one thing in common: we are all trying to structure the different parts of design reality by making models of it.
These models are the stepping stones to develop and refine prescriptive methods for design, to improve design teaching (with the

aid of a well-developed design psychology), and to help develop computer tools supporting the design ability. Four of us are developing these models of the design process on the basis of empirical research, i.e. protocol analysis of design projects, which has become a specialty of ours.

But the research projects are very much tied to the people - the projects have are too diverse to be summarized in a short introductory note like this. The small biographies below will provide more detail on all of the projects.

2. People and projects

Henri Christiaans

Henri H.C.M. Christiaans is a psychologist by training. His research activities into design during the last 8 years have focused on the following topics: the connection between the design process and the creativity of the design result, the information processing during the design process and the role of argumentative knowledge in communication processes of design teams.

The knowledge base of the designer (Christiaans and Venselaar)
The aim of this study is to understand how the knowledge base of the (novice) designer affects the quality of the design. The studies done sofar focus on the relationship between acquisition and use of knowledge in designing by novice design students, and the quality of their products. Three main knowledge components were measured: domain-specific basic and design knowledge, and general process knowledge. The studies described here suggest a close relationship between the amount of general process knowledge mentioned by the novices and the perceived quality of the designed product.

Information transfer (Van Andel & Christiaans)
This is an investigation into the question how problem solvers select relevant information and how they represent and retrieve expert knowledge. Designers cannot meaningfully identify and search for relevant information without the orientation of a solution concept. This study is concerned with the question under what conditions information from external sources is more accessible for designers, and influences the design output. Information is gathered which appears to come from two sources - knowledge from everyday, incidental experience or as a result of intentional learning by deriving information from the presentation of specific design related material. Through experiments with design students the effects of various methods of information transfer are studied.

The role of argumentative knowledge (Trousse & Christiaans)
One of the limitations of the current systems in complex problem solving is that hardly any attention is paid to the discursive activities performed. In general, every designer solving a problem starts a communication process and thus a process of argumentation. For a better understanding of problem solving activities it seems valuable to analyse the process within an argumentation linguistics framework. On the basis of such a framework more valid and reliable specifications for the development of real cooperative knowledge-based design support systems could be derived.

Recent publications:

Christiaans, H.H.C.M. (1993). *Creativity in design*. Utrecht: Lemma.
Christiaans, H.H.C.M. & VanAndel, J. (1993). The effects of examples on the use of knowledge in a student design activity: The case of the 'flying Dutchman'. *Design Studies, 14* (1), 58-74.
Cross, N., Christiaans, H.H.C.M. & Dorst, K. (1994). Design expertise amongst student designers. *Art & Design Education, 13* (1), 39-56.
Trousse, B. & Christiaans, H.H.C.M. (in press). Design as a topos-based argumentative activity. In Dorst, K., Christiaans, H.H.C.M. & Cross, N. (eds) *Analysing Design Activity*, Wiley, Chichester.

Nigel Cross
Nigel Cross is Professor of Design Methodology at the Faculty of Industrial Design Engineering, and also Professor of Design Studies at the Design Discipline, Faculty of Technology, The Open University, UK. He is Editor-in-Chief of the international research journal, *Design Studies*, published quarterly by Butterworth-Heinemann in cooperation with the Design Research Society.
Nigel Cross has academic and practical backgrounds in architecture and industrial design. He is well-known for his research in computer-aided design, design methodology and design education. His current principal research interest is in analysing the cognitive activities of designers. He was involved in organizing the two workshops on 'Research in Design Thinking' held at TUDelft in 1991 and 1994.

Books:

Design Participation (editor), Academy Editions, London, 1972.
Man-Made Futures: Readings in Society, Technology andDesign (co-editor with D. Elliott and R. Roy), Hutchinson Educational,London, 1974.
The Automated Architect: Human and Machine Roles in Design,Pion, London, 1977.
Developments in Design Methodology (editor), Wiley, Chichester,1984.

Design and Society (co-editor with R. Langdon),The Design Council, London, 1984.
Engineering Design Methods, Wiley, Chichester,1989.
Engineering Design Methods: Strategies for ProductDesign (2nd edition), Wiley, Chichester, 1994.
Research in Design Thinking (co-editor with K. Dorst and N.Roozenburg), Delft University Press, Delft, 1992.
Design Methodology and Relationships with Science (co-editorwith M. J. de Vries and D.Grant), Kluwer, Dordrecht, 1993.

Papers:
Design as a Discipline: Designerly Ways of Knowing, *Design Studies*, Vol. 3, No. 4, 1982.
Styles of Learning, Designing and Computing, *DesignStudies*, Vol. 6, No. 3, 1985.
The Nature and Nurture of Design Ability, *DesignStudies*, Vol. 11, No. 3, 1990.
Modelling the Design Process in Engineering and in Architecture (with N. Roozenburg), *Journal of Engineering Design*, Vol. 3,No. 4, 1992.
Science and Design Methodology: a review, *Research inEngineering Design*, Vol. 5, No. 2, 1993.
Design Expertise AmongstStudent Designers (with H. Christiaans and K. Dorst), *Journal of Art and Design Education*, Vol. 13, No. 1,1994.

Kees Dorst
Kees Dorst has been trained as an Industrial Design Engineer. He has worked in a number of design consultancies, working on some 50 products. He has given lectures on a number of design and art schools in Holland.

He has also been working on a PhD in Design Methodology in Delft, comparing the paradigms of current design methodology on the basis of empirical data.
The two main paradigms - a positivistic one, seeing design as a process of rational problem solving and a constructionist one, taking design as a process of reflection-in-action - tackle fundamentally different aspects of the design activity. In this study, the descriptive value of these approaches is estimated by looking at their ability to trace *integration* in detailed design processes. The thesis should be finished by the middle of 1995.

Another main line in his research is developing the use of protocol analysis for studying design activity. A major event of the last year was the organizing of the international protocol analysis workshop 'Analysing Design Activity' in september 1994. He is main editor of the book of commisioned papers to result from that workshop, and the guest-editor of a special issue of the journal Design Studies on the subject of protocol analysis. (april 1995)

Recent publications:
Roozenburg, N.F.M., Dorst C.H., Some guidelines for the development of performance specifications in product design. *ICED 91*, Zürich: Heurista (1991)
Christiaans H.H.C.M., Dorst C.H., Cognitive models in industrial design engineering: a protocol study *Design Theory and Methodology, DTM '92,* ASME, NY (1992)
Cross N.G., Dorst C.H., Roozenburg N.F.M., (eds) *Research in Design Thinking* , Delft University Press, Delft (1992).
Dorst C.H., The structuring of industrial design problems*proceedings of the ICED'93 conference,* Heurista, Zuerich (1993)
Bos A.C. and Dorst C.H., Marketeer & Ontwerper: naar een nieuwe rolverdeling. *Tijdschrift voor Marketing*, nov 1993.
Cross N.G., Christiaans H.H.C.M, Dorst C.H., Design Expertise Amongst Student Designers *Journal of Art & Design Education* Vol 13 no 1, (june 1994)
Hinte E.van , Samenspel - het ontwerpproces wordt complexer, *Items* november 1994.
Dorst C.H. and Dijkhuis J., Comparing Paradigms for Describing Design Activity, *Design Studies*, (april 1995)
Dorst, C.H., Christiaans, H.H.C.M. & Cross, N.G. (eds) *Analysing Design Activity*, Wiley, Chichester (1995)

Corine Kruger

Corine Kruger has a masters in social sciences with specialisation in artificial intelligence, scientific methodology, and cognitive psychology. She has worked for Bolesian (specialized in the development of knowledge based systems) and CAV (specialized in Multi Media productions). She has almost finished a PhD thesis on a computational model of Industrial Design Engineering.

The goal of her research project is the development of a design system in the domain of Industrial Design Engineering on the basis of empirical studies of the human design process. The empical study involded a protocol study. The data gathered were interpreted in the frame work of COMMONKADS (an knowledge based system development methodology). On the basis of the analysis of the empirical data a conceptual model of the Industrial Design Engineering process in COMMONKADS has been developed. This conceptual model is implemented in Prolog at this moment. The design system, SYNSYS, will simulate the Industrial design Engineering process, and will function as a means to test the conceptual model.

Publications:

Kruger, C., (1990), Een interpretatiemodel voor ontwerptaken (An interpretation model for design tasks), Masters Thesis, University of Amsterdam, SWI, Amsterdam.

Kruger, C., (1990), Naar een expertsysteem voor ontwerpers (Towards an expert system for designers), Masters Thesis, University of Amsterdam, SWI, Amsterdam.

Kruger, C (1991), Models of design based on empirical data to support the development of design systems, internal report, faculty of industrial design engineering, TU Delft, Netherlands.

Kruger, C, and, Wielinga, B (1993), A KADS model for the industrial design task, proceedings of 3rd KADS meeting, Munchen, Germany.

Kruger, C (1993), Cognitive aspects of re-use in industrial design engineering, proceedings of IJCAI '93, Chamberry, France.

Kruger, C, and, Wielinga, B (1994), Knowledge acquisition in Industrial Design Engineering; an empirical study (Idea-generation methods)., proceedings of KAW'94, Banff, Canada.

Kruger, C, Analysis in the conceptual stage of the design process, proceedings of ITD94, Moscow, Russia.

Kruger, C, Information selection strategies, to be published in the proceedings of ICED'95, Praag.

Norbert Roozenburg

Norbert Roozenburg studied Industrial Design Engineering (Industrieel Ontwerpen) and is associate professor at the Delft Faculty of Industrial Design Engineering, being involved in lecturing and research on design methods and theories. He worked for Total Design in Amsterdam as product designer and project manager and as assistant director of the Eindhoven Academy of Industrial Design, responsible for the education programmes in industrial design and fine arts.

He is editor of *Design Studies*, *Research in Engineering Design* and the Wiley book series *Product Development: Planning, Designing, Engineering* .

Research: Design and Science; A study into the significance of scientific knowledge and scientific method for designing artefacts.

The aim of this study is to clarify the relationship between science and product design in order to foster a more realistic view on the significance of both design and science for product development. From a methodological point of view designing material artefacts and scientific investigation are different activities, which pursue different goals and apply different methods. However, in practice, there is a

strong interplay between the two. Yet, the nature of this interaction in not well understood.
The relationships between design and science have been studied - from different angles - in the philosophies of science and technology and in the history and sociology of science and technology. Most of these studies focus on the relationships between research in physics and technical inventions. That is, they focus on the front-end of R&D. In this project the interplay between science and design during the second half of R&D is being studied. It focuses in particular on the new product development process in which well known or new technical possibilities, or even new inventions, are being developed into useful and commercially viable products. In particular an answer is looked for to three questions:

1 What is (can be, should be) the role of scientific *knowledge* in product design?
2 What role is (can be, should be) played by scientific *method* in product design?
3 Can design be seen as a science, and if so, what is (should be) the nature of that science?

Recent publications

Roozenburg, N.F.M. & J. Eekels, *Product Design: Fundamentals and Methods*. Chichester, Wiley, 1995 (forthcoming).
Roozenburg, N.F.M., On the pattern of reasoning in innovative design. *Design Studies*, 14(1993)1, 4-18.
Cross, N., K. Dorst and N.F.M. Roozenburg (eds.), *Research in Design Thinking*. Delft University Press,1992.
Roozenburg, N.F.M. & J. Eekels, *Produktontwerpen: structuur en methoden*. Utrecht: Lemma, 1991.
Roozenburg, N.F.M. & K. Dorst, Some guide-lines for the development of performance specifications in product design. In: *Proceedings of the International Conference on Engineering Design (ICED 91)*, Zürich, August 1991. Zürich: Heurista, 1991.
Roozenburg, N.F.M. & N. Cross, Models of the design process - integrating across the disciplines. *Design Studies*, 12(1991)4, 215-220.
Eekels, J. & N.F.M.Roozenburg, A methodological comparison of the structures of scientific research and engineering design. *Design Studies*, 12(1991)4, 197-203.
Roozenburg, N.F.M. & J. Eekels (eds.), *Evaluation and Decision in Design*. Zürich: Heurista, 1990 (Schriftenreihe WDK 17).

Adriaan Ackers

Adriaan Ackers is a student of Industrial Design Engineering doing a Masters project in Design Methodology, to be finished in januari '95.

This research is a collaboration between Delft and Cambridge University, where a computerised engineering design guidelines database, called the *Designers' Electronic Guidebook* has been developed. This database contains around 3,500 guidelines on good design practice. The objective of this research is to evaluate the guidelines database, as a possible design tool for decision support in the early stages of the design process. And this research will provide recommendations on improving the structure and the interface of the database, so that retrieval of relevant information becomes easier and more intuitively to the designer.
The research is being validated by testing the use of the guidelines database with students in Delft, and with professional design engineers in British industry.

Author's adresses:

Faculty of Industrial Design Engineering
Delft University of Technology
Jaffalaan 9
2628 BX Delft - The Netherlands
tel: 31-15783068, fax: 31-15787316
email: C.H.Dorst@io.tudelft.nl
N.G.Cross@io.tudelft.nl
N.F.M.Roozenburg@io.tudelft.nl
H.H.C.M.Christiaans@io.tudelft.nl
C.Kruger@io.tudelft.nl

RECENT ADVANCES IN COMPUTATIONAL MODELS OF CREATIVE DESIGN

John S Gero
Professor of Design Science
Director, Key Centre of Design Computing
University of Sydney

abstract

Design is one of the most complex of human intellectual activities. Creative design is at the apogee of design. The focus of design research has largely been on routine design. Recently, there has been an increasing interest in creative design and creative design processes. This presentation commences with a semi-formal definition of creative design and creative design processes using concepts of state space representation. This allows us to distinguish the notion of search which is used in routine design from its creative design counterpart - exploration. Exploration is concerned with developing state spaces within which search is carried out. It then proceeds to develop a class of computational processes capable of meeting the definition of a computational analog of a creative design process. The computational models of creative design processes which will be presented are:

(i) creative design by analogy - how to get ideas from designs of unrelated products;

(ii) creative design by evolutionary problem reformulation - how to change the way the design problem is formulated to improve the resulting solution;

(iii) creative design by graphical emergence - how to 'see' things in a graphical representation that were not represented originally but could be seen by a human designer.

Each of these processes will be described and results from implementations presented. Ongoing research at the Key Centre of Design Computing based on these concepts will be described. The implications of this research on computer-aided design will be discussed.

Group: Knowledge Based Systems

Faculty of Mathematics and Informatics
Delft University of Technology
P.O. Box 356, 2600 AJ Delft
email: henk@galaxy.tudelft.nl

Chairman: Henk Koppelaar

People (19, including guests and PhD students, excluding 29 master students): Aznar, Chakertsjawan, Chitchian, Jones, Jongeneel, Kerckhoffs, Kooijman, Kroes, Ludema, Mebius, Meijer, Netten, Noordzij, Rothkrantz, van Uffelen, van Vark, Vermeersch, Vingerhoeds, Ying (0.5), Zijderveld.

Their Research Interests:

AI in Engineering:

leader: Dr. Ir. Rob Vingerhoeds Real - time expert systems. Case - based reasoning. Constraint programming. Expert control. Automated (discovery of) building designs.

AI in Media:

leader: Dr. Drs. Léon Rothkrantz Biofeedback in virtual environments. Computer guided (unsupervised by a human being) training and monitoring. Automated stress analysis for aeroplane pilots.

Constraint-Based Approach for Designing Building Layouts

D. Chitchian[1] , H. Koppelaar[1] , R.A. Vingerhoeds[1]

[1] *Delft University of Technology, Faculty of Technical Mathematics and Informatics, Julianalaan 132, 2628 BL Delft, The Netherlands*

1. Introduction

There are characteristics attributed to artifact design in general such as, ambiguities, informalities, lack of information, and a vast number of conflicting constraints stemming from different sources. In architectural design *orientation, light, access,* and different *performance requirements* are examples of such constraints. Trying to find a design that satisfies a combination of those conflicting constraints is not an easy task, since satisfying some constraints might have a reverse affect on other imposed constraints. Several researchers have investigated or proposed the use of constraints in design related tasks, in different application areas, including architectural, electrical and electronic circuits and systems, job shop scheduling, process planning, mechanical design, and space planning.

2. Characteristics of Architectural Design

Computerized design generation is a major topic of research in many domains. This is not an exception in architectural design too. Contrary to this idea, it was thought that generation of a design required little domain knowledge as constraints in advance. In other words, design was seen as a quantitative, combinatorial problem defined in a very naive way. Numerical calculation was the only way of solving those problems. Various architectural plan generation techniques generally known as *space planning* or *space allocation* were in this direction. NP-complete inefficiency of these methods, and the need to devise new solutions. Heuristic rules for pruning generation was the new direction for attacking the design problems.

An artifact can be defined from different perspectives, for instance how it works, what it does, and so on. The characteristic aspects of a building can be called the *operation* and the *performance* of the building. The operation of a building might be defined as the pattern of flow of people and objects within that building as prescribed by the interrelations and associations between them [1].

In any design task, we like to identify some properties which have been stated either explicitly or implicity by means of some rules or by some experts. Then we want to transfer these extracted properties to the new design. Example of not explicitly stated properties, we are asked to design a building to have *"a good sense of privacy"* or *"a good sense of community."* These vague terms are hardly definable by means of some absolute values, rather they can be understood with respect to some other activities. For instance, having the "good sense of community" can be identified if people move in the building, they should have opportunity of meeting each other. Therefore, if we design a building to give this opportunity to people, consequently the building considered is having a good sense of community. A designer can describe the qualities of a building such as "having good sense of privacy or community" through formal properties. Some of these properties may be defined as follows. Minimize the public circulation distance, keep a specific distance between some locations, locate specific locations beside each other, etc.

3. General Scheme of the Approach

The layout generating problem is to derive a spatial configuration given generating rules, a set of elements and a set of conditions to be satisfied. In our case the elements are rooms, lots, corridors, halls, and other locations. The production rules are the means for deriving the spatial layout configurations. The architectural design constraints fall into a number of different classes: *distance, adjacency, access, position, orientation, space*. Design is at best of a combinatorial nature, being NP complete in complexity. If complexity is NP, then heuristics are the resource for speed-up computing. Also for overcoming the complexity of a design task it should be done in different steps or phases.

A overall/global design might show various "local" parts with emergent different tiling structure. When we consider every single or individual local parts or units, called segments, they will be constructed using one type of tilings. In other words, a building layout which consists of many segments or local units are supplied as a uniform spatial tiles. Figure 1 shows a global design and its various local parts.

The general scheme of this approach consists of different parts or layers. It is a very simple and generic way based on constraint concepts. Building layout design will be done in two different phases: *pre-parametric* and *parametric*. The inner layer called *topological design*, is responsible for generating the topology of a building. This layer actually is the pre-parametric phase of a design. In this phase our concern is just the accessibility of locations in a building. Constraints such as distance, position, orientation can be dealt in parametric phase. The pre-parametric phase considers other constraints such as access. The main focus in this phase is how a

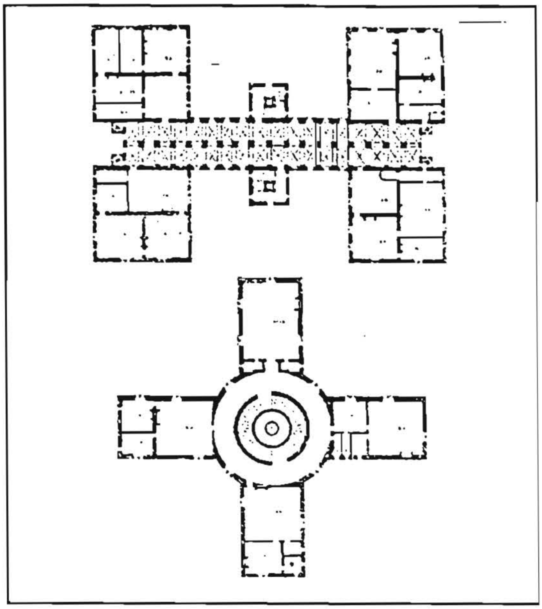


Figure 1: Samples of global designs

preliminary spatial configurations of a building can be constructed by means of spaces or locations and the operations on these elements. The preliminary layout delivered by this phase will be processed in the later phase in order to generate the final layout of a building. The reason for doing so is that we might apply a pre-parametric step first for judgement of qualitative constraints in order to prune the search space drastically, then we can use some constraint-based techniques for finding the solutions in the pruned search space [2].

To design incrementally we start with an initial state, not necessarily empty. An initial state could be the previously designed solution. The design elements are added to the initial state one by one. When an element is added to a design, i.e. a location to the layout of a building, the validity of the imposed constraints must be controlled. Addition of new elements to a design should be in such a way that none of the constraints is violated, otherwise there must be some kind of backtracking in order to annihilate the element causing the violation.

We need to define some rules to put together the single elements of the system in order to make larger part of the layout. For instance, in a formal language *concatenation* is for gluing symbols to words in that language. As our concern in the pre-parametric phase is the *accessibility* of locations in the layout, therefore the generating rules should be able to employ these characteristics of locations. There exists one operator called *genetic operator* in this approach for addition of the elements to the layout, because in any current state, it incrementally adds to a layout one location in a neighbor position of the current location. Regarding to the positions of two locations in a building, there are two possible ways of accessing the second location from the first one. If these two locations are adjacent, then the locations are accessible by means of common segments such as a wall. The other accessing possibility is via a third location. Therefore the generic operator in this approach combines at any step one more location to the current state of a building layout considering the accessibility characteristics of the new location and the current situation.

A designer during designing an artifact tries to satisfy the criteria which are imposed for designing that particular object in final design. In topological design phase norms are *community* and *privacy*, the common property related to these norms is the way of accessibility of different locations in a building. For instance, if we want a design to have more privacy then we should position the associated locations close to each other in order there is less possibility of disturbance. In contrast, if our intension is to have more community then it is better to separate locations, because if people move between locations they can meet other.

After constructing the topology of a building with norms such as high privacy or high community, the final floor plan in architectural design is provided by means of representation methods. In all representations a plan is divided into some smaller parts with the same size which can denote any location in a plan such as room, hallway, storage, etc. These small parts of a plan may have different shapes such as *rectangle, triangle, hexagonal*, etc. Well known tilings by polygons are: equilateral triangles, squares, regular hexagonals, and so on. Having different tile shapes for tiling the floor plan of a building we are able to design buildings that have more creative floor plans than the usual boxes.

Different choices of polygons can be fitted around a vertex so as to cover a neighborhood of the vertex without gaps or overlaps. A vertex around which, in cyclic order, we have an n_1-gon $\{n_1\}$, an n_2-gon $\{n_2\}$, etc, is said to be of type $n_1.n_2....$ Some types of possible tilings with regular polygonal tiles are depicted in figure 2. Accommodating of a topological designed building is another task in architectural design. There is a high degree of computational complexity associated with the method of accommodation. Some locations in a layout are rotation invariant, meaning that we can get the same layout situation, if the layout is rotated for some degrees. Also the number of alternative locations increases (these alterative locations differ in various tilings) exponentially with the number of locations in the design problem. The wise approach which overcomes the combinatorial problem, is to prune design by means of some rules.

The outcome of pre-parametric phase was a topology of locations in a building without considering any kind of tessellations. In accommodation phase which is actually a parametric phase, there should exist some rules in order to accommodate

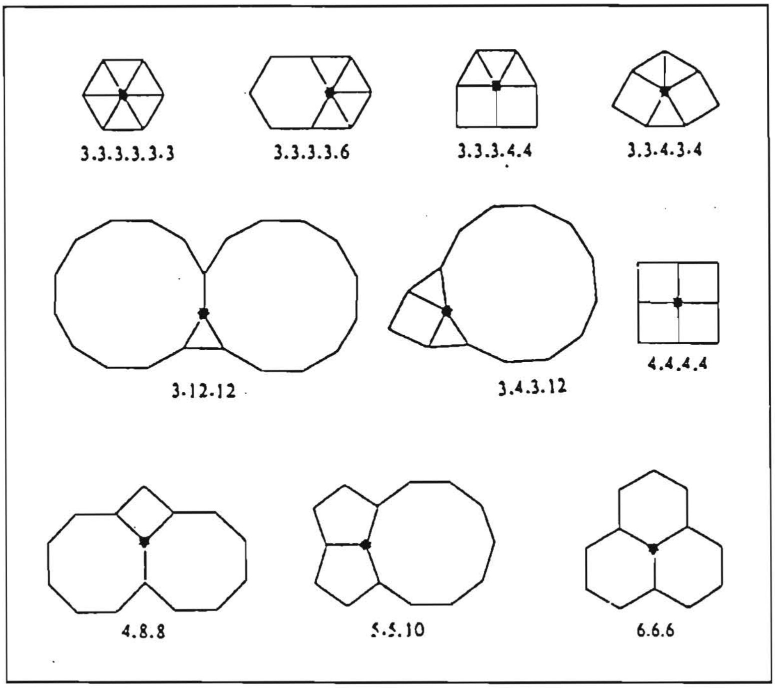


Figure 2: Some tilings with regular polygons

the outcome of pre-parametric design in different types of tessellation. One such a rule actually decrease design space by degree of adjacency (the number of fully adjacent locations in a tessellation) and prune the design to a specific tessellation. We need some other rules for further pruning of a design. If in this stage of the design, the system can interact through "user interface" by the user/architect of the system and asks his preference among many alternatives, consequently the design can be pruned further so that the end results look like the way that users/architects want.

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Expert Assisted Design of Aircraft

B.D. Netten[1], R.A. Vingerhoeds[1,2], H. Koppelaar[1]

[1] *Delft University of Technology, Faculty of Technical Mathematics and Informatics, Julianalaan 132, 2628 BL Delft, The Netherlands*

[2] *University of Wales Swansea, Department of Electrical and Electronic Engineering, Singleton Park, Swansea SA2 8PP, United Kingdom.*

1. Background

Aircraft design is a multi-disciplinary activity, involving several development stages and iterations. From the earliest phase, several aspects are combined in a well-structured manner. Since the early days of modern computers, aerospace institutes and companies have been leading in the development of CAD systems (Computer Aided Design). The ADAS system (Aircraft Design and Analysis System), developed by the Section Aerospace, Design and Flight Mechanics of the Faculty of Aerospace Engineering of Delft University of Technology, represents the state-of-the-art in computer assisted design of aircraft.

Input for the ADAS system is a conceptual design. Once the base-line design has been established, ADAS offers suitable functions for further development. In conceptual design phase, global characteristics of one or a few sketchy designs are subject to many changes, based on models, heuristic rules and statistical data. Relating to strategic decisions to take in this stage of design, ADAS does not offer much assistance to the designer. The need is felt for a flexible front-end to ADAS. A front end that assists in the design of a wide range of different aircraft, and is capable of evaluating the effects of variations on specifications. Evaluation on aspects of economy and performance.

Using recently developed Artificial Intelligence (AI) techniques, a reasoning process on symbol and numerical level is executed. It generates a design in both a symbolic and numerical representation.

The use of, for example, Constraint-Based Reasoning allows in this way for a structured support to the design process. Starting from this symbolic representation, using techniques from CAD/CAM and Computer Graphics, a design becomes generated in ADAS-format. This is a transformation of symbolic and numeric knowledge to geometric models.

The research project will offer new possibilities for the design of aircraft. Moreover it enables (due to the generality of the approach) more applications, such as designing cars.

2. The EDA-project

The goal of the project EDA (Expert assisted Design of Aircraft) is to create an interactive design environment, which actually assists the designer during the conceptual design process. EDA is a major research project at Delft University of Technology, managed by Dr.Ir. R.A. Vingerhoeds of the Knowledge Based Systems group, Faculty of Technical Mathematics and Informatics. The following partners are involved in this project: Faculty of Technical Mathematics and Informatics (our Knowledge Based Systems Group and CAD-CAM/Graphics Group) and the Faculty of Aerospace Engineering (Section Aerospace, Design and Flight Mechanics). As the subject of engineering databases is expected to play a major role in the development of the EDA-system, we intensively co-operate with the Database Research group in our Faculty (Technical Mathematics and Informatics).

The project started in 1993 and builds upon work at the University of Ghent, Belgium, from in the years 1987-1993. Especially the EGNOP concept and its application to process control and design of fibre reinforced composite structures were developed in Ghent (e.g. see [3] [5] [6] [7]). How we employ different AI-techniques in this EDA project is explained in [8].

3. Project summary

Design usually is characterised by an iterative process. Designers set up a framework for their design process and develop several consecutive designs, taking into account problems or shortcomings of previous designs. The main goal of this iterative process is to improve the design and recover it from previous errors. Over the last decade, the role of computers in design has evolved from a numerical calculation device, to task integration via several software packages, and supporting users via advanced (high end) interfaces. This new role of computers relieved the user from mundane computer oriented tasks, unrelated to his application work and domain.

In current aeroplane design practice, however, the designer still has to keep track of the whole design process. Every step needed to create a well-balanced design has to be initiated by the designer. Moreover, the designer himself also has to interpret output of calculations and evaluate the design.

Next step, with help of current state of artificial intelligence techniques, is that computers will support designers in the conceptual design phase. This again leads to a changing role of computers in design. The advantage of this development can be found in those situations where large and complex designs are created, when it becomes very hard for the designer to keep track of the whole design process.

Primary goal for our project is to enable designers to focus on the intelligent and creative design issues of the problem. Currently designers are rather managing their computer aided design tools.

Artificial intelligence will not be used to perform the design tasks autonomously. It will get a supporting role, to handle routine tasks of the design process. Taks such as non-procedural reasoning about the design, reasoning about examples, generating a preliminary design, evaluating qualitative and quantitative constraints, etc.

Incorporating artificial intelligence techniques in design activities may lead to drastic changes in industrial environments. The design time will be used more efficiently, leading to a more cost effective approach in design to manufacturing.

The proposed solution does not imply usage of any particular AI-technique alone throughout the whole design process, but rather the use of specific techniques for those tasks they are most suited for. The design process comprises three general consecutive phases.

- **Propagation of specifications to limit the design space.** Starting from a small number of initial specifications, the solution space can be reduced using constraint-based reasoning techniques [1]. The user-defined specifications determine which constraints in the constraint network are relevant. The remaining sets of variables from the constraint network define the feasible and practical design space on a merely qualitative basis.

- **Find a region of optimal solutions.** Within the reduced design space, the area around the optimal-practical design can be distinguished using case-based reasoning techniques [4]. Previous designs and examples are stored in a case-base, and can be retrieve d based on the (partially) matching specifications. Common features of the retrieved cases can be regarded as typical for the optimal solution, while differences in features indicate the yet unresolved design decisions, and alternative solutions should be formulated for each. To satisfy the specifications, retrieved cases will have to be modified in a rule-based system.

Until now, no numerically design analysis has been performed. Consequently, no problems were encountered for discrete numerical formulation of the problem. The remaining problem is to optimise the design. This optimisation problem is more quantitative in nature.

- Discrete optimisation. For the discrete optimisation, the EGNOP-concept [5] [6] is applied. The numerical optimisation problem is formulated from the modified solutions, where features are translated into analysis formulations, constants and design variables. The first task is to select the best solution for further optimisation. The features of the alternative solutions may provide the designer with some insight in the design space around the optimal solution. The selection and the following improvement phases of the design are performed interactively with the designer. Whenever appropriate, the user can stop the inference process, to examine the previous steps and to suggest improvements. Discrete optimisation should preferably be done by heuristic optimisation. Large numerical analyses should only be applied as verification of the design in the final design phase. Heuristic optimisation consists of 2 steps; a repair phase to recover from constraint violations and the improvement phase for minimisation within the feasible region [3].

The proposed concept allows incremental development of a knowledge based system on top of available numerical analysis and discrete optimisation routines. Numerical routines are incorporated within the general EGNOP-structure, while the other knowledge bases are constructed as separate modules within the system, governed by a meta-level strategy. Other artificial intelligence techniques can also be included within the general structure of the system. The previously described design framework will be applied initially for designing composite reinforced aircraft structures [2]. Next, a full-scale application of the concept for generating conceptual designs of aircraft will be implemented. Designing air craft is a multidisciplinary process, including several development stages. From the earliest stages of conceptual design, several aspects have to be taken into account in a well-structured manner. These aspects include flight performance, flight characteristics, operations, manufacturing, maintenance, etc. Based on the design framework, a front-end design system will be developed.

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Research Programme for AI and Design

Frances Brazier and Jan Treur

Artificial Intelligence Group, Department of Mathematics and Computer Science, Vrije Universiteit Amsterdam
email: {frances,treur}@cs.vu.nl

1 Introduction

Recent research within our Department in the field of AI and Design has focussed on the development of a compositional framework for the design and development of design support systems. Practical experience with the design and development cycle (task analysis, modelling, design, formal specification and implementation) within diverse domains has increased insight in the complexity of design and of the theoretical foundations required.

Complex reasoning patterns encountered during design have been analysed and formally specified within the design framework, determining the formal semantics of the resulting behaviour of the system and interaction between systems and users. The integration of various techniques, both knowledge-based and non-knowledge-based, is clearly essential for design. The compositional approach to system design facilitates such integration, both within systems, but also between systems and systems and users. Techniques for the specification of interaction between systems, and between systems and users have been explored and incorporated within the framework, although further research is clearly warranted. This also holds for the reuse of models and spcifications: a number of possibilities have been explored and tested. Reuse of the framework for redesign is the focus of a current project within which compositional architectures are the object of redesign.

In general our research can be viewed from 3 related perspectives: the empirical perspective, the foundational perspective and the developmental perspective. The integration of these perspectives is the challenge which we face.

A. Empirical perspective
Close analysis of design processes as required and performed by designers in cooperation with design support systems.

B. Foundational perspective
Development of logical theories covering both the static aspects and dynamic aspects of design processes.

C. Developmental perspective
The perspective of the developer of design systems and the support provided to him or her: modelling/specification languages, (task) models for design, implementation environments, etc.

The three perspectives are clearly intertwined. Design theories are based on design practice: either on current practice, or on current recognition of limitations for which solutions need to be found. Logical design theories (in particular) are used to define the formal semantics of both static and dynamic aspects of design: providing a basis for verification and validation, and for techniques supporting system design.

2 Empirical perspective

Practical experience in design support system design is an essential element within our research, providing insight in the design process. The design support systems modelled and specified, cover the following applications:

- curriculum design	(Novoware, DEBA)
- elevator design	(Sisyphus'94)
- chemical process design	(AKZO)
- financial portfolio design	(SKBS, Rabobank, ING)
- environmental policy design	(SKBS, RIVM)
- office plan design	(Sisyphus'91/'92)
- financial routing design	(SKBS, Rabobank)
- emission inventory design.	(SKBS, TNO)

A wide variety of design tasks for which our research has addressed the following issues:

- identifying (conceptual) design methods, models and strategies (to be) used for analysis of design processes
- analysing levels of cooperation and interaction between designers and design support systems
- developing techniques for verification and validation of design support systems

Each of these issues will be discussed below in more detail.

2.1 Design methods, models and strategies

To analyse design processes conceptual models for design tasks at different levels of genericity are being developed. From a global viewpoint these models include at least knowledge of:

(1) the tasks and subtasks involved in design (task decomposition)
(2) the way in which the tasks are controlled (control decomposition)
(3) the domain knowledge (knowledge structures), including multiple classifications (views)
(4) the agents involved in a design process (role delegation)
(5) the information links between tasks and agents

The design method and models include formal specifiation of static and dynamic aspects of design processes such as:

- non-monotonic reasoning, the use of (default) assumptions, preferences, revision,
- constraints and requirement qualifications,
- the acquisition of design requirements
- incomplete, uncertain and inconsistent information,
- reflective reasoning processes,
- the role and form of history and design rationale,
- identification and retrieval of known cases,
- strategic knowledge and control,
- interaction between agents (designers, design support systems) in cooperation,

- identifying and describing various forms of strategic knowledge and reasoning,
- dynamics of problem statement and (soft and hard) requirements,
- representation, integration and coordination of views.

2.2 Models of cooperation and interaction

Within the context of a given design task often specific subtasks may be assigned to either a designer or the system. For example, a design support system may ask the designer a value for an attribute of the design object that is yet undefined in the system. This type of interaction, object level interaction, in which one of the parties (often the designer) is requested to provide facts of this type, is not uncommon to design support systems.

Interaction between designers and design support systems is, however, often of a slightly different nature. In design processes designers frequently wish to influence the factors on which designs/decisions are based: the goals, the heuristics employed, preferences, assumptions, using the system to explore the results of different strategies. Interaction at this level, the level of strategic preferences, is not uncommon within design, but is not often included in design support system design.

Although a shared task model on which a design support system has been designed is the result of interaction with designers, it is not necessarily the correct model of the design task. A designer may want to be able to influence, for example, the sequencing or choice of subtasks in a particular situation. The design support system with which a designer interacts should make this possible. This is not only of importance for the individual designer for which a system may have been designed, but also for other designers (often the designer(s) involved in the design of a system represent a class of designers) for which the model can be seen as a model of consensus. This model may need to be adapted for individual designers. This level of interaction has been termed the level of task model modification.

To model the knowledge required at these three levels of interaction within a task model, a task based framework for design is required and appropriate forms of representations. It is often unclear not only which representations are best suited to the particular task at hand, but also which differences exist between preferred representations between designers. Some work on this area is reported in (Brazier & Treur, 1994; Brazier, Treur & Wijngaards, 1994).

3 Foundational perspective

Within our research design is viewed as a complex reasoning process within which different types of reasoning are entailed at different levels of concreteness such as: deductive (e.g., to infer properties of a design object on the basis of known properties), abductive reasoning (e.g., to assert properties to meet given requirements of the design object).

A substantial amount of research has focussed on defining models of design as a basis for the development of design support systems, without considering the underlying logical structure of these models. Although some research on AI and design includes logical descriptions of design systems, a logical framework such as the framework on which our research is focussed, that covers both the static and dynamic aspects of design processes has yet to be devised. A logical framework enables formal specification of domain-specific design systems and development of supporting tools for verification and validation.

3.1 Requirements

A logical framework should provide (see also the list in A.):
- logical representation of (incomplete) descriptions of objects
- a logical description of views
- means to formulate alternative requirement sets and to qualify these possible alternatives (e.g., preferences, possible relaxations of an initial requirement set, new requirements)
- means to formulate a problem statement
- flexibility to describe the dynamics of alternating steps made between the problem statement formulation space, the requirement qualification set space and the design object description space

- possibilities for defining design strategies based on different methods and coordination applied to the different spaces (including problem statement formulation, requirement qualification, design object description).
- a description of the complex patterns of (nonmonotonic) reasoning involved in design
- (multi-agent) cooperation

3.2 Semantics of reasoning behaviour

In recent research, a logical foundation of the dynamics of complex reasoning patterns has been based on:
(1) the notion of representing information states as partial models defined in many-sorted predicate logic (Langen & Treur, 1989);
(2) the notion of a functionality description as a mapping from partial models to partial models (Treur, 1991b);
(3) the notion of partial temporal models as traces of partial models acquired by well-defined transition functions between partial models (Treur, 1992); This approach has been successfully applied in a number of areas: to define a formal semantics for (the dynamics of) meta-level architectures based on temporal logic (Treur, 1992); to obtain semantics for default logic including the dynamics of default reasoning (Engelfriet & Treur; 1993, 1994); and to obtain a formal model for the dynamics of compositional reasoning systems (Gavrila & Treur, 1994). Application of this approach to design is one of the current focusses of research; in (Brazier, Langen & Treur, 1994) a first attempt is made to define a logical foundation incorporating dynamic aspects.

3.3 Techniques for verification and validation

During system design models and representations need to be continuously verified and validated. The empirical basis for decisions taken during the design of a design support system needs to be considered. A formal framework, has an important added value, namely that it opens a perspective to establish (verify) properties of design systems and to develop automated tools for verification and validation. Generic work on validation and verification of static and dynamic aspects of compositional reasoning systems is reported in (Treur & Willems, 1994ab). This work has yet to be specialised to design support systems.

4 Developmental perspective

Modelling (re)design entails modelling the domain (i.e., the world of interest), the requirements for each of the parties involved, the design objects, and the design process. Our research aims at modelling design tasks within a formal framework for the specification of complex tasks.

4.1 Declarative specification of dynamics

This approach is based on a (multi-level) logical analysis of complex reasoning tasks, using the notion of a meta-level architecture (Maes & Nardi, 1988), and has been discussed in publications on both fundamental and applied research (e.g., (Langevelde et al., 1992)). In a meta-level architecture, it is possible to reason not only with relations in order to infer properties of, for example, design objects (object-level reasoning), but also about such relations (meta-level reasoning) and (the control of) the dynamics of the reasoning pattern.

4.2 Compositional architectures and formal specification

Modularity in system design is a well recognised requirement for efficient and effective software development, maintanence and reusability. This is especially true for design support systems. Within current research, the implications of modular design for the design of such design support systems (based on meta-level architectures), are translated into specifications for a flexible environment for the development of modular design support systems. The transparant architecture of the environment in which system developers are provided re-usable modules for both knowledge-based reasoning and conventional components, is a fundamental concern. Design tasks require both knowledge- based resoning modules and conventional modules such as databases, calculation (or simulation) modules and optimisation algorithms (OR). The integration of such modules in the design and implementation of integrated complex systems for specific design tasks provide both (1) task-specific building blocks and tools and (2) generic task models. The task-specific tools (for example, shells) and generic task specificiations combined, provide the basis for well-structured, transparant, modular system development. The emphasis in our current research is on the phase of design, specification and implementation of design support systems. Figure 1 depicts the model of formal specification and implementation employed to this purpose. The employment of automated tools not only significantly decreases the time needed to develop a prototype, but also increases maintainability.

$$\text{specification} \xrightarrow{\text{generator}} \text{prototype}$$

Figure 1. Formal specification and implementation generation

4.3 Generic task models

Within our framework task-specific building blocks, tools and techniques for design tasks have been devised on the basis of experience. Within this framework for realistic design tasks the integration of both quantative and qualitative techniques is essential; for example, in some situations search and optimisation techniques and constraint manipulation need to be integrated with knowledge-based reasoning modules. The integration requires fundamental research and is thus being studied within this context.

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Design Methodology for the Social Sciences

University of Twente
J. Irene A. Voerman

1. Description of the program

1.1 Background

In 1994, four faculties of the University of Twente started a five year research program. The objective of the program is to lay the foundations for a methodology for social scientific design as applicable in various field of applied social sciences such as communication, management, education, and public administration. The program has been proposed jointly by departments from four social science faculties (Faculty of Educational Science and Technology, School of Management Studies, Faculty of Public Administration, and the Faculty of Philosophy and Social Science) to the 'Research Stimulation Fund' of the University and has been funded accordingly.

The research program starts from the consideration that the social scientific departments are increasingly engaged in professional design activities, either as an object of study or as a topic for teaching and training students. Increasingly, in these departments "design" is perceived as a full-scale scientific activity, comparable with "research". Within the social sciences, the urge is felt for more systematic approaches to design. Various of such systematic approaches have already started to become manifest in the departments involved in the program. These approaches differ, partly because of the wide range of different objects of social scientific design activities (e.g. law texts, curricula, media campaigns, etc). Yet, it is presumed that a common methodological foundation can be elaborated.

1.2 Objective of the Program

The objective of this research program is to establish the contours of a social scientific design methodology, that should:

- be general enough to cope with differences between the social sciences involved and yet should be sensitive enough to do justice to the variety of design approaches that are in practical use;
- be grounded in the reconstruction of professional design activities and practice as are common in the scientific fields involved;
- enable the establishment of normative models and prescriptions for social scientific design.

1.3 Planned Research Activities

In order to attain the program objective within five years, four major research activities are planned:

1. Empirical reconstruction

This research activity involves the empirical reconstruction of current design practices within the scientific fields involved, as well as reconstruction of transfer of design knowledge and (proto-) methodology.

Reconstructions of design practices are especially necessary in the fields of management science and communication science, for little has been recorded systematically on these practices yet. Though considerably more research has been done by the faculties of educational science and technology and public administration, several facets of design oriented research within these faculties need to be reconstructed as well. Here, reconstructions will help clarify relationships between current design practice and the scientific state-of-the-art.

2. Elaboration of facets

This research activity involves the elaboration of those facets of design practice that are considered to be pivotal for the development of a social scientific design methodology. To be considered are at least:

a. The relationship between design and the theory about society and human behavior.
b. The relationship between professional design practice (client oriented, contextualized) and design methodology (product oriented and (somewhat) decontextualized). This facet offers an important difference with the technical sciences; in the technical sciences clients are presumed to be interested in a product that will be delivered by scientists in accordance with their own scientific terms.
c. Evaluation and, in general, more explicit feedback in reflective design practice and design methodologies.
d. Instrumentation and sociotechnical design. With this facet, a bridge is build between social and technical sciences, as technical sciences might offer some "social considerations" in their design practice.
e. The (artistic) compositional aspect (including esthetical and (in a broad sense) literary aspects). Comparisons with fields like architecture learn that social siences cannot leave this facet of design out of consideration.

3. Translation into methodology

In a later stage of the program, the findings from the reconstruction studies and the elaboration of certain design facets will be "translated" into a methodology. The aim is to formulate normative models and prescriptions. The translation process will need considerable additional analysis and reflection. This includes the following activities:

a. Elaboration of general issues with respect to philosophy of science, of which some have already been identified.
b. Articuluation of "grounded methodologies" based upon the empirical reconstructions and available experience and insights of senior staff.
c. Elaboration and modifications of the "grounded methodologies" using insights from the facet-studies.

4. Synthesis

The last phase of the program consists of a step towards scientific synthesis, which takes the variety among social sciences into account. A "lead author" will take the responsibility for "integrative" publications, that will be commented upon by international researchers.

1.4 Organization of the program

The research activities are organized in Ph.d. projects and post-doc projects. Besides, worskhops will be organized.

PhD projects

The program involves 5 PhD projects, carried out within the faculties of management educational science and technology, public adminstration, and philosophy and social science. The PhD projects are anchored within departments of these faculties. The empirical reconstructions are the essential component of these PhD projects.

Post-doc projects

By now, three topics for post-doc activities have been distinguished:

- philosophy of science and design methodology
- epistemological aspects of design methodology
- evaluation and design methodology.

There may, however, emerge more topics during the program.

Workshops and other activities

Several workshops will be planned for program participants and other interested persons, about twice a year. In 1994, workshops were on "Articulation and Design Practice" and "Methodology of Reconstruction". For subgroups (for example Ph.D. students, small-scale workshops will be organized.

2. Composition and background of researchers

Following are the four participating faculties and the researchers involved in the program:

Educational Science and Technology (TO)

Departments

Curriculum (CRC), Instructional Technology (IST), Educational Instrumentation (ISM), Educational Administration (O&M)

Participants

Dr. J.J.H. van den Akker (CRC), Drs. H.W.C.H van Amelsvoort (O&M), Dr. R.J. Bosker (O&M), Dr. I.P.F. De Diana (ISM), Prof.

dr. J.C.M. Moonen (ISM), Prof. dr. J.M. Pieters (IST), Prof. dr. Tj. Plomp (CRC), Prof. dr. J. Scheerens (O&M), Dr. A.J. Visscher (O&M), Drs. J.I.A. Voerman (CRC)

School of Management Studies (TBK)

Departments

Operational Methods and Systems Theory (OMST), Technology and Organization (T&O)

Participants Prof. dr. ir. O.A.M. Fisscher (T&O), Dr. J. Geersing (OMST), Ir. K. Visscher (T&O)

Philosophy and Social Sciences (WMW)

Departments

Philosophy of Science and Technology (FWT), Applied Linguistics (TT)

Participants

Dr. C. Disco (FWT), Dr. T.M. van der Geest (TT), Ir. I.B. van de Poel (FWT), Prof. dr. A. Rip (FWT), Prof. dr. P.J.M. Schellens (TT), Dr. M.F. Steehouder (TT)

Public Administration (BSK)

Departments

Policy (B&B), Organization & Finances (O&F), Centre for Higher Education Policy Studies (CSHOB)

Participants

Prof. mr. D.W.P. Ruiter (B&B), Dr. B. Steunenberg (O&F), Prof. dr. F.A. van Vught (CSHOB), Dr. D.F. Westerheijden (CSHOB), Drs. W.G. Werner (B&B)

Program Leaders

Prof. dr. J.C.M. Moonen, Prof. dr. A. Rip, Prof. dr. F.A. van Vught

External Scientific Contributors to the Program

Prof. dr. M. Zwanenburg, Dr. J. A. Harbers, Prof. dr. P.J. van Strien, Prof. dr. P.G. Swanborn

3. Research areas and typical research programs

Because the research team consists of researchers from different faculties that were grouped together for this purpose, this research group does not have a common research past. In other words, there can not be given typical research programs of this group. Therefore, this paragraph will deal short with the research areas and interests and typical research programs of the participating faculties or departments individually. Especially those areas that are connected to design will be mentioned.

Educational Science and Technology

The faculty of educational science and technology investigates topics of educational technology. The research interests of the department of curriculum are in the development and evaluation of procedures for legitimization, design, evaluation, and implementation of curricula (including courseware) for general and vocational education and corporate training. They hold special interest in the development and use of formative evaluation as a means to improve curricula and training and in implementation improving factors. The department of instrumentation aims at the design, integration and transfer of interactive materials for learning and communication. The research from the department of educational administration focuses on the organization and curriculum conditions of school effectiveness and schoolperformance.

School of Management Studies

The School of Management Studies develops knowledge for professional designers in the field of management of technology and innovation. The department of technology & organization focuses on management of research & development, quality management, production, innovation, concurrent engineering. Research programs are continuity of organizations, innovation of production systems, and information technology.

Philosophy and Social Sciences

The two departments from the Faculty of Philosophy and Social Sciences, that are committed to the project are the department of Philosophy of Science and Technology and the department of Applied Linguistics. One of the cross-cutting interests in the research of the department of Philosophy of Science and Technology is design: philosophy of design, cases of design work and the emergence of stabilized design conceptions, changes that occur in design conceptions and practices, attempts to influence design processes in an early stage ("Constructive Technology Assessment"). Current PhD research in the department focuses on constructive technology assessment in product development in biotechnology firms. The central aim of the research program of the department of applied linguistics is to develop methods for evaluating and optimising the quality of textual communication. With respect to the design of texts, the main focus in the program is on those apsects of design processes

Poel, I., van de (1993). Ontwerpen van ontwerpen: De ontwikkeling en het gebruik van ontwerphulpmiddelen in de Werktuigbouwkunde, Electrotechniek en Informatica [Design of design: the development and use of design tools in technical sciences such as mechanical and electrical engineering, and computer and information science]. Haalbaarheidsstudie 3. Enschede: University of Twente.

Poel, I., van de, Rip, A., & Vught, F., van (1993). Ontwerpen in de technische wetenschappen: Studies, ervaringen en methodologie [Design in the technical sciences: studies, experiences and methodology]. Haalbaarheidsstudie 2. Enschede: University of Twente.

Rip, A., Westerheijden, D., & Vught, F., van (1993). Reconstructie van ontwerpprocessen: Een op Schön geïnspireerde aanpak [Reconstruction of design processes: an approach based on Schön]. Haalbaarheidsstudie 1. Enschede: University of Twente.

Schellens, P.J., Steehouder, M.F., & Heuvelman, A., & Poort, P.C. van der (1993). Voorstudie Ontwerpbenadering in de communicatiekunde [Study to design approaches in communication science]. Haalbaarheidsstudie 9. Enschede: University of Twente.

Visscher, K., & Fisscher, O. (1993). Reconstructie van ontwerpprocessen in de bedrijfskunde [Reconstruction of design processes in the field of Business Administration]. Haalbaarheidsstudie 5. Enschede: University of Twente.

which anticipate on the quality of the text. Text design processes are studies with respect to several types of texts.

Public Administration
The faculty of Public Administration commits to research into the field of manegerial and political practice. They are particularly interested in the ways in which these practices are designed and in economic and legal institutionalism/.

4. List of recent publications

Akker, J. van den., & Plomp, Tj. (1993). Ontwerpen vanuit implementatieperspektief [Design from an implementation perspective]. Haalbaarheidsstudie 7. Enschede: University of Twente.

Diana, I., de, Geelen, A., Broeke, A., ten, & Moonen, J. (1993). Ontwerpen van interactief onderwijs: rapportage van een haalbaarheidsonderzoek naar ontwerpmethodologiën bij onderwijskundige instrumentatietechnologie [Design of interactive instruction: report on a study on design methodologies in educational instrumentation technology]. Haalbaarheidsstudie 8. Enschede: University of Twente.

Faculteiten der Bestuurskunde, Technische Bedrijfskunde, Toegepaste Onderwijskunde, & Wijsbegeert en Maatschappijwetenschappen (1993). Een sociaal-wetenschappelijke ontwerpmethdologie: Aanvraag in het kader van het Onderzoeksstimuleringsfonds van de Universiteit Twente [A social-scientific design methdology]. Enschede: University of Twente.

Visscher, K., Fisscher, O., & Rip, A. (1993). Bedrijfskundig construeren; een verkenning naar ontwerpprocessen in de bedrijfskunde. intern paper UT.

Voerman, J.I.A. (1994). DATE: Design Approaches in Training and Education: Findings from a preliminary study. Paper presented at the European Conference on Curriculum, August 31 - September 2, 1994, University of Twente: Enschede, The Netherlands.

Werner, W., Steunenberg, B., & Ruiter, D.W.P. (1993). Het ontwerpen van instituties [The design of institutions]. Haalbaarheidsstudie 6. Enschede: University of Twente.

Zwanenburg, M.A. (1993). Methodologie van sociaal ontwerp: Voorbereiding op epistemologische aspecten [Methodology of social design: Preparation to epistemological aspects]. Haalbaarheidsstudie 4. Enschede: University of Twente.

Design research in the Stevin project

P.M. Wognum N.J.I. Mars
Knowledge-based Systems Group
Department of Computer Science
University of Twente
P.O. Box 217
7500 AE Enschede
The Netherlands
E-mail [wognum,mars]@cs.utwente.nl

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1 The Stevin project

The Stevin project is one of the research projects performed in the Knowledge-based Systems group of the University of Twente. The Stevin project is aimed at developing knowledge-based models and techniques to support engineering design in technical domains like mechanical, electrical, and civil engineering.

The research approach adopted in the project is based on the so-called product view, which means that we aim at developing knowledge-based systems which produce results that are equal to or possibly even better than those achieved by humans without necessarily imitating human problem-solving behavior. The main focus of our research is on modeling product-related design knowledge. One of our objectives is to develop large and reusable knowledge bases. An ontology, called YMIR, for structuring design knowledge is used for this purpose (Alberts [1993]).

Modeling design knowledge with the ontology YMIR offers several advantages, because the concepts in YMIR are uniquely defined. One of the advantages is that the resulting knowledge bases may easily be integrated to support the execution of particular design tasks. In addition, the knowledge bases are exchangeble between domains. Moreover, the knowledge can be verified formally, since the concepts in YMIR are defined in terms of network models in system theory.

A second advantage, not offered by many other product models, is the integration of different aspects in one design description. This integration is made possible because the concepts in YMIR explicitly relate form, consisting of material and geometrical properties, and behavior, expressed in terms of the form-related variables. Function is defined as an instantiation of the behavior in a particular context in which the design has to operate. This property of YMIR provides us with the possibility to model different types of requirements, among which life-cycle requirements, in such a way that they can be checked automatically and as early as possible during the design process.

In the Stevin project, we view design as a synthesis process in which abstract functional specifications including requirements on the realization of the design are gradually translated and refined into a design description which is physically realizable. To bridge the gap between abstract functional specifications and realizable design description, several abstraction layers have been defined. Each abstraction layer is a true abstraction of the layer directly below it. At each layer, the specifications are satisfied by a design description consisting of combination of components defined at that layer. Next, the design description is translated into new specifications at the next lower layer. At the lowest layer, the design description consists of YMIR components which have physical counterparts.

2 Researchers in the Stevin project

The Stevin project consists of four Ph.D.-projects, a post-doc project, and a project aimed testing YMIR with real product data. The projects are supported by a scientific programmer, undergraduate students of the Department of Computer Science and the School of Polytechnics , and by graduate students from the OTIS program, a two-year program to educate students as a designer of technical information systems.

The Stevin project is one of four projects performed in the Knowledge-based Systems Group, headed by Prof.dr.ir. N.J.I. Mars. The project's daily supervisor is Dr. P.M. Wognum. The project further consists of Dr.ir. L.K. Alberts, who performs a SION-postdoc project, the Ph.D.-students Ir. F. Dikker, Ir. F. Tempelman, V. Sushkov Ms.C., and Drs. S.J.M. van Eldonk, who performs a project in the SION special attention area 'Evolutionary knowledge-based systems, called Revise, in cooperation with UvA, VU, and UT/ECN. V. Sushkov is a researcher from the Invention Machine Laboratory in Minsk. The scientific programmer supporting the project is Ir. F. van Raalte.

3 Research projects

3.1 Early evaluation of design requirements

In a design process, many requirements play a role in addition to the functional specifications. These requirements are often left implicit at the outset of a design problem and are incorporated in the design process as soon as they become relevant to the design at hand. Examples of such requirements are design codes and safety requirements and are rather general in nature, which means that they are applicable to a large variety of design problems.

In this part of the Stevin project, we investigate how requirements can be modelled on the basis of YMIR and how they can be used in the design process as early as possible. Our objective is to apply requirements to the design description as soon as they become relevant to the design at hand (Dikker & Wognum [1993a], Dikker & Wognum [1993b], Dikker, Alberts & Wognum [1993]). As a result, conflicts are detected as early as possible thus preventing unnecessary iterations.

To be able to formally structure requirements, we have developed a model of requirements (Dikker et.al. [1994]) which consists of a scope part and a restriction part. The scope part is a design description representing the situations in which the requirement is applicable. The restriction part describes the actual requirement and restricts specific parts of the scope. With the help of this requirement model, requirements can be used in the design process as desired. The scope part can be matched with the description of the design under construction to determine whether the requirement is applicable. When after matching an applicable requirement is found, the restriction part can be applied to the design at hand possibly leading to the elimination of possible instantiations. If, as a result, the design description becomes inconsistent, resolution of the conflict is needed. This part is left for future research.

The approach has been implemented using Galileo (Bowen [1992]), a constraint programming language. Currently, the requirement model is tested against a number of design codes. In june 1995, the results of this study will be published in a Ph.D.-thesis.

3.2 Case-based design

In practice, designers often reuse earlier experience in new design situations. Such experience mainly exists in the form of already finished (successful or possibly rejected) design cases. The main problem in reusing such knowledge is in formalizing, representing, retrieving and adapting old cases to satisfy new functional specifications.

In this project, we study how existing cases can be retrieved to be used as starting points for a new design problem. Such a problem consists of new speccifications for (part of) a product to be designed at any point during a design process. To be able to reuse cases, we need methods and techniques for selecting them. We further assume that cases are represented as YMIR product models.

A case is considered to be 'most suitable' if it requires the least adaptation compared to other candidate cases. To be able to determine the suitability of a case, we first need to classify adaptation according to its complexity in terms of, for instance, the number of computation steps involved in performing the adaptation. Second, we need models and techniques to designate the case which best suits the new specifications for (part of) the design at hand.

To predict the possible adaptations needed for a case, we may use traditional case-based reasoning techniques extended with knowledge on the complexity of adapting cases. We should aim at restricting the additional amount of knowledge as much as possible, however, since one of the advantages of case-based reasoning is deemed to be the avoidance of the knowledge acquisition bottleneck. The addition of a large amount of adaptation knowledge clearly removes this advantage.

It is expected that case-based design enhances the efficiency of the design process. The objectives of this subproject are to define indices to enable retrieval of cases which are candidates for a new design problem, to model adaptation knowledge to determine similarity of the candidate cases with the new design problem, and to test the model and techniques in several practical situations. The results of this project will be published in a Ph.D.-thesis in October 1996.

3.3 Redesign

This subproject of the Stevin project concerns the process of redesigning a specific technical system to let it meet new requirements. The project is performed in the context of the SION special attention area 'Evolutionary knowledge-based systems', called Revise. This attention area is a cooperation between the UT, UT/ECN. UvA, and VU.

The aim of redesign, in general, is to produce a new design in a very efficient way. The possibility to design a new product by slightly modifying an old design, often results in a reduction of costs and effort in the design process. The success of redesign depends on the similarity of an old design with the new one. When the modifications that have to be made, are large, redesign is not a very good idea; designing from scratch seems then more appropriate.

For our subproject we assume that an old design description is given. The process of selecting a relevant case from a case-base is the subject of the subproject described above. Besides an old design, we assume new specifications, which differ from the specifications of the old design. Further, both design and specifications are described in the same way, within our modeling framework YMIR.

The output of the redesign process is a new design, which meets the new specifications. To accomplish this result, several subtasks can be distinguished:

- Diagnosis: The localization of the part of the original design which has to be adapted and the part of the design which may remain the same.

- Respecification: For the part which has to be adapted, a new specification has to be found, such that the overall new specification is met.

- Design: This partial specification must actually be designed. Several tasks are possible, like design from scratch, case-based design, redesign again, or enlisting a human designer.

- Evaluate: The result of the design step has to be evaluated. It has to be checked whether the new overall design meets the required overall specification.

The crux of redesign is formed by the diagnosis and respecification subtasks. At the moment we study Model-Based Diagnosis techniques for accomplishing these two tasks. To this end, we consider a design description as a MBD-model, consisting of components and connections and functional descriptions of the components. The difference between a new specification and an old design can be seen as the equivalent of a MBD conflict. The result of our use of MBD is a new partial specification, the equivalent of a MBD diagnosis. For details, we refer to (Bakker et.al. [1994]). The results of this project will be published in a Ph.D.-thesis in July 1997.

3.4 Innovative design

In the fifties, after G. Altshuller had studied a large number of patents from various patent collections, he concluded that most innovative design solutions were obtained by the transfer of ideas from one engineering domain to another. By "idea transfer" Altshuller means the transfer of a known physical or design principle (conceptual design knowledge, in other words) from a domain in which the principle has been effectively used to another domain where the use of this principle was unknown or its applicability has not been investigated yet.

Altshuller further developed this idea and formalized it in TIPS, the Theory of Inventive Problem Solving. The theory was tested thoroughly and proved the workability of Altshuller's concept.

To organize innovative design as a process which reuses previous knowledge, as suggested by TIPS, we need to represent this previous design knowledge in a form which will make it possible to share this knowledge between different engineering domains. This can be done with the use of AI techniques for reusing previous experience, for instance, case-based reasoning (CBR). Various physical principles can be modeled and stored as previous design cases, and retrieved through (specific or general) functions which serve as indices to these cases.

We can distinguish several problems to be faced and possible solutions to them when using a CBR approach to model innovative design:

1. What knowledge to store as previous design cases. In our research, we intend to use the collections of physical and design knowledge which are contained in TIPS.

2. Modeling the various types of conceptual design and physical knowledge in a uniform way. This problem might be tackled by using YMIR.

3. Effective case retrieval by defining suitable indices. To solve this problem, the lists of both general physical functions and specific technical functions, as already present in TIPS, can be used.

4. Adaptation of a selected case to a new situation. In this project, adaptation is currently left to future research.

For more details on TIPS, we refer to (Sushkov, Mars & Wognum [1995]).

3.5 Forms of abstraction in YMIR

This two-year project is a postdoc project financed by SION and started in january 1994. The goal of this project is to define abstraction operators to enable translation of design descriptions between abstraction layers as defined in YMR. In addition, views are modeled to allow selections of parts of design descriptions.

One of the objectives of this project is to extend the reasoning techniques developed in the Stevin project to reason with YMIR-based knowledge. These techniques enable automated abstraction transitions. In addition, techniques are developed to select views from a design description. These techniques will in future provide support by presenting product information to members of a multi-disciplinary design team.

To test the feasibility of the approach taken in this project, the domain of the Cruquius project will be used as a test bed.

3.6 The Cruquius project

The goal of this project is to test YMIR with real product knowledge. The product to be modeled is an oil compressor (van Raalte [1993]). The knowledge will be used to test different configuration strategies. The questions to be answered by this project are;

- Is YMIR suited to model a real product?
- How suited is YMIR to model a real product?
- What part of the knowledge can not (yet) be modeled with YMIR?
- Can we model a configuration task for a real product?

Currently, a shell is being developed to support the representation of and reasoning with the product knowledge. Students of the School of Polytechnics in Enschede have supported part of this work (Bom&Bouma [1994]).

After finishing the shell, we will develop the compressor knowledge base in cooperation with Delaval Stork in Hengelo. At that time, we will be able to answer the questions raised above. In addition, several other examples will be worked out.

3.7 ConcERT

The Stevin project participates in the research program ConcERT (Concurrent Engineering Research Twente), a joint program of the School of Management Studies, Civil Engineering and Management, and the Department of Computer Science. The goal of the program is to develop a method for supporting organizations in adopting, implementing and developing techniques, both from organizational and computer science, for Concurrent Engineering. The research is currently performed by undergraduate students from both departments. Their research consists of case studies of R&D processes in several industrial organizations.

4 Recent publications

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L.K. Alberts & F. Dikker [1994], "Integrating standards and synthesis knowledge using the Ymir ontology," in *Proceedings of the Third International Conference on Artificial Intelligence in Design, 15-18 August 1994, Lausanne, Switzerland*, J.S. Gero, ed., University of Twente, Enschede, The Netherlands.

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J.A. Bowen & D. Bahler [1992], "Frames, quantification, perpectives, and negotiation in constraint networks for life-cycle engineering," *Artificial Intelligence in Engineering* 7, 199–226.

F. Dikker, L.K. Alberts & P.M. Wognum [1993], "A constraint-based approach to design critiquing," in *Proceedings of the 6th International Conference on Industrial & Engineering Applications of Artificial Intelligence and Expert Systems, Edinburgh, UK*, P.W.H. Chung, G. Lovegrove & M. Ali, eds., Gordon and Breach Science Publishers, Yverdon, Switzerland, 6–9.

F. Dikker, L.K. Alberts, P.M. Wognum & N.J.I. Mars [1994], "Structuring design requirements using Ymir," University of Twente, Memorandum Informatica 94-41, Enschede, The Netherlands.

F. Dikker & P.M. Wognum [1993a], "Constraint-based critiquing: a knowledge-based approach to design for quality," in *Proceedings of the 9the International Conference on Engineering Design, The Hague*, N.F.M. Roozenburg, ed., Heurista, Zürich, Switzerland, 926–933.

F. Dikker & P.M. Wognum [1993b], "Knowledge-based quality assurance: a critiquing approach to support ISO9000 in design," University of Twente, Technical Report UT-KBS-93-22, Enschede, The Netherlands.

S.J.M. van Eldonk [1994], "Literature report on redesign," Technical Report, UT-KBS-94-22, Enschede, The Netherlands.

P.C. Hulleman [1994], "Design of an information support system for the sign-off procedure at Delaval Stork," Master Thesis, Enschede, The Netherlands.

S.H. Kloosterman [1994], "Developing an executor for KbsSF," University of Twente (PTT Research), Master Thesis, UT-KBS-94-08, Enschede, The Netherlands.

M. Kroese, P.M. Wognum, A.M.C. van Rijn, S.M.M. Joosten & N.J.I. Mars [oktober 1994], "Methoden voor het ontwikkelen van kennissystemen," *Informatie* 36, 696–706.

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V.V. Sushkov [1994], "Reuse of physical knowledge in creative engineering design," in *Workshop Notes of the ECAI94 Workshop on models and techniques for reuse of designs*, P.M. Wognum, ed..

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DESIGN KNOWLEDGE SYSTEMS

ARTIFICIAL INTELLIGENCE FOR THE INTELLIGENT ARCHITECT

ARCHITECTURAL DOMAIN DOCUMENTATION AND ANALYSIS

DECEMBER, 1994

John Linke Heintz

1. INTRODUCTION: ENDS AND MEANS

Design Knowledge Systems (D.K.S.) is a multidisciplinary group of researchers whose objective is to improve design methods and theory through joint investigations in design cognition and computation. The group was founded in 1985.

D.K.S. research aims:

1.Develop design knowledge through scientific research.
2.Improve design methods applied by professionals through the development of design knowledge.

D.K.S. research programs:

1.Studies documenting the design process and analyzing the conceptual framework and cognitive structures that constrain it. These comprise a program of empirical historical investigations under the name *Architectural Domain Documentation and Analysis (A.D.D.A.).*

2. Reconstruction of models and methods in use by practitioners into a computational theory of design cognition. Development of normative knowledge-based, computer-based intelligent design systems; a program under the name *Artificial Intelligence for the Intelligent Architect (A.I.I.A.).*

Why this dual approach?

1.Understanding Domain Design Knowledge, expressed in terms of design principles and design precedents, is a prerequisite to the development of efficient and effective computer-based design methods.
2. Reciprocally, the development of computational design methods leads to better understanding, to more explicit and transparent design thinking. Both developments increase the control over the mental production of design, making it more reliable and robust.

The two research directions, (1) *domain theory* and (2) *computational systems*, are considered as closely interdependent and complementary and are pursued by the group in parallel.

The research draws from:

1. *Design Theory* and *Design Methodology*
2. *Cognitive Science*
3. *Artificial Intelligence and Informatics*
4. *Design History*

The research focuses on the following aspects of design:

1. *Morphology* of an artifact; the *structure* of a design solution
2. *Operation* of an artifact; the *behaviour* contained in the solution when used
3. *Performance* of an artifact; the *function* of a design solution in respect to accepted programmatic norms

The orientation of the research group towards *computational* theory of design and the view of the machine as a simulator of intelligent design thinking can offer insights about design creation, problem solving and the production of felicitous artifacts. The approach may also shed some light on broader questions of creative cognition.

To meet these multiple goals the group brings together a number of prominent specialists who advise on specific research areas.

The research leads to:

1. Scientific theories and support documentation offering rigorous explanations of design intelligence, expanding frontiers in the understanding of design thinking and the opening of new perspectives in design practice.

2. Design methods resulting in better control of the design process. From the social contribution point of view these methods implemented in new thinking routines or in new computer programs lead to improvements in:
   - efficiency
   - effectiveness
   - reliability
   - reflective creativity and value learning

2. ARCHITECTURAL DOMAIN DOCUMENTATION AND ANALYSIS (A.D.D.A.)

The domain studies of the group investigate the knowledge–principles categories, rules, precedents, types of problems and heuristics–applied in design practice. Research activities are divided into:

1. Case studies of prototypical character to identify:

1.*Conceptual frameworks;* the product typologies and conventions accumulated through history inside design belief systems, theory and methodology (canons of spatial composition, product program stereotypes, design routines), through which intelligent designing is exercised.

2.*Cognitive constraints;* the structures and properties of the mind through which design artifacts are recognised, compared, classified, memorized, conceived and evaluated. These include typologies of artifacts, spatial arrangements, and shape preference rule systems.

2. Architectural Archives

The group has been focusing on the creation of architectural archives the systematic cataloguing and publication of archives of conceptual design drawings, recording the creative thinking on a project. The project is carried out in collaboration with Garland Publishing, New York and major museum archives.

3. ARTIFICIAL INTELLIGENCE FOR THE INTELLIGENT ARCHITECT (A.I.I.A.)

The A.I.I.A. projects concentrate on the development of the *Intelligent Architect* (I.A.), an automated system for the production of new design solutions which satisfy programmatic requirements using previously acquired *domain knowledge.*

The A.I.I.A. group is involved in studying the following problems:

1. How are cognitive constraining structures applied in design inference?
2. How do design knowledge, conceptual structures and precedents control the design process?
3. How does reasoning interrelating aspects of form, operation, and performance take place in creative design?

AIIA research is subdivided into *projects* as the needs of specialized investigation demand:

1. ***Plan Representation, Recognition and Typology***
   Development of methods to recognize and classify, pre-parametric artifact representations, spatial diagrams, sketches, and technical, production drawings.

2. ***Principles and Precedents : Design Thesaurus***
   Analysis and storage of precedent plans in a *Design Thesaurus*, an organized intelligent memory whose structure reflects architectural knowledge constraints. Identification of design principles capturing large numbers of design rules, generalizing and organizing expe-rience drawn from precedents concerning form/operation/perfor-mance relations.

3. ***Programmatic Analysis***
   Development of methods to parse, analyze and structure normative statements from verbal discourses. Recasting values of such discourses into explicit design product programmatic constraints.

4. *Analogy and Creativity: ABCD*
   Analogy and metaphor as mechanisms of inference, are characteristic of learning and most intelligent creative thinking. Projects in this area contribute to the development of an analogical design inference system for Automation Based Creative Design (ABCD) using constraints of form - operation - performance.

5. *Community and the Mind*
   Development of multi-agent, cooperative, distributed design systems employing all the above (1-4) methods. Such agents are either professional specialists who collaborate in the design process or users who also play a participatory role in decision making of the product.

4. COMPLETED PROJECTS

Dr. ***P. Scriver*** has studied the thinking processes that helped produce the distinctive architecture and settlement planning of British India in the 19th century. The work offers insights on the rationalization and institutionalization of design thinking, and the role of socially constructed conceptual systems in such processes. The project is undertaken with the collaboration of Prof. A.D. King and Prof. B.V. Doshi.

Dr. ***Li Yu*** has examined the role of Number in the representation of building design knowledge. His research investigates two culturally distinct systems for the prescription and categorization of architecture, employing theories of number: a traditional Chinese system employed in the classic Chinese house-builder's manual, *Zhai Pu Zhi Yoa* (1741); and the system developed for universal use by contemporary architectural professionals, Le Corbusier's *Le Modulor*. The study is carried out in collaboration with Dr. K. Ruitenbeek.

Dr. ir. ***M. van Leusen*** (1994) has developed an automated design support system for the design of residential buildings. The system provides information interrelating spatial form types with operational and performance requirements. The project was undertaken in collaboration with Prof. K. Rijnboutt and Dr. Ph. Steadman.

The development of a system for classifying and analyzing building sites, taking into consideration multiple points of view and cultural belief systems, was the topic of the doctoral research of Dr. ***Xiaodong Li***. His study compares an archaic with a contemporary case; a traditional Chinese theory of architecture from a 15th century text, *Xian Puo Ji*, and the theories of Kevin Lynch. The project was undertaken in collaboration with Prof. Schmid and Dr. Ruitenbeek.

Dr. ***A. Zandi-Nia*** (1992) has developed TOPGENE, a computer-based system for generating pre-parametric spatial arrangements of buildings. The system employs deep models of expertise which can (1) generate (2) evaluate (3) analyze and (4) give diagnosis of malfunction with respect to multiple social performance norms. The system uses Q-analysis to organi-se circulation operation data, an iterative bottom-up approach in conjunc-tion with hill-climbing and heuristic techniques, to arrive at a design. The research included analysis of the computational complexity of architectural design, the role of domain heuristics reducing such complexity and means for diagnosing the structural complexity of systems having a topological property representable as a graph, as is the case of designing buildings in relation to social performance norms. A new theorem for keeping track of distances in incrementally growing graphs was developed. The study also produced topological indices useful for quick diagnosis of alternative design solutions.

A framework for automated recognition of metric properties of architectural plans has been developed by Dr. ***A. Koutamanis*** (1990). Recognition includes identification of spatial primitives, grouping of primitives/subdivision of the plan and investigation of well-formedness. Image understanding and well-formedness concepts employed derived from the classical canon domain study.

Under a contract from the *Rijksgebouwen Dienst* of the Ministry of Housing and Planning ***J.S. de Boer*** and ***V. Mitossi*** prepared a typological study of morphological aspects of buildings related to performance criteria of flexibility and multifunctionality.

The identification of the conceptual system contained in the early arabic discourse on architecture was the topic of investigation of Dr. ***B. Al-Abed*** (1992). The research also involved an extensive documentation of Arabic texts on architecture from the early Jahiliyya (pre-Islamic) period to the 18th century when foreign influences begin to be evident in the arabic culture. Prof. I.R.T.M. Peters collaborated in the study.

Methods and techniques for the management of the urban environment by means of CAD systems was the research topic of ***Ronald Stenvert***. The project was undertaken mainly in the University of Utrecht with Prof. dr. J. van der Berg.

In collaboration with ***I. White, A. Tzonis*** edited a special issue of *Construction Automation* (1993) and a book, *Automation Based Creative Design* (1993), devoted to this topic.

Nan Fang in his *Architectural Precedent Analysis* (1993) developed a computational methodological framework for the use of precedents. The research drew from the analysis of a case-study of urban renewal in the ancient residential quarter of Beijing was carried out by the prominent Chinese architect and planner Prof. L. Wu, whose work relied heavily on the use of traditional precedents.

M.W. Ludema has worked on developing a framework for an expert system for identifying buildings fitting new programmatic demands on operation and performance out of a large stock of unused buildings in the possession of the *Rijksgebouwen Dienst.* of the Dutch Government.

C.J. Baljon (1993) developed a method to analyze conceptual systems contained in architectural discourses. He used texts by Ruskin, Sempter, and Viollet-le-Duc as cases. The project was undertaken in collaboration with Prof. D. van Zanten.

A computer-based system for urban design, GLOBAL, which identifies zones of land use on given sites using reasoning from first principles and constraint propagation, was developed by ***N. Harkes*** (1993).

The problem of architectural inference by analogy to precedent cases has been studied initially by ***E. Offermans*** and subsequently by ***M. Cohen***, focusing on the case of the Unité d'Habitation of Le Corbusier. The project was continued by ***D. Giannisis*** who employed hyper-media techniques to represent the precedent-based dynamic creative design process (1993).

J.W. Croon used DELPH 2, an expert system shell developed by TU Delft, to investigate formal operational relations in dimensioning steel construction elements in buildings.

5. ONGOING PROJECTS

R. van der Bijl is researching the argumentation structure of the problem of security of buildings. The study aims at developing a design support system providing designers or managers of projects with advice about theft and vandalism.

The partially published writings of S. Stevin on architecture are studied by ***H. de Mare***. The research explores the knowledge structures underlying these texts and drawings to reveal the role of belief systems in giving shape to Stevin's theories. The project is undertaken in collaboration with Prof. W. Frijhoff.

M.W. Ludema works on the development of a framework for an expert system for resource allocation in Ministry of Defense buildings. The knowledge based system will provide support for decisions in choosing and acquiring construction materials considering their total life costs and not only their price at the moment of acquisition. The project is undertaken in collaboration with Prof. H. B. Roos.

The heuristic role of sketch drawing in the design process and its representation conventions is being researched by ***J.S. de Boer***.

V. Mitossi is working on industrialised housing in the Netherlands between 1940-1965 as a case study towards the development of an automated knowledge base of buildings, analyzing and integrating data concerning architectural plans, construction, space us, of space and industrialisation. The project is undertaken in collaboration with Prof. H. Priemus.

Hoang-Ell Jeng is working on developing a dialogical computational model for the participatory design process. The work employs recently developed theories in cognitive science (discourse analysis of multiple communication), social psychology (dialogical self), artificial intelligence (multi-agent problem solving) and design methodology (negotiation design process).

ir. ***M. A. Noordzij*** is exploring recent developments in genetic algorithms. He aims to introduce these into the larger framework of a multi-criteria negotiation model.

The design discoveries by the French engineer Jean Prouvé and the role of prototypes in it is the study undertaken by ***Jean-Marc Weill***. The topic was chosen to provide material towards the development of a more general theory of problem solving in pre-parametric design of construction elements and the development of a computer-based knowledge system to support it.

The research of ***D. Bilodeau*** examines the definition and organization of knowledge in 18th century French instructional books on architecture (1671-1793). Principle themes are the institutionalization of architectural education, and the recognition of architecture as an autonomous domain of knowledge.

Luca Molinari is studying the role of belief-systems and precedent knowledge in design innovation, in the work of the post-war Italian architect, Ernesto Rogers. This cognitive historical case study involves in-depth research in the archives of the firm.

John Heintz is developing a multi-agent model for the analysis and documentation of the design decision making process. The model will analyse the roles played by the client, the architect, regulating authorities, consultant engineers, quantity surveyors and other similar agents contributing to the architectural design process. Analysis will identify the factors contributing to the efficiency of the process and generate a framework for concurrent architectural practice. The model will also allow for comparative studies to be made of architectural practices in distinct working environments. ***Peter Donker*** will apply this model to an actual case, using the drawings, corrispondence and other records of a project to create an objective picture of a specific instance of design process.

6. CONFERENCES ORGANIZED BY DKS GROUP

In December of this past year, the group, in collaboration with prof. ***Ian White*** of Cambridge University, organized a conference entitled ***Precedents in Creative Design***. Critical topics discussed at the conference included: the role of precedent in design, where precedents come from, applying precedents to new design problems, the use of precedent in other fields, and historical examples of the role of precedent. Speakers included: S. Anderson (M.I.T), J. Lee (Edinburgh), P. Boudon (L'AREA), W. Bohm (Kaiserslautern), S. Los (I.U.A.V.), R. Oxman (Technion & T.U.E.), and L. K. Alberts (T.U.E.). Sections on: Typology and Design, Computation and Precedent, History and Theory. Round Table (chaired by prof. S. J. Doorman): A Critical Examination.

In 1992 our research group was asked to organize, in collaboration with prof. dr. ***H. Koppelaar***, an international conference on the occasion of the 150th birthday of the Delft University of Technology and the meeting of the Association of Collegiate Schools of Architecture (A.C.S.A.) of America in Europe (May 15, 1992). The theme chosen was ***Automation Based Creative Design Education*** (A.B.C.D.E.). Issues discussed: innovative use of computers in architecture, cognitive foundations, domain applications, new directions, and technological, social and moral implications. Speakers included: G. Stiny (U.C.L.A), W. J. Mitchell

(M.I.T.), D. Schodek (Harvard), D. Schon (M.I.T.), W. Oechslin (E.T.H.), I. White (Cambridge), G. Schmitt (E.T.H.), S. Pollalis (Harvard), J. P. Protzen (U.C. Berkeley), M. Benedikt (U. Texas), R. Aroca (Madrid Polytechnic), R. Oxman (Technion), Ph. Boudon (Paris), L. Kroll, P. Quintrand (E.A. Marseille), Th. Chastain (M.I.T.), C. Boyer (Princeton). Sections on: Design Conception and Reasoning Information Support Systems on Technology, Visual-Spatial Information Systems. Round Table (chaired by prof. S. J. Doorman): Design, Computers, Morality.

7. Conclusions

The work of the group, while being deeply theoretical and computational in outlook, remains devoted to the notion that practicing architects can improve both the quality of their products and the efficiency of their practices through an intelligent, rational and reflective approach to the design process.

RESEARCH PLAN / ONDERZOEK WERKPLAN

1994 - 1995 - 1996 - 1997 - 1998

COMPUTATIONAL DESIGN / ONTWERPINFORMATICA
DESIGN METHODS / ONTWERPMETHODEN

COMPUTATIONAL DECISION / BESLISSINGSINFORMATICA
DECISION METHODS / BESLISSINGSMETHODEN

COMPUTATIONAL MODELLING / MODELLERINGSINFORMATICA
MODELLING METHODS / MODELLERINGSMETHODEN

Computational & Methodological
Studies

D
C M S
D
L.A.B.

Laboratory
for
Computational
Design, Decision & Modelling Methods
for
Land-Use, Architecture & Building

Research Coordination:
Ir. P.P.van Loon, Universitair Hoofd Docent Bouwinformatica
Prof. A.Tzonis, Hoogleraar Ontwerpmethodieken
Dr. ir. A.Koutamanis, Universitair Docent Ontwerpinformatica

1 Project 1

Title:
Computational methods for project design and design management
Computer methoden voor project-ontwerpen en ontwerp-management

Projectleaders:
P.P.van Loon en C. Krebbers

Participating researchers:
E.Berkhout, R. de Graaf, B.Deeleman

Cooperations:
Vakgroep Bouwmanagement/Vastgoedbeheer
(prof. drs.ir. B. Menheere, prof ir. H. de Jonge)
Faculteit der Luchtvaart & Ruimtevaart Techniek
(prof. dr. ir. B. Mulder)
TNO-Bouw, sectie Technische Informatica
(ir. P.Kuiper)
TNO-Bouw, sectie Bouwproces-Informatie
(ir. M.Groosman)
VCA-Instituut voor Bouwinformatica
(ir. T. van Hoorn)
Harvard School of Architecture
(Prof. dr.ir.S.Polalis)

1.1 Objectives:

In this research project we shall defend the view that in architecture, building and urban development the present methodological (computational) premise of design is unsuitable for the present general occurrence of decentralised project design in these fields. We shall demonstrate that this premise is unfeasible as it does not include the following three essential characteristics of decentralised design:

- Decentralised design is based on parallel positions of authority.Parallel positions of authority are a special feature of decentralised design. Hierarchical design, however, is characterised by superior and subordinate positions of authority. In decentralised design the team members (both professionals and non-professionals) are equal partners, each with their own goals and means of achieving them.

- Decentralised design is based on individual decision areas. In decentralised design each member of the team is responsible for decision-making in his own particular area.
- Decentralised design is based on negotiation. Decentralised design involves a special form of negotiation. This in contrast to hierarchical design in which instructions are issued.

In this research project we shall develop a new methodological(computational) premise for project design which incorporates the three above features. In addition, we shall demonstrate that many of the existing design methods function effectively in design teams using this new premise.

1.2 Background and approach:

One of the most radical changes which has taken place in the fields of architecture, building and urban development over the past few decades has undoubtedly been the shift from hierarchic to decentralised design. Some 25 years ago, the design process in these fields was almost always headed by one, or perhaps several, professional designers. While these were usually architects, they were sometimes building design engineers or, in the case of large-scale projects, urban and landscape designers.

Today, however, a comprehensive design team consisting of all the parties involved in the preparatory work is responsible for the design process. In other words, parties other than professional designers now also have a direct influence on the design.

In recent years the new participants have acquired their own responsibility for a particular aspect of the design: the structural engineer for stability, the building services engineer for the installation systems, the building materials manufacturer for the building materials used, the costing expert for the prices, the traffic engineer for infrastructure, the urban planner for the allocation of land, the building contractor for the construction work, the investor for funding, official bodies for standards and technical specifications and the user for the functional requirements. It is clear that professional designers have less influence than was formerly the case, the other participants often allowing them only to design the form and plan of the building and the site.

During a cooperative process within a design team, all parties put forward their ideas, alternatives and combinations of alternative solutions are discussed and evaluated and the best possible solution selected. Team design in architecture, building and urban development has come to be what is known in political and management science as a multi-actor' or 'multi-party' negotiation and decision-making process.

2 Project 2

Title:
Computational methods for design, decision and modelling
Computer methoden voor ontwerpen, beslissen en modelleren

Projectleader:
A. Tzonis en P.P. van Loon

Participating researchers:
R.Noordzij, S.Inanc, A. Angulo, A. Bridges

Cooperations:
Faculteit Wiskunde en Technische Informatica
Association for Education in Computer Aided Architectural Design in Europe (ECAADE)
University of Strathclyde (Scotland)

2.1 Objectives:

In this research project we shall outline the framework within which we are to reflect upon computational design methods, using basic concepts and definitions. This framework serves first and foremost as a simple way of representing and modelling design. It should also enable the methodological characteristics of design to be set out in a way that allows evaluation of the suitability of existing design methods (and individual aspects of those methods) for use in the design process. Finally, it should be possible to incorporate past experience into the framework, and to generalise and summarise it so that it can benefit the further development of design.

We shall include in the computational design framework both the individual decision-making process and the group decision-making process.

Classic decision-making theory often assumes that both processes are structured in the same way. If one assumes that a group of decision-makers within an organisation is in fact a hierarchy of individuals, their decision-making process can be defined as a logical series of individual decisions. The decision made by each individual must always fit in with the decision of the individual who is above him in the hierarchy. Since each individual makes consistent decisions, the group also decides consistently, as if it were one fully informed, rational individual.

This classic theory takes little account of the processing of differences of opinion and conflicting goals, to power imbalances and lack of information and rationality. These issues certainly come into play in design processes involving several individuals and organisations. We shall therefore use decision-making models which incorporate differences of opinion and power imbalances, and which cope with insufficient information. These models occur mainly in political science (the study of, among other things, decision-making in representative bodies, such as parliament and local councils) and negotiation theory.

2.2 Background and approach:

A large number of innovations in design methods were introduced during the last 25 years. They began at the end of the 1960s with what was known at the time as 'systematic design'. The design activity was divided into a logical step-by-step procedure, with each step being given rational consideration. The designer had to work only with the information which was 'known'. Separate systematic methods were developed for each step (Foque,1975, p.118; Jones, 1970; Alexander, 1964).

This was directly followed by a second wave of new methods known as the 'interdisciplinary' approach. In the interdisciplinary approach tasks were also split up, but now among those involved in the design. This took place under the pressure of growing specialisation in knowledge and skills. The split took place along the lines of the various disciplines cooperating in the design team. Even then, cooperation was an important precondition for tackling difficult and complex commissions. The new methods were directed at improving this interdisciplinary communication. (Foque, 1975, p.61; Jones, 1970).

Around 1975, a third wave of innovations occurred which related to 'project design'. This wave was influenced by the new views on management and teamwork prevailing at the time, particularly those relating to ad hoc cooperation and non-hierarchic working relations among specialists. New design methods tailored to the unique nature of each design commission were developed. A new design team had to be brought together for each project and each team had to follow a design method for that specific project.(Mintzberg, 1979; Bennett, 1991; Wijnen et al. 1984).

The last innovations took place towards the end of the 1980s with the emergence of computer aided design (CAD). This fourth wave of innovations is still in full swing. The micro computer and the personal computer have made it possible to use two and three dimensional drawing techniques for the purposes of cooperation and communication within a design team. CAD techniques still have a great deal of potential in the field of the methodical improvement of design, particularly as regards managing the complexity of design projects (Bijl, 1989; McCullough et al., 1990; Pipes et al. 1985).

These new methods regularly come in for criticism both from the professional designers and from the other participants in design teams, particularly the non-professionals such as users, principals and politicians. The main criticism was mainly of the technocratic and rational design that went with the new methods. Even those whose specific task it was to introduce the new design methods were critical; the new methods were too rigid and often too complicated to lend themselves to teamwork.

3 Project 3

Title:
Computational methods for building design, architectural design and land use planning
Computer methoden voor bouwkundig ontwerpen, architectonisch ontwerpen en stedebouwkundige planning

Projectleaders:
A. Koutamanis en P.P. van Loon

Participating researchers:
S. Micheels, E. Wilms

Cooperations:
Vakgroep Architectuur
Vakgroep Stedebouwkunde
Faculteit der Civiele Techniek
Faculteit Industrieel Ontwerpen

3.1 Objectives:

We shall deal in this research project with the computational design methods for building, architecture and urban development from the individual points of view of all the parties involved in the process: principals, investors, owners, experts, officials, builders, users and residents. This is possible only if one assumes that the parties involved have their own standpoints in the form of a collection of definable goals, that they will endeavour to achieve those goals and that they will adjust their actions and decisions during the design process to serve those goals.

From the individual point of view the design process takes place between all the individuals involved and it can therefore be described as an inter-individual process. However, as individuals are usually part of an organisation (the body commissioning the project, the design firm, the structural engineering firm, the owners of a building, the users' organisation etc.) and as they usually participate in the design process in that capacity, it is more accurate to speak of an interorganisational process.

3.2 Background and approach:

Assessment from an individual point of view is uncommon in the field of design methods. Design is usually assessed only from the point of view of the official principal. The question of how the design process is to be conducted and how the team is to achieve the principal's goals is examined.

The underlying assumption is that the team is made up solely of experts, each of whom is capable of executing his particular part of the design process in harmony with the others. This assumed harmony is possible because consensus is expected on how the design commission is to be carried out. Furthermore, it is assumed that the design process will proceed according to a specified schedule and allocation of tasks which have been derived from the commission. The views of the user, as the third important party involved, will be considered only when the design is ready and has been approved by the principal. At that stage they can do no more than accept or reject the design.

This view of the design process reflects a hierarchical 'linear' structure with respect to the cooperation between principals, designers and users.

However, from the individual points of view, cooperation in a design process does not take place in a hierarchical structure but in a flat 'matrix' structure. This is based on the idea that it is not only the experts who are responsible for the design, but that all the parties involved contribute. Thus, principals, professional designers and users together form the design team, all pursuing different and often conflicting goals. Naturally, these individuals can operate in sub-groups within the process: e.g. users' interest groups, experts from a particular department, a consortium of investors etc. All this means is that a number of individuals have grouped their goals to form one set of common goals and that they will attempt to achieve these goals as a group.

Discussion of the individual point of view will be based on 'methodological individualism', which is a concept in economics and, more specifically, in the economic theory of political decision-making (Van Den Doel, 1978). The view that a group of people working together form one independent entity is replaced by the view of the group as a collection of individual sub-groups producing something for another collection of individual sub-groups, who may or may not be working together.

In methodological individualism it is out of the question that the group which produces something together has its own responsibility for taking decisions for others, but rather individuals and sub-groups of individuals working together have special authority which enables them to take decisions for others and renders them accountable (Van Den Doel, 1978, p.20-21).

Methodological individualism is becoming increasingly relevant to team design. The growing complexity of design commissions has made it impossible for professional designers to decide alone what is relevant to achieving the (individual) goals of all the parties involved.

We should say at this stage that the individual approach cannot be applied to all design teams. The view of the various conflicting interests is less relevant to teams designing products for individual consumption the use of which will have no effect on non-users and which therefore do not have to be taken into account in the design process. However, if a team is designing a public utility (with one or more user and affecting non-users too) then, as we wish to demonstrate in this research project, the idea of individual interests provides a great deal of insight into the design process in general and into the fields of architecture, building and urban development in particular.

Alexander Koutamanis (koutamanis@bk.tudelft.nl)

Psychology and design research

Ronald Hamel
(Faculty of Psychology, University of Amsterdam)

A brief account is unavoidably superficial in one way or another. I will try to describe adequately the questions my research addresses, the importance of these questions, the data I gathered in order to find answers, the conclusions drawn, and the references. As a consequence, I will not mention many details, although these are important to understand the design of the experiments, the analysis of the data, and the conclusions that are drawn.

A model of the design process

Psychology regards designing as a distinct category of cognitive behavior (Simon, 1973). It is only rather recently that the differences between design problems and other kinds of problems have been outlined (Goel & Pirolli, 1989). Design problems have a number of features that are not shared by other problems. One of the most important is that design problems need extensive structuring. In order to structure a problem one has to gather and use information. This information stems from various sources. My first involvement in design research consisted of studying the intake and processing of information during the design process (Hamel, 1982). Soon, however, it became evident that I needed an empirically based description of the design process to be able to study the use of information by architects.

At that time many models of the design process were proposed (for example, Broadbent, 1973; Foz, 1972; Jones, 1970; Lawson, 1980; Wade, 1977; Zeisel, 1981), but these were meant as normative models describing how the design process should look like. No descriptive theory or model was available that was tested against empirical data. In my opinion the normative models contained valuable notions about the structure of the design process, its components, and the relations between these. I set out to study the design process of architects. The task analysis for my model was based upon the literature, the curicula in architectural design in the Netherlands, the description of the process by the Organization of Dutch Architects, and 15 structured interviews with practising architects. The model also incorporates the outcome of a psychological analysis of the possibilities and the boundaries of the human cognitive system pertaining to the task of designing.

Designing is regarded as a kind of problem solving. Problem solving is the execution of cognitive actions upon information. This information has to be active in memory, in other words, the spotlight of attention has to be cast on it. On the one hand, the information may concern the problem itself and the state it is in. This is information about 'what', it is called declarative information. On the other hand, the information regards the regulation of the design process. This is information about 'how', it is called procedural information. My research firstly concentrated on the design process, its components and how these are related to each other. Thus, the model describes the cognitive activities of experienced architects during designing. It was tested against data of 15 architects gathered during designing. They all worked on the same assignment. To test the model the data had to reflect the information that was attended to during problem solving. Therefore, the subjects were instructed to design while verbalizing everything they thought and did. The verbal protocols were analyzed together with other data like notes taken, sketches made, and a record of observed activities. After the analysis of the data it was concluded that the model is an adequate description of the design process with regard to its components as well as to the relationships between them. It consists of three domain specific components: analysis, synthesis, and moulding. Each of these has three domain independent components: orientation, execution, and evaluation (Hamel, 1990; Hamel, 1994). The model describes the design process, but it does not represent the development of the information about the design problem during the process. The next project to describe is aimed at the study of precisely this development.

The project was initiated at the Faculty of Philosophy and Social Sciences of the Technological University of Eindhoven with the collaboration of Willem A. T. Meuwese. It was further conducted at the Department of Psychonomics of the Faculty of Psychology of the University of Amsterdam in collaboration with Jan J. Elshout. Jan J. Elshout is professor of psychology, his background is cognitive psychology and psychology of intelligence and expertise. Ronald Hamel is assistant professor of psychology, and has a background in cognitive psychology and environmental psychology. Willem A. T. Meuwese is emeritus professor of psychology, and his background is cognitive and educational psychology.

Problem solving consists of both understanding and search

In everyday language, the knowledge about a problem one is trying to solve is: everything one is able to tell about the state the problem is in. The knowledge one can verbalize about a problem reflects how well one understands the problem. Since the knowledge about a design problem develops during designing, the study of the descriptive information that is active during designing should have a double goal: firstly it has to account for the development of knowledge during problem solving and secondly, it has to account for the interaction of the development of knowledge with the cognitive activities that constitute the process. The task of designing involves the manipulation of a vast amount of knowledge. This knowledge stems both from memory and from external sources. To study the development of knowledge during designing may turn out to be very difficult, because one has to account for prior knowledge. And of course, designers differ regarding their prior knowledge. Therefore, it was decided to firstly make an attempt at the study of the development of knowledge during problem solving with a task for which every subject's prior knowledge is the same. This task is a puzzle that is novel to the subjects, therefore at the outset they all operate at chance level.

The puzzle is presented on a computer. Its solution can only be attained by one sequence of moves. The moves are constrained: a move is only possible if a set of criteria is met. These criteria are represented in the pattern the subject sees on the screen. The subject has to learn to discriminate between patterns that fulfil the criteria and patterns that do not. The difficulty of the task resides in the fact that it can only be learned by trying moves. Unfortunately, if a try succeeds, the pattern changes. This makes learning very difficult. Subjects typically need hundreds of attempted moves before they reach the solution. We gathered two kinds of data. Firstly, a record was kept by the computer of every attempted move, together with its outcome, the state of the puzzle, and the time per attempt. Secondly, our subjects worked on the puzzle thinking aloud. The verbal protocols are data reflecting the information the subjects' attention was focused on.

Looking at the move records, one gets a strong impression of a long period of muddling on in which no progress seems to be made followed by a short and rapid rush towards the solution. It seems as if nothing happens until some insight makes the solution possible. However, when the verbal protocols are analyzed together with the move records, we see a gradual development of knowledge about the puzzle throughout the whole process. Simple constraints are verbalized before the more complex and underspecified knowledge precedes fully specified knowledge, but on the other hand, misconceptions are not abandoned altogether. The move making process itself also develops during working on the puzzle. The study (Hamel, 1994 October; Hamel, Elshout, Frie, & Jaarsveld, in preparation) clearly showed that the process of problem solving consists of two cooperating processes, search and understanding. Tentative search (move attempts) leads to a better understanding (knowledge about the puzzle), while at the same time a better understanding leads to better search. The relevance to design research is clear. Designers often express as an observation from their own daily practice that an assignment or a design problem is only fully understood once a design is produced. From this it can be inferred that designers too develop knowledge about a problem during the design process. Yet, for a good design a good understanding of the problem is necessary. The development of the understanding can be promoted by presenting designers with information. This presentation has to be in line with both the stage of the process and the level of understanding.

These studies are conducted at the Department of Psychonomics of the Faculty of Psychology of the University of Amsterdam in collaboration with Jan J. Elshout, and also with the assistance of the students: Liesbeth Bakker, Lonneke Frie, Saskia Jaarsveld en Natascha Weitenberg.

The task of the construction planner

I am involved in a research project of the Faculty of Architecture of the Technological University of Eindhoven that aims at the development and testing of a process model of the planning process of the construction planner. I collaborate with Ger Maas who is the supervisor of the project, and with Eric Vastert. The PhD student who is conducting the research is William Stockings. To me this project offers the opportunity to test the descriptive model of the architectural design process in a different domain of design: construction planning.

Ger Maas is professor of architecture, his background lies in construction and construction planning. Eric W. Vastert is assistant professor of architecture, and has a background in construction and construction planning.

Sketching in the design process of industrial designers

What is the role of sketching in the design process? Does sketching enhance the quality of solutions? Do abilities of the designer, like general intelligence, visual abilities regarding imagery and perception, and creativity, influence the usefulness and quality of sketching? Does expertise influence the usefulness and quality of sketching? These are questions Ilse Verstijnen tries to answer in her PhD project. Jim Hennesey supervises the project, and I collaborate with him an with Wim Muller.

Jim M. Hennessey is professor of industrial design, and is head of the IDEATE Project at the Faculty of Industrial Design of the Technological University of Delft. Wim Muller is assistant professor of industrial design.

The representation of characteristics of visual images

If a subject is presented with a simple linear pattern, he or she is readily able to decide if the pattern has a characteristic like parallelism, continuation, symmetry, or one of several kinds of junctions. Are subjects able to make the same decisions without the pattern in front of them, on the basis of their memories, in other words on the basis of mental images? An answer to this question is interesting for design research, because it is likely that the information which is active during designing is at least partly pictorial, and thus partly consisting of mental images. An answer puts us in a better position to face the problem of the mental manipulation of images.

Romke Rouw, a student who is under my supervision, is conducting this study under the daily supervision of Stephen Kosslyn at Harvard University. Stephen M. Kosslyn is professor of psychology, and has a background in mental imagery and cognitive neuroscience.

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DESIGN MORPHOLOGY GROUP

Eindhoven University of Technology, Faculty of Building and Architecture, Department of Architecture and urban Planning
P.O. Box 513, 5600 MB Eindhoven, The Netherlands

Roel Daru, Senior Lecturer, Design Morphology

OBJECTIVES

• SCIENTIFIC: better understanding of the generation of built forms, their description, evolution, intentional and esthetic expression and experience, meaning and use,

• PRACTICAL: the development of tools for the generation of built forms and the heuristics for obtaining them.

INTERESTS

• working more on the side of the production of forms than their reception, but with a definite interest in both,

• enhancing an explorative approach but making use of strict research methods, without losing sight of the hermeneutic tradition,

• redirecting efforts onto the pluralistic styles of designing as an alternative to pursuing an unifying model of the design process,

• developping and testing specific simple, focused and if possible generic tools adaptable to various design situations and modelling them to specific personal working styles, as an alternative to technologically 'heavy' tools.

ACTIVITIES

(development of the field as reflected in the activities of the group)

• PAST (1): form perception (geometric and arithmetic proportions)

• PAST (2): form description and (re)presentation

  * Symbolic (morphographic and morphometric descriptions),
  * Analogic (spatial and stylistic conformations),
  * Iconic (geometric and genetic descriptions).

• PRESENT: form reception and generation

  * Reception (analogic form and pattern recognition),

* Generion (styles of designing and 2D form generation in the sketch design phase, based on the symbolic, analogic and iconic principles of form description and (re)presentation),

• FUTURE: form generation, reception and logics of prescriptive rules

* Generation (personality dependant tactics of designing and 3D form generation in the sketch design phase, also for group processes),
* Reception (analogic and iconic form and pattern recognition),
* Logics (non monotonic design thinking: abduction and adduction)

ISSUES

• which aspects of the design process should be supported to stimulate effective design of high quality buildings?

• is designing the same activity accross all domains of designing? (architecture, industrial design, mechanical engineering, graphics, etc.)

• are design tools developed for one domain transferable to another?

• are design tools adaptable to the individual personality, heuristics and working styles of designers?

• is canned, pre-packaged design knowledge useful during the early phases of the design process or rather in other phases (i.e. evaluation)?

• what is design knowledge? (information, heuristics, attitudes, experience, imagery, etc.)

• can we develop design tools which inspire designers enough to apply them in daily practice? Can certain design tools hamper the creativity of the designer?

• what is so special about using computers in the design process?

• was Marshall MacLuhan right after all? (the medium is the message/massage),

• in the past decade, the end-users of buildings has been forgotten in favour of the expression of the designers' views translated in bold forms, is'nt it time to get them back into focus?

• how can the designed characteristics be made measurable as a basis for objective comparison?

STAFF

- Professor Visual Arts and Architecture: Jean Leering
- Senior Lecturer Design Morphology: Roel Daru
- Lecturer Design Morphology: Tom Dubbelman
- Technical staff member: Ton de Caluwe
- PhD candidates and post-graduates (see reearch projects)

INTERDISCIPLINARY COLLABORATION

Many of the projects named hereafter have been the result of interdisciplinary collaboration, combining design background, psychological and computational knowledge within and without our institution, in particular with the universities of Delft, Nijmegen and Tilburg. Tools have been tested and assessed in practice.

TYPICAL PhD RESEARCH PROJECTS

(published by 'Bouwstenen': the scientific press of the faculty)

- Wim Adams, 1991: 'SUPPORTING DECISION MAKING PROCESSES, a graphical and interactive analysis of multivariate data' (about datagraphics and the perception of proportions; the perception of the plastic-number series of Dom van der Laan empirically supported),
- Anton van Bakel, 1995: 'STYLES OF ARCHITECTURAL DESIGNING' (about identifying and assessing personal preferences in architectural working and product styles for didactical design management),
- Martin Veenendaal, 1996: 'DATAGRAPHICAL HEURISTICS' (as a logical follow-up of Wim Adams' research, is about the cognitive underpinning of the perceptual and predominantly heuristic aspects of pattern forming and recognition),
- Philip Snijder, 1998: 'SKETCHER' (about probing the support of conceptualisation by very fast automatic, but constrained sketching and exploration of the results by the designer, employing evolutionary programming techniques),
- (P.M.) Piet Venemans, 1997: 'PREVENTION OF DESORIENTATION BY ARCHITECTURAL DESIGN' (about the influence of geometric and topological spatial structure for way finding and how this knowledge can applied in the design process),

TYPICAL POST GRADUATE RESEARCH PROJECTS

(published by TUE IVO: Institute for Continuing Education)

- Hugo de Haan, 1992: 'ELECTRONIC SKETCHING IN THE DESIGN PROCESS',
- Phil Winteraeken-Bruls, 1992: 'RAP, GIOS AND ROP IN THE HOUSING PROCESS OF THE GOVERNMENTAL BUILDING AGENCY',
- Jianping Li, 1993: 'ROP AND SPACE, comparison of the building layout programs with two case studies in architectural design',
- Cristian Popescu, 1993: 'THE USABILITY OF ROP TO SUPPORT FACILITY SPACE PLANNING',
- Piet Venemans, 1994: 'ORIENTATION WITHIN BUILDINGS: TOWARDS A DESIGNTOOL',
- Joost Burger, 1994: 'IMAGE EXPECTATION IN THE INITIAL PHASE OF THE BUILDING PROCESS',

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The Eindhoven School for Technological Design IVO

Henk M.G.J. Trum
Institute for Continuing Education,
Eindhoven University of Technology, Eindhoven, The Netherlands

0. INTRODUCTION

Eight years after starting two-year post-graduate programmes on technological design[1]), Eindhoven University of Technology (EUT) is about to enhance the development of synthesis-oriented engineering education by establishing a post-graduate school for technological design. The new school will be an interdisciplinary cooperation of all eight faculties of EUT, in which the ten two-year full-time post-graduate design courses of the Institute for Continuing Education IVO will be accommodated with about 350 post-graduate students. Over 400 students already earned their designers' certificate. The school will comprise a design research centre where fields of knowledge, relevant for technological design, such as design philosophy and methodology, design instrumentation and design learning and teaching, will be elaborated. The main new task of the school will be to stimulate young designers - working on a design task in close cooperation with industry - to earn a doctorate (Ph.D.) by devising and defending a doctoral design.

1. DESIGN EDUCATION

Unlike traditional university programmes, the design programme was originally proposed by the Dutch employers' organisation RCO[2]). In 1985 the industrial employers urged the establishment of a two-year post-graduate programme in technological design in high-tech areas[3]). The employers' major goal was to bring design education into regular university engineering programmes.

In the last decade the industrial, educational and public interest for design has grown remarkably. Technological design is considered essential for the international market position of The Netherlands. The design programme has to set international standards, as this is the level on which Dutch industry has to compete. The design school should contribute to attaining and holding the required level.

The design programme at Eindhoven University of Technology started in 1986 in the Institute for Continuing Education (IVO-TUE). The emphasis in the design courses is on acquiring and practising skills for finding technological solutions to problems in complex high-tech areas. Since designers have to be specialists in one of the skills of their own trade and should also be able to get a quick insight into their colleagues' activities, both a high specialization and a broad orientation in technology are needed. The design courses incorporate interdisciplinary work in teams, creativity, modern design techniques, cost-accounting, manufacturability, design methodology, design strategy, quality, managerial skills, communication, presentation of ideas, both orally and in writing.
Basically, a course consists of two parts: one year of lectures and practical training, and a second year on a supervised design task in industry. As all courses are principally multi-disciplinary, several EUT faculties participate in each course, some in cooperation with other universities or on an international university-industry level. Students are admitted through a highly selective process. Once in the programme, they are appointed by the university as assistants-in-training and receive a modest salary.

The post-graduate programme on technological design comprises courses in the following design fields[4]):
- Computational Mechanics;
- Computer-aided Design and Manufacturing of Discrete Products;
- Architectural Design Management Systems (in preparation);
- Information and Communication Technology;
- Logistic Control Systems;
- Mathematics for Industry;
- Mechatronic Design;
- Physical Instrumentation;
- Process and Product Development in the Process Industry;
- Software Technology.

2. DESIGN RESEARCH

The new school will provide the opportunity to stimulate, coordinate and perform research activities in fields that are considered relevant for the further development of the technological design programme. The research centre will start up this year with design research in at least three fields:

- design philosophy and methodology, including ethics;
- design instrumentation: domain specific and generic design tools, methods, strategies;
- design learning and teaching: design education, adult education.

For scientists the centre will function just as research schools in other fields. It will also provide the possibility for young graduates to earn a doctorate in one of the research fields of the centre.

The first research projects of the Design School are:

• **Towards a multi-disciplinary framework for design**
Aimed at inventarization, description and modeling of issues related to the provision of a multi-disciplinary framework; identification of generic design methods and rules; of the specifics of the different design disciplines. Some aspects of a multi-disciplinary framework are: multiple design dimensions, based on generic high-level frameworks to partition the design space (as provided by e.g. Domain Theory); project management for complex artifacts; simultaneous modeling of static and dynamic system properties; process-oriented design. The research concentrates on design methods, and involves project management methods, tools and environments.
Theme: Design Methodology - Faculties: Mathematics and Computing Science; Architecture, Building and Planning; Philosophy and Social Sciences.

• **Design History Information System**
Aim of this project is to develop an integral system for archiving and accessing the information, occurring in a design process. A structured system will allow easy acquisition and retrieval of vital design information. The system, in which the whole design process is being archived, can be used for supporting the individual designer as well as the design team. Re-use of the design information will accelerate the design process and increase the product quality.
Theme: Design Instrumentation - Faculty: Mechanical Engineering.

• **A design method for implementing sequential machines with limited building blocks and limited communication channels**
The project aims at the development of an effective and efficient

design method for implementing sequential machines with limited building blocks and limited communication channels between the building blocks, and to design and implement a prototype CAD tool which automatizes this method. This design method will be based on the theory and methodology of general decomposition.
Theme: Design Instrumentation - Faculty: Electrical Engineering.

• **Design learning and teaching, design education**
It is necessary to pay attention to the difference between educating students for research or for design. For the understanding of these differences and their implementation in the school it is essential that some research is done in the field of educational psychology. It is clear already that, considering the age of our post-graduate students, inspiration must come more from the field of adult education and andragogy than from the field of pedagogy.
Theme: Design learning and teaching - The project will be carried out by a working group of internationally invited experts.

3. A DOCTORAL DEGREE FOR DESIGNERS

It is the task of the design school to stress the specific features of design as a distinct, full-fledged species of practising technical sciences with specific characteristics[5]): aimed at synthesis instead of analysis, directed at knowledge of the specific, unique artefact in its environment instead of discovering general laws of nature; engaged in conceiving the not-yet-existing instead of explaining observed phenomena; involved in the realisation of a desired future instead of the description of today's reality. Neither design tasks, nor their results are limited to the boundaries of scientific disciplines. Though design in many respects differs basically from research, the design programme is essentially a scientific programme.
The doctor's degree is the societal distinguishing mark of scientific maturity. For those who practise technical sciences as a designer a doctor's degree should be attainable. Dutch legislation recognizes this way of earning a doctoral degree: by devising a doctoral design. For the design school doctorates on design are of importance, as they lead to developing and establishing criteria by which a "good" design can be judged. This is essential for the quality maintenance of the design programme. A doctorate by design should have the following characteristics[6]):

The doctoral student shall provide evidence of being able to practise science by creating technical solutions for products, systems and processes, starting from functionally and commercially determined demands. Such shall be attained through a methodic approach with the following characteristics:

- the client's objective should be concretized into measurable and verifiable specifications;
- with adequate scientific, technological and domain-specific knowledge, a concept for the product or system should be devised, principally based on existing knowledge and techniques;
- this concept should be checked against the set of requirements and be concretized within a previously set time limit.

So as to give evidence of his professionality the doctoral student should prove of being able to plan the complete design process, to compose the design team and to decompose the design task in such a way that participants can work out partial design tasks simultaneously or sequentially. He or she shall give evidence of being able to function in a multi-disciplinary design team. A doctoral design should be presented in any adequate form that - for that type of design - is common in industry. Preferably the designed artefact should be demonstrated at the doctoral degree ceremony.

A doctoral design comprises the description of the artefact devised; of the design process as it was originally planned and eventually carried out; and (if necessary) of the research carried out to acquire new knowledge which is indispensable for the design task. The design should meet general scientific demands: inter-subjectivity, reliability, verifiability. A profound study of one aspect (cf. research) is not sufficient.

The required description of a designed artefact comprises:

1. Analysis and specification of the design task;
2. Results of testing the design against the initially specified requirements. The synthesis of all properties the artefact should have, is emphasized.
3. Evidence of the quality of the artefact as a means to attain the objectives[7] (as far as relevant for the case considered):
   - properties concerning performance, functioning, effectiveness, utility (in the physical, physiological and psychological

sense, e.g. user-friendly, easy-to-handle); wanted and unwanted side-effects, etc;

• properties concerning the makability; material, energy and information needed for manufacture, type and means of production, types of work and workers needed, required educational level of production personnel, etc.;

• properties concerning the lifespan: stability, solidity, robustness (also against unintended use), safety, reliability, reparability, maintainability, etc., including effects of demolition, storage, residue, waste production, pollution, environmental stress, re-use, recycling, etc.;

• properties of the artefact as a successful commercial product on the market: vendibility, price, customer's requirements, warranty, patents, licenses, investments, development-, production-, exploitation costs, etc.;

• properties concerning society requirements: manageability, control (what social groups or individuals have what type and degree of control over the artefact: property, rent, lease, etc.), type of management, desirability, acceptability, effects of large-scale use, influence on individual and social behaviour, comply with laws, rules, regulations, norms, standards, etc.

• formal (morphological) properties: structure, composition, (anatomy, in informatics and electronics: "architecture"), the artefact as a system, composed of parts, the artefact as a constituent part of its environment;

• static and dynamic properties (temporal/procedural): changeability during the life-cycle, adaptability, the artefact as a stage in a process of development or as a final stage; intermediate stages in the design process, etc.;

• properties of the artefact concerning the professional organisability of design, production, use, demolition.; manageability related to professional codes and ethics, social responsibilities of professionals (deontology), etc.;

• properties concerning the scientific relevance of the artefact: application of knowledge, the artefact as a source of new knowledge, as a hypothesis, as a touchstone of knowledge, etc.;

• aesthetic properties: the symbol or sign function of the artefact, as an intermediary between the impression of the beholder and the expression of the maker, the artefact as a "work of art";

- properties concerning the embedment of the artefact in the ecological system: environmental stress, consumption of materials, energy, emissions, toxicity, residue, (in all stages, including production);
- properties concerning the embedment of the artefact in the cultural and geographical context: adjustment to and compatibility with other cultural expressions of society.

Principally, the school shall stimulate that a doctoral design will start as a regular design project in the second year of the design programme. Teachers select suitable projects for students who want to complete their design education with a doctorate. Preferably, projects in or assigned by industry will be selected. The principal should agree that the design task is worked out into a doctoral design and enable the student to do so by allowing him to use the firm's design facilities. Industry is the eminent environment experienced in judging design work. Therefore, the opinion of industry in judging a doctoral design is highly appreciated.

Doctorate design projects being presently carried out:

- **Design of a high-precision spindle, based on an active axial bearing**

The aim of this project is to develop a spindle for high-precision diamond turning. The concept is based on an active axial spindle bearing, using a voice coil actuator, a position measuring system and a controller system. With respect to the current spindles, this concept has to lead to a higher axial stiffness and a smaller axial error motion of the spindle. The spindle must also have the capability to fabricate non-rotationally symmetric optical surfaces, by controlled axial movements of the spindle.
Design field: Mechatronic Design. - Combined project between industry, Philips Research, and Eindhoven University of Technology.

- **Large scale continuous flow membrane-electrophoresis**

The prospects of large scale continuous flow membrane-electropho-

resis are studied with the aim of separating proteins and enzymes from biological suspensions. The study comprises the formulation of a general model which describes fluid dynamics, heat generation and transport of charged components in an electric field. This model will be verified experimentally in different electrophoresis cell configurations and in case of different experimental conditions. Finally, the model is used for simulations to deduce optimal scale and operation of the membrane-electrophoresis cell.
Design field: Process and Product Development in the Process Industry. - The project is carried out at the Faculty of Chemical Engineering in cooperation with industry.

• **Geometrical optimization of lip seals for reciprocating shafts**
The aim of this work is to be able to create new or improve existing seal designs with a for practical seal design applicable design method based on existing theoretical knowledge about the sealing and lubrication mechanism. The main result of this work will be a new seal design procedure, in which seals can be judged on leakage and friction in the design stage resulting in an optimal, new or improved seal geometry for a certain given set of demands and operating conditions.
Design field: Computational Mechanics. - Combined project between industry, PL Automotive, and Eindhoven University of Technology.

• **Data synschronised parallelism in High Energy Physics software development**
Design and realisation of a software engineering environment to support the development life cycle of parallel programs aimed at the rapid analysis of huge amounts of data taken during High Energy Physics (HEP) experiments. Two tools wil be added to the existing environment, providing facilities for testing, debugging and performance tuning of parallel programs: a tool which visualizes the behaviour of the program execution, and a tool which allows interactive analysis of different processor-to-processor allocation strategies. Moreover, the project will yield a set of general design criteria for parallel HEP event reconstruction programs.
Design field: Software Technology - The project is carried out at CERN, Geneva.

• **On-line parallel HEP event reconstruction using real-time data-bases on massively parallel platforms**
Design and realization of an on-line parallel HEP event reconstruction software system, which uses a high performance real-time parallel database. The amount of data produced by HEP experiments is in the order of Gigabytes or Terabytes. On-line reconstruction means that the events are reconstructed at the moment they are produced. The project will also result in a set of general design rules for constructing on-line parallel event reconstruction systems, aimed at a more structured and easier to maintain HEP software. One of the major design demands is flexibility: with minor changes, it should be possible to use the system in several different HEP experiments.
Design field: Software Technology - The project is carried out at CERN, Geneva.

• **Design of a VLSI circuit for lossless data compression and decompression**
The sliding window algorithm with Huffman coding is chosen for its good compression ratio. A hardware implementation can be more than a 1000 times faster than software. A good trade-off between speed and chip area must be made. The design must be flexible so that it can be used for many variations of the chosen algorithm.
Design field: Information and Communication Technology - The project is carried out at the Faculty of Electrical Engineering.

• **3-Dimensional Imaging Radar**
Applying ISAR (Inverse Synthetic Aperture Radar) allows accurate target identification provided that a physically large aperture and sufficient bandwidth are available. For unknown motion patterns, motion compensation algorithm must be applied first. A new system based on an interferometer radar and advanced tracking algorithm provides motion compensated data in three dimensions. The latter results in 3-dimensional ISAR capabilities and improved identification performance. Various applications are foreseen, i.e. air traffic control, robotics or medical applications.
Design field: Information and Communication Technology - The project will be carried out at the Faculty of Electrical Engineering in close cooperation with industry.

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Telephone +31 40 47 24 52, Telefax +31 40 44 51 87,
E-mail ivaaje@ivo.tue.nl.

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