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Editors

Design Research in the
Netherlands 2000

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Design Research in the Netherlands 2000

24-25 May 2000, Eindhoven University of Technology

Edited by:
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Design Research in the Netherlands 2000

Introduction

The first Design Research in the Netherlands symposium was organised in 1995, with the specific aim to offer a forum for academics active in the widely varied field of design research. People studying architecture, industrial design, mechanical engineering, computer science, etc. took part in this meeting. In 1997, a follow-up with an accent on design education was organised under the title "Design Education in the Netherlands." On that occasion, design disciplines with a less research-oriented approach such as fashion design and graphic-design participated in the symposium as well.

We are proud to present the proceedings of the second Design Research in the Netherlands symposium, which took place on 24-25 May 2000. Again, the aim of the symposium was to gather academics in the field to discuss their research methods, findings, approaches, and positions. The organisers were very happy to have Mark D. Gross as keynote speaker for the symposium. Mark Gross has been involved in architectural design support with computer tools. His early work has been with, among others, John Habraken at MIT. Research areas include graphic constraint-definition, diagrams, concept design games, and user interfaces. The "Cocktail Napkin" project received widespread acclaim in the human-computer interaction for design field. Mark Gross is currently Associate Professor at the University of Washington, Seatle, where he directs the Design Machine Group.

Proceedings

These proceedings include two additional papers with respect to the preprints. The paper by Ad den Otter on information ecologies was presented at the symposium, and the paper by Beheshti, Tolman, and van der Veer was submitted afterwards to provide an overview of the Design and Building Informatics Group of Civil Engineering in Delft.

The articles included here are by no means a complete overview of all the design research activity that takes place in the Netherlands. To name a few, the departments of Structural Engineering, Computer Science, and Curriculum Development at Twente University, the Artificial Intelligence group of the Vrije Universiteit Amsterdam, and most design schools in higher education. Furthermore, there is an ongoing interest within industry to reflect about design and good design practice, although these findings are typically not communicated externally. Nevertheless, the papers gathered here provide a provisional map of design research activity in the Netherlands.

Four themes

Contributions to the symposium came from the following disciplines: Architecture, Civil Engineering, Technology Management, Industrial Design Engineering, Aerospace Engineering, and Information Technology. The papers have been organised into four themes: Theory, Process, Representation, and Computation. These themes are not absolute categories; they serve to identify main issues that are dealt with in the various papers.

Theme 1: Design theory

Design theory aims to provide a general framework within which design can be studied or results from research to be interpreted. Like design methodology, the results can be descriptive studies of design as it happens in practice, experimental set-ups or prescriptive studies of how design should happen and how the process should be organised. Generally speaking, design theory also deals with the appropriate (knowledge) structures for design. The first two papers touch on a basic question in the field: is it possible to make a general description of design that holds for all design disciplines, while being specific enough to be of value in any of these disciplines? The second set of three papers in this theme specifically focuses on the discipline of architectural design.

Beheshti, in his paper "Domains of Design Research", aims to provide a comprehensive map of the field in order to chart all advanced technologies that can be utilised in the design process. He first sets up a general structure and then subdivides design tools into the following categories:

1) General application tools that help with decision support.

2) General application tools that help describe specific aspects of design.

3) Basic tools for processing information.

4) Basic tools for reasoning about design.

The resulting taxonomy is of particular importance for exchanging experiences and research on advanced technologies among the various design disciplines.

Van Aken's motivation for a general theory of design lies in providing a context-free design theory for the Postgraduate Design Engineer studies in Architectural Design Management Systems (ADMS) at Eindhoven. ADMS falls under the Stan Ackermans Institute, which houses several studies for different disciplines. In his article, "Domain Independent Design Theory", van Aken distinguishes between three kinds of design:

1) The design of the design process itself.

2) The design of the object.

3) The design of the realisation process.

In particular the design of the design process has van Aken's special attention.

Bax and Trum are, as van Aken above, interested in designing the design process. Both authors have been actively engaged in describing architectural design by means of a taxonomy of concepts that comprehensively describes all aspects of architectural design. By also distinguishing between the dimensions Form, Function, and Time, they are able to describe any object in design in a generalised manner. In their paper, "A Building Design Process Model", Bax and Trum then set out to describe the design of the design process in terms of this theoretical framework. They establish a design process model that consists of eight steps and then elaborate each of these steps for architectural design.

Ad den Otter's paper, "Improvement of the Design Process", identifies a number of characteristic problems in architectural design and design teams. Information and Communication Technology generally are conceived to tackle these problems. However, den Otter notes some practical issues that block such development. Den Otter advocates a renewed attention to the managerial structures that play a role in design, and introduces seven formative aspects for a so-called "information ecology".

Mick Eekhout presents in "Design Methodology for Building Products", a prescriptive and detailed stepwise plan for designing new building components. This method, the "Organogram for Product Development" is structured in five phases:

- Design Concept.

- Preliminary Marketing.

- Prototype Development.

- Final Marketing.

- Product Manufacturing.

Each phase is further detailed in activities that need to be undertaken. In total, Eekhout discusses sixty-nine activities. The order is presented sequentially, but the author indicates where and how parallel processes can take place, and how the recursive nature of design is accommodated in the Organogram. Eekhout also notes that for some activities there also exist more specific methodologies, and states that the Organogram can function as the framework for these more specific methods.

Theme 2: Design process

The study of design processes provides the main body of knowledge of concrete design processes, and allows for further inquiry into methods, descriptive techniques, cognitive studies, and the development of tools. In this theme, the authors are mostly interested in precisely this descriptive research of the design process. The first two papers are from the discipline of Industrial Design, and the third from Architectural Design.

Henri Christiaans and John Restrepo in their paper, "Information Processing in Design", point to the importance of contextual information in the design process. They note difficulties in information processing due to time constraints, information load, and so forth. The authors claim that provision of better-suited information-handling tools can considerably help design and improve the quality of the design (and process). To illustrate this theoretical approach, they list four empirical research projects in which various aspects of contextual information and information processing are studied. Based on these findings, they are able to nuance their position and identify related further questions.

Jan Buijs presents an overview of the work done in the Design Methodology Group and the Management and Organisation Group of the Department of Product Information and Management in the Sub-Faculty of Industrial Design Engineering, Delft. The Design Methodology Group has a research tradition in design methods, protocol analysis, and research paradigms. The Management and Organisation Group has a research tradition in design in context; studying in particular design teams in practice. In his paper, "Developing NPD-Process Knowledge", Jan Buijs lists the research findings for both groups during the past five years.

Mieke Oostra, in her paper "Product Development and Design Research", discusses the findings in her Ph.D. work on how architects develop new building components. From interviewing and reconstructing actual cases, she identifies a number of themes and patterns that occur regularly. There are two main themes: Resources (such as product development budget, time, and information and facilities), and Constraints. There are three general groups of patterns: Motivation, Roles, and Strategies. Oostra elaborates these in a listing of specific patterns that were found in her case studies. They are further organised on the aspects of: Time, Money, Quality, Information and Communication, Organisation, and Atmosphere.

Theme 3: Design representations

The theme of design representations deals with the external representations such as drawings, sketches, and models that designers use in the design process. The papers in this theme deal with sketches and drawings, in particular as they are used in the discipline of Architectural Design.

In the "Prolegomena to the Recognition of Floor Plan Sketches", Alexander Koutamanis sets out to classify the basic graphic elements that make up sketches. This classification is informed both by architectural content on the basis on drawing-conventions as well as computer vision. The latter plays an important role when in a further stage of research sketches need to be recognised by CAD-tools. Koutamanis distinguishes first a number of dimensions that hold for most representations, and then describes a number of general higher level structures in architectural design, such as organisational lines, spaces, relationship lines and building elements, and positive and negative representation. After that, he outlines a number of graphic primitives: solid lines, multiple lines and bubbles, broken and dotted lines, blobs, textured and coloured surfaces, and annotations. He proposes that these can be used as a basis for automated sketch-recognition.

The second paper, "On Representation", by Alexander Koutamanis and Vicky Mitossi, deals with the concept of coordinating devices. A coordinating device is a structural relationship between a number of graphic elements that denote some architectural objects, for example, the way a door can be placed relative to a corner in a room. In this manner, information about the drawing can be inferred that goes beyond the straightforward function-space mapping in current systems. The authors aim to automate simulation on the basis of drawings in order to make performance predictions.

Theme 4: Design computation

Design computation deals with the computational support and description of design. This work is motivated by the recognition that ICT can improve design in many ways. Tools for design require an understanding of design (at least of the practical needs of the designer) and thus, developing tools can be an additional way to understand design. Papers on design computation are submitted from Aerospace Engineering, Computer Science, Industrial Design, Civil Engineering, and Architectural Design.

Date Rentema and Erik Jansen in "An AI Tool for Conceptual Design of Complex Products" report on an ongoing research project to develop advanced tools for conceptual design. The application area is the component configuration for aircraft in the early design stages. The assembly of these components and reasoning about their configurations is done in separate modules, using the techniques of Case-Based Reasoning, Rule-Based Reasoning, and Constraint-Based Geometric Modelling. The modules operate under a general system called "AIDA": AI-supported Design of Aircraft.

Paul Hekkert, David Keyson, Kees Overbeeke, and Pieter Jan Stappers describe in "The Delft ID Studio Lab" how the combined effort of four research groups in an interdisciplinary research lab yields new research directions for (computational) design support as well as cognitive research. The focus of research has shifted from (usually isolated) cognitive and perceptual-motor skills of the single designer to describing and supporting the experiential context comprehensively. This also includes novel research interests in the emotional aspects of products and the design process.

Reza Beheshti, Frits Tolman, and Peter van der Veer present the work of the Design and Building Informatics Group of the Faculty of Civil Engineering and Geosciences at Delft University of Technology in the paper "Design and Building Informatics Research". The group has been actively engaged in research fields such as new modelling methods, integrated method modelling, and the study of its effects in application. These are in particular elaborated in electronic project data modelling, modelling objects and processes in various life-cycle stages, dealing with multiple discipline views, and knowledge modelling and engineering. The authors present past performance and ongoing research projects of the group.

Henri Achten, Bauke de Vries, and Jos van Leeuwen present in "Computational Design Research" an overview of the work in Design Systems of the Department of Building and Architecture at Eindhoven University of Technology. The research work is coordinated in the VR-DIS research programme, which sets out to incorporate design- and engineering knowledge from all disciplines in the so-called VR-DIS platform. Virtual Reality is seen as an important enabling technology to convey this knowledge and these findings to designers in a natural and more accessible way. The authors present the past-performance of the group, achieved academic results and software prototypes, as well as currently running projects.

Conclusion

Design Research in the Netherlands 2000 provided a venue to discuss the current state-of-the-art in design research from many different perspectives, such as research method (theoretical, cognitive, computational, etc.), strategic approach (research by design, through experiments, by making design tools, etc.), design discipline, and so forth. From the papers, and discussions during the symposium, a number of observations can be made.

There is a growing interest in design from the field of management studies, and vice versa, design researchers are becoming again aware of the managerial aspects of the design process (see van Aken; Chapter 2, and den Otter, Chapter 4). As stated, this is not entirely new: the Management and Organisation Group of Industrial Design in Delft has always had a focus in this respect (see Buijs' overview in Chapter 7), and the term "designing the design process" has been a recurring theme in the Design Methods Group of Building and Architecture in Eindhoven. Furthermore, the notion has been present already in the classic studies of design by Broadbent, Gregory, and Jones.

For a solid scientific basis, it is necessary to define the concepts that describe the research discipline. Taxonomies are important structures in which the range of scientific vocabulary is established. Beheshti (Chapter 1) and Bax and Trum (Chapter 3) are active in this respect. The relationship of the terms of a taxonomy with the everyday practice of design is not without difficulty as designers often use their own vocabulary or tend to shift the meaning of words or introduce new terms. This 'play with words' could be important to prevent fixation, stimulate creative thinking, or to define a point of view that differs from the competition in the field. Research on these aspects would be welcome. However, the professional and academic competency of a designer should include a reflective attitude that adheres to a set vocabulary, such as is defined in taxonomies.

The 'classic' means of design research by protocol analysis, structured observations of designers in lab experiments, interview techniques, and so forth, are well-established and produce an essential body of knowledge about the design process. There is an active rethinking of the basic paradigms in this field of work (in particular at Industrial Design in Delft; see Chapter 6 and 7), there is ongoing research in new concepts that play a role in

design (Oostra's research for patterns and themes in Chapter 8), and formulation of design methods (the Organogram for Product Development by Eekhout in Chapter 5). More detailed investigation and extension of the basic elements of design is presented in Chapter 9 and Chapter 10 by Koutamanis and Mitossi.

Making tools for design is increasingly becoming a productive means in design inquiry. This trend is evident in the submissions presented here: the AIDA system presented by Rentema and Jansen (Chapter 11), the work of the ID Studio of Industrial Design Engineering (Chapter 12), the prototypes developed by Design and Building Informatics Delft (Chapter 13), and Design Systems Eindhoven (Chapter 14). Most of this work requires an understanding of design on various levels. By making prototypes for design support, this understanding can be enhanced and also revised after application of the tools in practice. This trend seems to be sufficiently different from the established distinction of 'descriptive' and 'prescriptive' studies of design, and warrants further attention and development in the future. In particular, research methodologies for this kind of research are still wanting and need to be further developed.

The editors,
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Bauke de Vries
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DESIGN THEORY

1.   Domains of Design Research

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1.1   Introduction

The goal of this short paper is to invoke a discussion of fundamental principles of design thinking, allowing us gaining insight into the nature of design as an innate human faculty.

We can find every kind of lines for the comparison between different design disciplines, their approaches and unfolding phenomena of design events in time. In addition we notice that approaches are markedly complementary. In the early days of design research Broadbent noted that all design processes are based on scientific methods. Therefore the aim was to devise rationalised procedures or rules analogous to the mathematical expressions that are sets of instructions for solving design problems. Popper noted that we cannot expect profound truth from methodology, but it may help us to clarify the logical situation and even to solve some far-reaching problems. Design science according to Hubka and Eder is understood as system of logically related knowledge, which should contain and organise the complete knowledge about and for designing. The (design) science requires systematic descriptions (declarative knowledge and descriptive statements), which belong in the area of theory, methodology and instructions for the practical (design) activity (procedural or prescriptive knowledge), and/or (deterministic and flexible) algorithms and techniques for part processes and operations. Archer has introduced boundaries of attention in design research through identifying the following ten areas of the whole field of design (science): design history, design taxonomy, design technology, design praxeology, design modelling, design metrology, design axiology, design philosophy, design epistemology and design pedagogy. Perhaps we can add the following additional areas: design management, design policy, design aesthetics, design semantics, design decision-making, design evaluation, design logic, design ontology, design logistics, design syntaxis, design ethics and design informatics. This prompts us to seek and define a general framework or classification for these areas. In this regard we recognise the following three major categories:

- Areas that define the agents of design and can describe the study of creative and cognitive activities of design;

- Areas that define the influences of design in terms of studying both internal and external experiences of designing; and

- Areas that define the operations of design in terms of studying the organisation and the product of designing.

We can argue that these discussions are relevant to all design disciplines. This paper will attempt to group together a coherent range of discussions to explore the design science. In this paper our attention will be on the design of the built environment (architecture, urban design, urban planning, civil engineering and policy analysis). On the other hand the emphasis and

accent of this paper will be on advanced technologies (applications of information, communication and computer technologies). These issues will distinguish the goal and objectives of this paper. The issues discussed will be complementary and will cover the entire spectrum of design science in the light of the applications of the information, communication and computer technologies.

Our goal in this paper is to create a platform for introducing and the exchange of ideas and experiences related to the study and application of advanced technologies to fields of designing the built environment. Further we discuss terms and conditions for introducing new tools (offered by the latest developments in the fields of artificial intelligence, robotics, image processing and information technology) and new strategies (required by the inevitable changes of the professional and educational working environments of architecture, building engineering, civil engineering, urban design and urban planning). In this regard, relevant subjects and themes include but are not limited to domains of artificial intelligence, design support environments, decision support systems, knowledge representation, human and machine intelligence, image processing, building and construction robotics, computer vision (applications and components), machine training and learning systems, case-based reasoning systems, construction robotics, computer vision, intelligent design and planning tools, computer graphics, interactive virtual realities for design and planning of the built environment, intelligent CAD/ -CAM/ -CIM/ -GIS, design and planning informatics, geoinformatics, hydroinformatics, building informatics, etc. These can be divided into two major categories of the applications domains and the basic tools domains. Also, the studying and discussing issues related to design of the built environment in each area of the design science will occupy a central place in this paper. In this paper we can propose the following discussion which can provide an overview of possible design research domains.

1.2   The agents of design

These are the areas that define the agents of design and can describe the study of creative and cognitive activities of design.

1.2.1 Cognition

Cognition in design regards the faculty of knowing design knowledge and all activities related to design awareness. We can recognise the following areas to discuss in the context of cognition.

- Design philosophy. Design philosophy is the study of ways of design thinking. It is a search for general understanding of design values by chiefly speculative rather than observational means. It can be an analysis of the grounds and concepts expressing fundamental aspects of design. The design philosophy concerns the general theory underling the design thinking. It can describe the general beliefs, concepts and attitudes about design or designer.

- Design logics. The design logics are the study of principles of design reasoning and the underling foundations of the design thinking. It can describe the principles and criteria of design inference and demonstration. It can cover the arguments about the interrelation or sequence of design events when seen as inevitable or predictable.

- Design modelling. It is the study of cognitive models, externalisation and communication of design ideas.

- Design epistemology. It is the study of the nature and methods of knowing, feelings and beliefs regarding design (design knowledge theory).

- Design psychology. It is the study of mental processes and behavioural characteristics of individuals and groups influenced by the design activity or affected by the products of designing.
- Design syntaxis. It is the study of the system of rules and the structure of the design process (design grammar).

1.2.2 Creativity

Creativity in design concerns all processing activities of intelligent performance, which contribute to existence of design according to recognisable structures and syntactic rules. It relates to the learning and reasoning processes of designing and a starting point for perceiving design in mind for modelling an empirical existence.

- Design aesthetics. It is the study of a particular theory or conception of beauty in design. It deals with the nature of beauty and taste in design as well as the creation and appreciation of beauty in design regarding an approach to what is pleasing to the senses and especially to the sight.
- Design semantics. It is the study of meaning and intentions in design. It concerns the classification of changes in the significance of forms in the development of design. It is about innovative meanings to achieve a desired effect through design especially by the use of novel design factors.
- Design ontology. It is the study of the general characteristics and principles of the design process.

1.3   The influences of design

These are the areas that define the influences of design in terms of studying both internal and external experiences of designing.

1.3.1 Internal experiences

These are the observation of design facts and design events and are considered to be the source of design knowledge.

- Design history. It is the study and analysis of design cases with regards to reasons for designing as well as social, cultural, political and economic factors with their influence on the design cases.
- Design pedagogy. It is the study of principles, methods and techniques of teaching design.
- Design evaluation. It is the study of values and criteria for the evaluation and selection of design decisions and methods for comparing different courses of action during the design process.

1.3.2 External disciplines

These are the areas dealing with design facts and events as well as ways of producing design knowledge and acquiring design skills.

- Design axiology. It is the study of the nature, types, and criteria of values in design with emphasis on the relationship between technical, economic, moral, social and aesthetic values of design.
- Design policy. It is the study of a definite course or method of action selected from amongst alternatives and in the light of given conditions to guide and determine present

and future design decisions. It concerns a high level overall plan embracing the general design goals and acceptable design procedures.

- Design decision-making. It is the study of design statements and the ways design decisions are made as well as the principles of design decision-making and methods for arriving at decisions during the design process.
- Design ethics. It is the study of definitions and code of conduct for the design process including all moral, social, political, cultural and personal understandings, insights and norms.

1.4   The operations of design

These are the areas that define the operations of design in terms of studying the organisation and the product of designing.

1.4.1 Organisation of design

The organisation of design refers to a purposeful and systematic arrangement for the design activity.

- Design taxonomy. It is the study of the general principles for the classification of design as phenomena. It also concerns the orderly classification of designs and their relationships.
- Design praxeology. It is the study of the nature, organisation and the instrument of design.
- Design management. It is the study of the organisation of design. It concerns the act of conducting and supervising design, using design means to accomplish design ends.
- Design logistics. It is the study of all the activities required for the handling of the design process as well as the planning of these activities.

1.4.2 Product of design

The product of design is the result of design actions, operations or processes.

- Design technology. It is the study of the principles of scientific treatment of designs and their relationships as a system. It concerns using technical processes, methods or knowledge for designing.
- Design metrology. It is the study of the qualitative aspects of measurement and weight systems regarding design.
- Design informatics. Seen from a design point of view, it is the study of information about the design process, design in an information environment and the means of collection, organisation, classification, transformation, retrieval and use of design knowledge. It refers to the application of the information, communication and computer technologies to the design process.

1.5   The design application domains

The design application domain is the set of areas from the design science that use basic design tools to perform essential tasks that belong to those areas.

1.5.1 Design decision support systems

Design decision support systems are processing tools that developed to support decisions in design processes.

- Design support environments. Design support systems are processing tools developed to support the design activity.
- Intelligent design and planning tools. These are design and planning rules and tools devised with AI principles. They provide logical inferences and are specifiable by formal design and planning rules, content of the design and planning activity and how design and planning activity takes place.
- Interactive Virtual Realities for design and planning of the built environment. These are interactive AI-based tools for design and planning of the built environment.
- Intelligent CAD/ -CAM/ -CIM/ -GIS. These are necessary AI-based tools for design and engineering in an information environment. It involves the application of the information, computer and communication technologies to the areas of designing the built environment.

1.5.2 Design informatics disciplines

These disciplines are concerned with the study and application of methods for data processing using the information, communication and computer technologies.

- Design informatics. Seen from an informatics point of view it is the study of methods for processing design data using the information, communication and computer technologies.
- Planning informatics. It is the study of methods for processing planning data using the information, communication and computer technologies.
- Geoinformatics. It is the study of methods for processing geographical and geotechnical data using the information, communication and computer technologies.
- Hydroinformatics. It is the study of methods for processing hydraulic and hydrological data using the information, communication and computer technologies.
- Building informatics. It is the study of methods for processing building data using the information, communication and computer technologies.
- Construction robotics. It is the study of methods and techniques for performing building and constructions tasks by machines that perform monitoring tasks and use monitoring data for the execution of these tasks.

1.6   The basic design tools domain

The basic tools domain is the set of methods and tools from informatics science that can be used for the performance of design tasks.

1.6.1 The processing tools

Processing tools are methods and techniques for data processing tasks using the information, communication and computer technologies.

- Image processing. It is the study of methods for processing graphical data on computers. It refers to the recognition and structuring of design images in the context of the design activity.
- Computer vision (applications and components). It is the study of methods for processing real time graphical data on computers and the recognition and structuring of captured and real-time design.
- Computer graphics. It is the study of methods and techniques for graphic data representation in the design process.

1.6.2 Artificial intelligence tools

These tools concern methods and techniques for data processing in situations of high complexity and/or uncertainty and/or incomplete data.

- Knowledge representation. It is the study of methods for representation of design knowledge in a way that processing tools can use it.
- Human and machine intelligence. This is the area of studying the complex structure of knowledge concerning the design activity in an information environment.
- Machine training and learning systems. These are processing tools that use the design data, representing the state of a real design system to define its behaviour and performance
- Case-based reasoning systems. These are processing tools that use the design data, representing experiences of pervious design-cases to define their behaviour, outcome and performance.

The field of design research has yet to be explored fully. All discussions of fundamental principles of design thinking and the study of design from different points of views and a variety of contexts will help understanding design as a unique innate faculty of humans. The author invites you to submit your comments, suggestions and views as notes or papers. These contributions will eventually form the basis for further discussion of Design Research Domains in a broader perspective.

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- Audi, R. (ed.) (1996), The Cambridge Dictionary of Philosophy, Cambridge University Press, Cambridge, UK.
- Bullock, A. and Stallybrass, O. (eds.) (1979), The Fontana Dictionary of Thought, Fontana/Collins, London, UK.
- Miriam-Webster On-line Dictionary (1999).
- The Shorter Oxford Dictionary (1980), Volumes 1 and 2, Oxford University Press, Oxford, UK.
- Van Dale Woordenboek der Nederlandse Taal (1999).

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1.8 References

Archer, L.B. (1981). A View of the Nature of Design Research, in: Jacques, R. and Powell, J.A. (eds.), *Design: Science: Methods*, Westbury House, Guildford, UK.

Asimov, M. (1962). *Introduction to Design*, Prentice-Hall, USA.

Beheshti, M.R. (1993). Design Decisions and Uncertainty, *Design Studies*, Vol. 14, No. **1**.

Beheshti, M.R. (1993). Editorial, *Design Studies*, Vol. 14, No. **1**.

Beheshti, M.R. (1999). *Handbook Systematic Design in Architecture and Civil Engineering*, Delft University Press, Delft, The Netherlands.

Beheshti, R. and Veer, P. van der (1999). *Design Science and Technology*, EuropIA, France.

Blalock, J.Th. (1984). *Theory Construction, Prentice-Hall*, USA.

Bono, E. de. *Parallel Thinking*, BCA, London, UK.

Broadbent, G. (1988). *Design in Architecture: Architecture and Human Science*, John Wiley, Chichester, UK.

Cassirer, E. (1957). *The Philosophy of Symbolic Form*, Yale University Press, USA.

Clegg, G.L. (1969). *The Design of Design*, Cambridge University Press, UK.

Clegg, G.L. (1969). *The Selection of Design*, Cambridge University Press, UK.

Clegg, G.L. (1973). *The Science of Design*, Cambridge University Press, UK.

Cross, N. (1984). *Developments in Design Methodology*, John Wiley, UK.

Gregory, S. (1966). *Design Methods*, Butterworth, UK.

Hubka, V. and Eder, W.E. (1996). *Design Science*, Springer-Verlag, London, UK.

Lawson, B.R. (1982). *How Designers Think*, AP, UK.

Loire, R. (1989). *The Design Way*, Tramco, Paris, France.

Mitcham, C. (1994). *Thinking Through Technology*, University of Chicago Press, USA.

Morre, G.T. (1973). *Emerging Design Methods in Environmental Planning and Design*, MIT Press, USA.

Nadler, G. (1981). *Design and Planning Approach*, John Wiley, N.Y., USA.

Norberg-Schulz, C. (1977). *Intentions in Architecture*, MIT Press, USA.

Norman, D. (1988). *The Psychology of Everyday Things*, Basic Books, USA.

Petroski, H. (1994). *Design Paradigms*, Cambridge University Press, UK.

Petroski, H. (1997). *Invention by Design*, Harvard University Press, USA.

Popper, K.R. (1972). *The Logic of Scientific Discovery*, Hutchinson, London, UK.

Teymur, N. (1982). *Design Discourse*, Question Press, London, UK.

Zeisel, J. (1981). *Enquiry by Design*, Brooks, CA, USA.

2.   Domain Independent Design Theory

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2.1   Summary

This article provides a stepping-stone for the development of domain-independent design theory, based on a study initiated within the framework of the postgraduate Eindhoven design engineer program for Architectural Design Management Systems. This design theory is being developed to support the design of large-scale, complex design processes, such as one has in large building projects. The article will deal with the nature and the content of such theory.

2.2   Introduction

The two-year postgraduate design program ADMS (Architectural Design Management Systems) was established in 1997 at Eindhoven University of Technology, more specifically at the Stan Ackermans Institute. The target group for this program consists of building and business engineers. Its objective is to train engineers to design the design processes for large building projects and to support these processes with methods and IT-tools.

Within the framework of the ADMS program work is being done on the development of domain-independent design theory, i.e. design theory that is independent of the domain or discipline related to the entity to be designed. More specifically, this concerns the development of domain-independent design theory to support planning and organizing large-scale, complex design processes. The first results are presented in this article: a discussion of the nature of design theory and of domain-independent design theory, as well as a first sketch of its content. There is no pretence that all of this is new; the discerning reader will recognise much of what is written. The goal is to provide a stepping stone for further development of such theory, which is not only of interest for ADMS but also for engineering design in other disciplines.

At the same time also work is being done on domain-specific design theory, building on a longer tradition of developing such theory. The results of that are presented in Trum and Bax (2001).

2.3   Reasons to develop domain-independent design theory

The main issue in ADMS is to produce process designs for large-scale design processes, i.e. processes that are technically and organisationally complex, because they need input from various disciplines and because there are many individuals and parties (i.e. independent organisations) involved.

Process design in building usually is variant design. On the creative-routine scale of design processes (Sriram et al. 1989) they tend to be rather at the routine end. An individual or an architect firm usually operates on the basis of a way of working, developed on the basis of

personal experience and under the influence of branch-specific factors (e.g. in the Netherlands the classic BNA model). When given a new assignment, one tends to start working on the basis of a variant of that proven method, using the technical and organisational characteristics of the new assignment and also recent experience to design that variant: what went wrong the last few times and what should we look out for this time, and what went right last time and is worth repeating?

The problem of such a craftsman-like approach is that the process design for the new assignment is not thoroughly thought through (almost all attention is paid to the design of the object). This means that there will be no revolutionary solutions and that there will be no systematic approach to the technical and organisational complexity of the new assignment. Especially for complex, large-scale design processes such an approach has a severe limitation. ADMS has the ambition to rethink the building design process as a whole and to replace the traditional and experience-related process designs by a more conscious, rational, and theory-based approach. One of the approaches to this is to develop domain-independent design theory.

Each design, but especially craftsman-like designs, contains many implicit design choices, i.e. solutions for certain design problems selected because they seem obvious on the basis of experience or rational thinking, without the awareness of possible alternatives and therefore without an explicit consideration of alternatives. Domain-independent design theory searches for fundamental problems and fundamental design steps in each design process. It is partly developed through the comparison of design processes in various disciplines. Since various disciplines often have different solutions for design problems, these problems then become apparent. The results of such research are 'design science products' (see e.g. March and Smith 1995), which include:

- 'Design language', i.e. a system of concepts or constructs with which design processes can be described and which can be used to make actual designs.

- Design models, which can be used to analyse design processes, but also as exemplars to design such processes.

- Design methods to support certain activities in the design process.

- Specific tools, possibly computer-based, also to support certain design activities.

- Design methodology, i.e. theory on the use of models, methods, tools and general approaches to design.

A domain-independent approach to process design, finally, can also facilitate interdisciplinary communication within complex large-scale design processes.

2.4 Design theory

Design processes are nearly as old as civilisation itself; even hand-held rock tools were designed. However, generally they were designed by the user and followed an evolutionary design process: passed on from generation to generation, these tools underwent an evolutionary design process involving gradual improvement. In this way, Stone Age tools were developed, as well as instruments like the scythe and the violin. Also the designs of houses and ships have undergone many centuries of such evolutionary development.

A radical improvement of the design process arose from the use of drawings, which allowed a separation of designing and the realisation of designs and which facilitated innovations in the designs of artefacts. Generally, it is far easier to experiment with new designs on paper than in physical reality.

However, for many centuries the design process itself continued with craftsman-like variant designs. In crafts, building and other engineering disciplines, the design of artefacts was learned through experience and under the guidance of masters and colleagues. Process knowledge (i.e. knowledge about the characteristics of the design process itself) was usually implicit and explicit process designs were seldom used. Process knowledge or design theory first became a field of scientific study in the nineteen-sixties, mainly through British initiatives (Jones and Thornley 1962; Gregory 1966; Glegg 1973; Jones 1980). In this context we may also mention Simon's seminal book "the Science of the Artificial" (Simon 1969, 1980), an important contribution to the development of design science as a field. These pioneers had powerful ambitions and great expectations: the traditional and intuitive designs of the various engineering disciplines would be replaced by rational, theory-based and possibly even formalised approaches. These were to be used for the design process itself, but also to train young designers, and to serve as a point of departure to fit the design process with methods and tools. It was all for the benefit of mankind and would lead to revolutionary improvements in the quality of designs.

However, up until now there has only been limited success. Theory has been developed, but the impact on actual practice, training, and tools has remained modest. Interesting parallels can be drawn to General System Theory and Cybernetics (Boulding 1956; Ashby 1956; Beer 1972) and decision-making theory (Simon 1960). These too arose in the same period with great expectations for more rational, and possibly more formalised approaches with an aim to improve actual practice. Decision-making theory only started to mature after the rational and normative desk theories were supplemented with results from thorough empirical studies about real-life decision-making processes. General, supra-disciplinary System Theory dissolved into the various mono-disciplines, but did leave traces in the shape of concepts and analytic approaches.

The best road forward for design theory is to use extensive empirical studies on real-life design processes in various disciplines, in order to obtain more fundamental insight into such design processes. Following that, this insight can be used for approaches that are more normative. This article will not take us down this road however. Using knowledge from experience in various engineering disciplines and turning to the literature, an attempt is made from behind a desk to develop a first sketch of domain-independent design theory.

This is not to say that this article is based on a modernist ambition to develop a single all-encompassing General Design Theory (such as general System Theory attempted to do for the formulation of scientific theory in general). There are many possible and useful different approaches to the design process, and the choice depends on the objectives one wishes to serve with the approach. The design process can be viewed, for example, as a problem-solving cycle, as a series of decisions on design problems, as a process of developing successively more details of a description of the artefact to be realized, etc. Every different perspective leads to a different model of the design process and to a different design theory, domain-independent or not.

So there can be many domain-independent design theories. An interesting example is the one of Reymen (2000), who uses a state-transition model for the design process in order to structure it and to develop methods and tools to support it. As said, this article is concerned with domain-independent design theory to be used in planning and organizing large-scale, complex design processes.

2.5 Design

A *design* can be defined as a *representation of an entity* (object or process) to be realised, *made as an instruction for the next step* (in the design or realisation process).

A design is a special case of a model; much of the knowledge on model building is relevant to design. A model is an abstraction of reality. Examples of models are schemes, texts, scale models, and computer 3D representations.

The entity to be designed will have a particular physical realisation and must fulfil a particular function for a particular target group. *Designing*, then, *is the process of determining the required function and creating a model of its physical realisation*. One can also say that designing is the development of a *functional specification* of the artefact to be designed, i.e. a specification of the functions it has to perform for its users, combined with the development of its *technical specification*, i.e. a specification of the artefact in such detail that it can be realised, produced by a producing party.

In general, three kinds of design are made: an *object design*, a *realisation design*, and a *process design* (see Figure 2.1).

In the field of building, the object design is the collection of drawings of the building to be realised. The realisation design concerns the plans for actual building and the process design describes the design process itself.

To make an object design, one must have intimate knowledge of the properties of the entity to be designed. This knowledge can be described as *object knowledge. Realisation knowledge* (knowledge about the processes needed for the production of the entity) is used to make a realisation design. Knowledge about the design process itself, *process knowledge*, is used to make the process design, i.e. the design of the process of designing. Our research on domain-independent design theory is undertaken to support the development of such process knowledge.
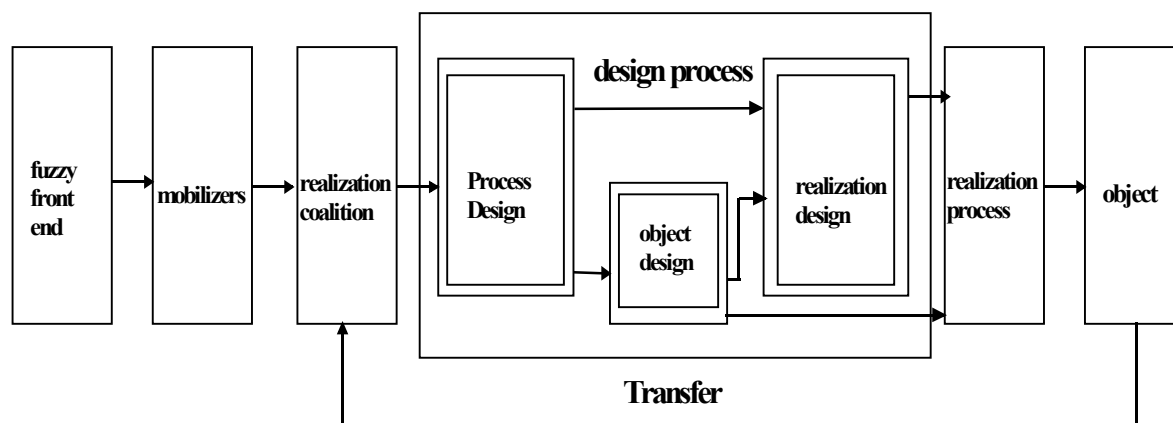
Figure 2.1: Process, object, and realisation design.

There are various approaches to the creation of a design process. It can, for example, be spontaneous, evolutionary, or craftsman-like. A spontaneous approach is not guided by process knowledge. Often there is considerable object knowledge and experience with design. In an evolutionary approach, the object design is gradually improved (as discussed in section 2.3). In a craftsman-like approach to the design of a design process, the working methods of teachers are followed. This way of working is often used in smaller building projects. As discussed, an existing method is used and somewhat adapted to a new situation.

In large-scale complex building projects, however, the traditional approach is insufficient. A more professional process design is required, i.e. a more conscious, rational consideration of

alternatives is needed that is guided by scientific process knowledge. As said, such process knowledge consists of design language, design models, design methods and tools, and design methodology.

2.6 The design process

In this section, we discuss various aspects of the process design for a physical object:

- Generic step model of a design process.

- Design specifications.

- Basic activities in design.

- Process and task structure.
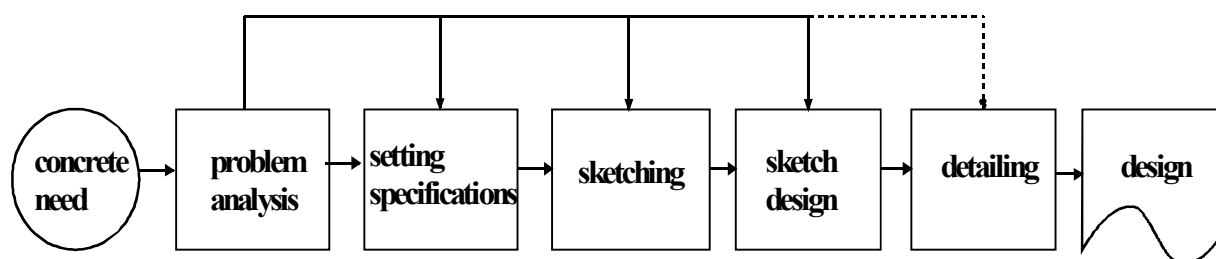
Figure 2.2: Generic model for a design process

In the generic model of Figure 2.2 the design process is described as a series of stages with *iterations* - going back to one or more previous stages - and *explorations* - going ahead to subsequent stages in order to explore already the design problems in those stages.

A key element in that process is the *concept design*. This concept design is a design in main lines, which contains all the design decisions with respect to the key design dilemmas. The intention is that many iterations and explorations may take place during sketching and the making of a concept design, but that the concept design should be fixed before the time and money-consuming detailing starts.

The design process is created because of a concrete need among mobilizing parties. These parties consist of the following agents:

- Principal: Decides about the content and has authority over resources.

- Problem-owner: Responsible for the solution of the problem.

- User: The actual user of the object or process to be designed.

2.6.1 Design specifications

The mobilizing parties set down their needs in design specifications in consultation with the designing parties. Managing these specifications is a main issue in the design process. During the design process, these specifications are detailed for the following points:

- Boundary conditions: Must be met.

- Functional requirements: Performance demands.

- User requirements: Perspective of the user.

- Design restrictions: Preferred solution space.

Examples

A. Freezer
- Boundary conditions: Uses 220 V.
- Functional requirements: Cool space to –2 ^{o}C.
- User requirements: Easy to defrost.
- Design restrictions: Use the same compressor as in existing types of freezers.

B. A building
- Boundary conditions: Building law and building regulations.
- Functional requirements: International appeal, educational function, etc.
- User requirements: Accessibility.
- Design restrictions: Budget and completion date.

2.6.2 Basic activities in design

After problem analysis and the definition of functional specifications, the basic activities of designing are *synthesis-evaluation iterations*: the synthesis of possible solutions to design problems and the subsequent evaluation of those solutions against specifications. Synthesis is achieved through creativity, experience and design examplars. Evaluation is done through testing, calculation and judgement, based on object knowledge. During those synthesis-evaluation iterations the designer searches for alternatives, avoiding 'to marry his/her first design idea'.

2.6.3 Process and position structure

A design process is a special case of a general '*production process*'. A production process is created to produce something, such as a machine, a building or a painting. It can also be created to produce a design.

Every production process has a process structure and a position structure. The process structure is built up of elementary process steps with time relations, such as sequential relations or with iterations and explorations. In each process step a number of tasks have to be performed. Every task can be allocated to a different agent, but usually similar tasks, maybe in different process steps, are allocated to the same agent or position. In this way a set of positions is created. Usually these are not independent from one another, but have certain (static) relations, for instance by again combining related positions into compound positions, thus resulting in a position structure. Next to primary positions there are also control positions, controlling the execution of tasks.

2.7   The design of the design process

The objective of designing a design process is to realise an effective and efficient system of activities that produces a design that meets the specifications and expectations of the mobilizing parties.

The process design specifies the process structure, i.e. the what and when (or, in other words, plans the whole design process). And, secondly, it specifies the position structure, i.e. the 'who' and 'where', by allocating these process steps or elementary tasks to certain simple or compound positions. One may compare the process design to a script of a play or movie, specifying actions (text and behaviour) and parts (people with specific characteristics and with certain relations to one another). The script specifies and guides actions, but does not

completely determine it: the actors still have some freedom in their interpretation of the script. One can call this freedom the '*realisation freedom*' of the design, i.e. the degree of licence the design allow to those who have to realize it.

In the design of technical objects or processes, like the design of a TV-set or of a manufacturing process, there is usually a clear separation between design (by the development department or by the engineering department) and realisation (by the manufacturing department), while the design usually leaves very limited realisation freedom. In the design of an essentially social process as a design process, however, such a clear separation is undesirable. One needs some degree of involvement of the designers themselves in making the design and the resulting design should still leave those designers quite some realisation freedom.

For the role of the process designer there are at least three design exemplars: he/she can be a technical consultant of the design team, he/she can be the project planner without formal authority and he/she can be the project manager, having specific authority over the people involved in the design process.

The design of a design process entails the decomposition and integration of that process. The decomposition results in process steps and elementary (or compound) tasks or positions. Proper decomposition leads to a nearly decomposable system (Simon 1969): the whole is decomposed in such a way into subsystems that the relations within a subsystem are stronger than between subsystems. Integration is realised through coordination, sometimes supported by the creation of a hierarchical system (again Simon 1969), i.e. a system with a part-within-part structure.

A process structure consists of process steps and time relations. The time relations can be sequential, iterative or explorative. The process steps can be fluid (weak boundaries), transitional (transition phase between steps) or overlapping (limited but without distinct time boundaries). One example of transitional process steps is that you are working on a task that actually belongs to the task of the next process step. The following design exemplars can be used for the design of a process structure:

- The Dutch BNA model for the design process: This is a specific model of a step structure.

- A fluid structure.

- A phase structure: Sequential, defined boundary for each phase, each phase as a black box.

- Step structure: Iterations and explorations, defined in advance or result dependent.

- Concurrent structure: Phases or steps overlap or run in tandem.

The position structure of a design process is conditioned by its structure of *contracting parties*. A contracting party is a group with unity of property, leadership and loyalty. In a multi-party coalition, one has to work with distributed property, leadership, and loyalty. A design coalition has relations with parties outside the coalition. The boundaries of the design coalition are an important issue. Who are the participants of the design coalition and who are only relations?

For the design of a position structure, we can make use of the following design exemplars:

- Traditional tender model: Coalition with relations ('bag of marbles').

- Building team: Design coalition with partnership (one-party model).

- Virtual organisation: Multi-party that is univocal towards the client.
  - With a core partner (main contractor with subcontractors)
  - Without a core partner (balanced network)

Once resources have been made available at governance-level, then a structure for design and management positions can be created on the basis of the following:

- Transformation specialisation (e.g. technical expertise).

- Object specialisation (on the basis of design fields).

- Environment specialisation (contacts with relations).

- Geographical specialisation (for large geographical distances).

People in managerial positions may have the following types of authority:

- Authority to take final decisions.

- Authority to provide advice:

    - Obligatory or facultative advice (from the perspective of the part being advised).

    - Upon request or otherwise (from the perspective of the consultant).

The formal division of decision authorities can deviate from the actual division of powers of decision.

The following design exemplars can be used to organize the design team:

- Chief designer with a team

- Balanced team

    - With self management

    - Without self management

- Modular team

- Design team with sub-teams

2.8 Final remarks

This article gave a rough sketch of the content of domain-independent design theory, developed in order to support the planning and organising of large-scale complex design processes, in building or in other engineering disciplines.

Much work and many critical discussions are still needed to develop it in a really useful system of concepts.

2.9 References

Ashby, W.R. (1956). An Introduction to Cybernetics, Chapman & Hall, London.

Beer, S. (1972). Brain of the Firm, Allan Lane, The Penguin Press, London.

Boulding, E.K. (1956). General Systems Theory – The Skeleton of Science, Management Science 2.

Glegg, G.L. (1973). The Science of Design, Cambridge University Press, Cambridge.

Gregory, S.A. (1966). The Design Method, Butterworth, London.

Jones, J.C. (1980) Design Methods - Seeds of Human Futures, Wiley, London.

Jones, J.C. and Thornley, D.G. (1962). Conference on Design Methods, Pergamon Press, London.

March, S.T. and Smith, G.F. (1995). Design and Natural Science Research on Information Technology, Decision Support Systems 15, pp. 251-266.

Reymen, I. (2000). Towards a Multi-Disciplinary Framework for Design, Working paper Eindhoven University of Technology, Eindhoven.

Simon, H.A. (1960). The New Science of Management Decision, Harper and Row, New York .

Simon, H.A. (1981). The Science of the Artificial, MIT-Press, Cambridge.

Sriram, D. et al. (1989). Knowledge-Based System Applications in Engineering Design: Research at MIT, *AI Magazine* 10(**3**), pp. 79-96.

Trum, Henk and Bax, Thijs (2001). A Building Design Process Model: According to Domain Theory, in: Achten, H. and Vries, B. de and Hennessey, J. (eds). *Design Research in the Netherlands 2000*, Eindhoven University of Technology, Eindhoven, pp. 19-30.

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3. A Building Design Process Model

According to Domain Theory

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3.1 Introduction

In prevailing official descriptions and regulations concerning the architect's responsibilities no explicit attention is paid to the task of designing the design process. However, just like any other artefact, design processes have to be designed.

Next to the mere building design activities, the design process comprises preparation of the brief (the functional building design) and process design. The architectural design process is part of the complete building process which, next to design and construction, consists of phases of use and management, adaptation and demolition.

In designing the constituent phases of the design process it is important to consider them in relation with all other phases of the building process, as their contents are contributory to the content of the design process and therefore they should be anticipated. Traditionally, all kinds of tasks have been combined in historically, socially and culturally determined roles of participants. These traditional patterns tend to fix positions and to limit possibilities for the introduction of new design strategies.

This observation regards a trajectory of design processes on the level of the complete life span of a building. On the level of a project, design processes consist of serial and parallel connected activities; serial activities take place in a sequence of phases, parallel activities take place simultaneously in so called concurrent engineering or design.

Concurrent design is in comparison to traditional processes characterised by a shift in emphasis from serially linked design tasks to parallel performed tasks. For serious reasons the concept of concurrent engineering is introduced in modern industry. This does not only concern production, but also design. For example, in the aircraft industry there are nowadays design teams consisting of over a thousand designers working at the same time at the design of one new aeroplane. Only a few reasons for this approach are:

- To attain a shorter time-to-market from a first new idea up to a successful new product on the market, especially in those branches with strong competition in order to achieve a higher efficiency and better cost control: the best product for the lowest price.

- To cope with the revolutionary increasing complexity of new technological products, in which designers and manufacturers of a wide variety of high specialisations work together; in this way the creativity and craftsmanship of numerous specialists of very different disciplines can be used for the design of new products.

These issues are also of importance for the building industry and for modern architectural design tasks, which tend to become more complex and are increasingly characterised by collaboration of a variety of different designers and the participation of all kinds of participants.

The design of design processes has become an important issue. A major problem is how to design such processes and projects, how to organise and manage them. How should all the partial design tasks be defined and co-ordinated, how should such vast design teams be organised and how should all partial design results be integrated into a definitive overall design?

In order to provide a conceptual framework for concurrent design we have tried to describe design tasks and parties in a design process separately, so that they may recombined in the end in such a way that optimal configurations for a concurrent design strategy can be found, depending on the specific demands and circumstances of specific projects (Bax and Trum 1996).

In this approach the definition of properties of artefacts (the objects to be designed), design tasks, their articulation and demarcation, their interfaces and the assignment to various designing and decision-making parties in different phases of design projects is emphasised.

In this paper a model of the design process is devised and described. This (general) model can - through confrontation with the project context - be transformed into a (specific) process plan. The process model is useful for analysis and evaluation of existing or already completed processes, as well as for synthesis of processes to be designed. By using the same model in subsequent projects it is possible to gain knowledge and experience from earlier projects and re-use it in the design of new processes.

3.1.1 Domain Theory

Domain Theory (Bax 1979; Trum 1979; Bax 1989; Trum and Bax 1992; Bax, Trum and Nauta 2000) is applied as the theoretical reference for the development of the process model. This theory yields a general design framework describing objects and processes in the field of technological design (Trum and Bax 1990). The theory, which originates from the building design field, is an elaboration of General Systems Theory in the field of technological design. Designed objects as well as objects under design are considered systems, containing sub-systems (hierarchical, aspect- and phase-subsystems) and their elements.

3.1.2 GOM-model

The framework comprises a number of descriptive models, of which the Form-Function-Time model (the so-called GOM model, Figure 3.1) is the most important. This model considers form, function and time as three dimensions of any artificial object. This means that an object is always - independent from its stage of development – defined by its form, function and time properties. The three dimensions, depicted on the x-, y- and z-axis, are articulated in terms of formal scales, functional domains and temporal states of the object respectively.
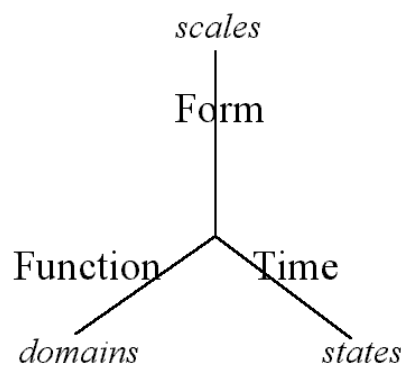

Figure 3.1: GOM-model: Object model of architectural object in statu nascendi.

3.1.3 Concept model

The Concept model – an other descriptive model in Domain Theory – is a taxonomy (Bax and Trum 1993) representing an object as a notional and imaginary object with both an instrumental and a symbolic meaning. Its specific properties make the concept legible and understandable to people who share the same culture; its general properties make the concept applicable to a range of situations. A concept arises in the designers' mind at the beginning of each phase in design in any (partial) design field and directs his or hers thinking and action. Concepts have structural properties, enabling the generation of variant objects (as plans) when confronted with a context.

The Taxonomy of Concepts completely and consistently describes all aspects relevant to a (disciplinary) design situation, arranged into three levels of concepts (Figure 3.2). This arrangement does not imply the order they are dealt with in a phased process. Each concept is represented as a GOM-model, putting emphasis on the functional dimension of the object. In the taxonomy the concepts are ordered according to this dimension.

Policy Concept		
Artistic Concept 'symbol' (intelligibility)	*Scientific Concept* 'model' (testability)	*Professional Concept* 'partitura' (organisability)
Planning Concept		
Physical Concept 'building' (conceivability)	*Economic Concept* 'capital' (payability)	*Social Concept* 'territory' (manageability)
Design Concept		
Constructional Concept 'installation' (tenability)	*Technical Concept* 'work' (makability)	*Use Concept* 'facility' (usability)

Figure 3.2: Taxonomy of Concepts

In Domain Theory an architectural design is the result of a process in which, according to the GOM-model, three types of partial designs are integrated. This means that a formal, a functional and a temporal design are integrated in the overall design. A formal design in architecture emphasises the morphological aspects, articulated in scales; a functional design focuses on the functional aspects corresponding to the Concept-model, and a temporal design stresses the procedural aspects, reflecting the organisation and the procedure within a project. So, the three dimensions of the GOM-model constitute three fields of design, which have a relative autonomy, though co-ordinated in the GOM-model. These observations are valid for an architectural object, but they are valid too for each object which is subject of a design process: e.g. an organisational object (Van Aken 2001) and a process object, which together with the architectural object, form the constituent partial objects or designs of a project.

A formal architectural design is a configuration of spatial elements, together with its syntactic rules of composition.

A functional architectural design is a list of rules and norms, expressing quality, in the formulation of a brief or program of requirements, related to elements of the formal design.

A temporal architectural design relates the formal and functional elements of their corresponding designs to parties and activities of a design procedure in terms of time.

So, formal, functional and temporal design are ordered in a hierarchy of presumption or actual decision making within the framework of the GOM-model. They are defined in an interrelational way; this means that e.g. a functional design, just like any other design, has formal, functional and temporal aspects. However, in a functional design, the emphasis is on the functional aspects, based on formal presumptions within the perspective of future developments by mandated parties.

3.1.4 Outline of the process model development

For the development of the process model the following pairs of subjects are analysed equivalently and analogously: objects and processes; architectural and organisational objects; programme and situation.

The following conditions are applied for the achievement of synthesis: model-plan-cycle in the development of objects; matching of functions of architectural and organisational objects according to concepts and matching of the forms of these objects according to levels; matching of contents of levels (of architectural and organisational objects) and phases.

For the process model development the following phasing is applied: identification or initiative phase; definition or model phase; specification or plan phase.

3.2   Objects and Processes

Projects concern the development of both objects and processes. Objects and processes are considered both subjects and results of (distinct, but similar) design processes. In Domain Theory, objects and processes are described principally in terms of the same categories. This means that the description method of objects also applies to processes. Objects under development are described in terms of their *state* at any time in the process. A relatively stable and temporary state is denoted as a stadium or *stage* of the object. Processes are composed of phases and phases are composed of serially or parallel connected activities. Stages of an object correspond with phases of a process. The term stage mediates between the state of an object and the phase of a process; a stage is the expression of the state of an object in terms of its place in a process. During its development the object passes through several intermediate stages and in each stage it is in a particular intermediate state. States, stages and activities are entities characterised by size, place and quality within a system: an object system or a process system. The process system is of a higher order than the object system: formally, the process comprises the objects. Because of the formal characteristics of its elements, the process system is considered to be an object-system, and as a consequence processes are represented in the GOM-model in the same way as objects.

3.3   Architectural and organisational objects

Both architectural and organisational objects are described according to the same general design framework provided by Domain Theory. The framework comprises a taxonomy of concepts, which provides a 'format' to the designer that enables him to completely, consistently and transparently describe a relatively autonomous design situation, without the necessity to go into the territory of other designing disciplines. The taxonomy is supposed to be valid for all designing disciplines, for all levels and for all phases and steps in the design process.

In the architectural design discipline, concepts enable attachment of attributes to physical/spatial elements, yielding several (sub) systems that correspond with the concepts.

In the organisational design discipline, the same concepts are supposed to enable attachment of attributes to organisational elements, yielding several (sub) systems corresponding with the concepts.

The necessity of co-ordination of the design situation within a project involves a seemingly overlap between the descriptions made by designers of diverse disciplines, in this case the architectural and the organisational discipline. This image is evoked mainly by the fact that both types of designers make use of the same concepts. This overlap however, is just apparent, as architectural descriptions concern architectural objects with among others organisational attributes and organisational descriptions refer to organisational objects with among others architectural attributes. The overlap of both types of descriptions determines the field of interaction and iteration between the design of architectural and organisational objects. An example may clarify this.

During the design of the architectural object decisions are made that emerge from its socio-political context in terms of descriptions according to the Professional Concept, the Use Concept, the Social Concept and the Technical Concept. They involve manipulation of the architectural object by the designing organisation, the organisation to be accommodated, the managing organisation and the production organisation. Designing the organisational object involves manipulation of the organisational object by the physical/spatial context. For this reason the architectural and the organisational object ought to be designed simultaneously and interactively. This means that the dimensions and articulations of both, architectural and organisational objects have to be adapted, 'tuned' or 'matched' to each other. Though all mentioned types of organisation are relevant, the process model emphasises the designing organisation. In the Professional Concept of the architectural object, the articulations i.e. subsystems of the physical/spatial design, are provided with attributes derived from the design of the designing organisation. That is, for groups of elements it is determined which parties have which mandates. Thus, the building is represented in terms of design tasks.

The organisational discipline is a special discipline, insofar that it is involved in the design of all kinds of artefacts, and thus in all branches of technological design, whether of an architectural, mechanical, information-technical, etc., nature. Though not further elaborated here, is it argued that multidisciplinary design with more than the two disciplines mentioned above passes off in a similar way.

In the description of a design situation, the concepts of the taxonomy do not only deal with potentially synchronously designing disciplines, but also disciplines acting in successive phases are involved. For example, the Social and the Technical Concept anticipate decisions to be made on a more detailed level in future phases of the total building process. This means that these decisions in the design stage - the subject of the model under consideration - should be structural: they should establish things as well as leave space for future decision making. In the construction and management phase of the building process the parties involved will perform decisive roles, whereas in the design phase they have a limited mandate, for instance as advisors.

In general, it does not matter whether actual parties are involved consisting of actors, or factors that influence the design. It is possible to depict the whole process as a process of actors as well as of factors. Factors or actors cover the whole field of design. Factors determine not further dividable forces of influence on a certain level of specialisation. The number of actors is equal to or smaller than the number of factors; in an extreme case one actor can fulfil all factors. It is the mere objective of designing a designing organisation to decide which actors have to be distinguished and which factors they have the mandate to decide about.

As the taxonomy implicates the contents of other (functional) disciplines and of other phases in the phase in which the actual designer is at work, a complete and practicable design situation can be described in terms of the three object dimensions of Form, Function and Time.

3.4   Situation and programme

All phases of the design process concern the design of an object based on the interaction between the requirements from the programme and the requirements of the (existing) situation, which are brought to synthesis in a plan. The situation is that particular part of the context of the project that has already been decided about (in a former process or in a former phase of the same process) and therefore can not be changed or influenced by the designer. In fact, the situation is the complete set of constraints, i.e. all starting points and limiting conditions, if possible translated into verifiable criteria.

As to form, function and time, the object to be designed will have to fit into this situation. This fit takes shape in a process; a basically never-ending process, as continuously adaptations will turn out to be necessary. This applies to the design as well as to the surrendered building. In a snapshot in time of that process a synthesis of a formal and a functional design may be perceived. In the early stages of the process the functional design dominates, while in later stages the formal design prevails. A complete and well-structured brief is an example of a functional design; a complete and well-structured situation is an example of a formal design. Moreover, in principle a programme always has a form-dimension too, and a situation always has a function-dimension.

3.5   Model-plan cycle

A model of an object is a structural representation of reality; it is simultaneously a conceptual system of meaningful elements, a conceptual system of qualitative norms and a conceptual system of rules by which material, sensory perceptible variants can be generated. This phenomenon occurs when the (abstract) model is confronted with a (concrete) context. Even in the case of structural description, just like in any object, a formal, functional and temporal dimension occurs. Any concept interpreted as an object, defines a corresponding aspect system, of which both the model description and the plan description are possible. The total object is thereby considered a mergence of several systems within the boundaries of the object.

A plan appears as follows: The plan is a choice from a set of plan-variants generated by the model. In a more complex design situation several (partial) models of the object to be designed generate, whether or not simultaneously, several sets of plan variants. In such a case first the mathematical cross-section of the sets should be determined, from which a selection can be made.

The transformation from model into plan may occur several times in a process. This means that a plan can be interpreted as a model again, which can be worked out into a plan. The principle of transformation from model into plan, from plan into (a more specified) model and then again from model into (a more specified) plan, indicates, because of the double role of the plan, a level-transition. The principle is applied in describing the whole design process, in a sequence of phases. The principle is also applied within a phase, where analysis of programme and situation results in two models that produce an integrated plan by means of synthesis.

The principle of plan making interpreted as a confrontation of a model with a context, or as a confrontation of two models, is a way of representing the hardly fathomable process of

synthesis. In that, the design approach according to the so-called conflict model is chosen, in which the eventual design is considered a reconciliation of incompatibilities.

3.6 Match of levels, functions and phases

Activities are characterised by their position and duration in a design process. Activities can be connected in series or in parallel. Within an activity synthesis of architectural and organisational objects is performed. This means that parties of a designing organisation have the task to make decisions about elements of architectural systems. In order to establish this synthesis, a linking should be made of the diverse dimensions determining these parties and elements in an activity.

In accordance with the theory, architectural as well as organisational objects have a functional dimension, i.e. the elements of the systems to which they belong, have functional attributes defined by the concepts of the taxonomy. Architectural objects have properties of physical/spatial elements; organisational objects (groups and parties of a designing organisation) possess knowledge about these properties. By using the same concepts of the taxonomy a functional linking occurs, a 'match' between architectural and organisational objects, in which the architectural object is also defined by the organisational object and vice versa. Application of one and the same taxonomy is compulsory for this match.

A second condition for synthesis is a match of levels of architectural objects organisational objects. Both kinds of objects have an articulation in levels. According to the conventions of the GOM-model a design space is represented by a cube with three dimensions: Form, Function and Time. A designer finds him/herself in the middle of this space and has 2 x 3 orientation possibilities: up and down, left and right, front and back The position of the designer is determined by dividing every dimension of the model in three parts; more divisions are not needed for this view. This means that the Form dimension is subdivided into three levels, the Function dimension into three domains and the Time dimension into three stages of development. There are only three domains (Usability, Tenability and Makability), but more levels and stages are conceivable. The presence of a middle level enables the consideration of its relation with a higher and a lower level; a stage may be considered in relation with its preceding and following stage and a domain may be considered in relation with its adjacent domains. Thus, all occurring relations can be represented schematically.

In this way the original single cube is subdivided into three 'tranches' representing level-bound design spaces, three 'tranches' representing domain-bound design spaces and three 'tranches' representing stage-bound design spaces (Figure 3.3).
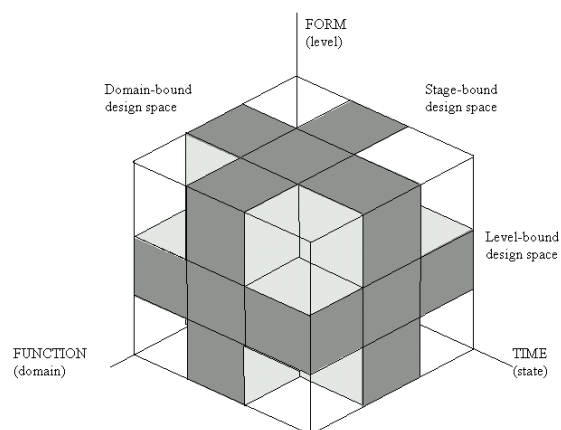

Figure 3.3: Design spaces of architectural and organisational objects according to Domain Theory.

The upright standing functional design space is sliced horizontally by three level-bound design spaces and vertically by three stage-bound design spaces. According to Domain Theory not only forms are articulated in levels, but functions too. These are specification levels as e.g. described by (Jones 1992) in his chapter about Specification Writing. As for the aforementioned bridging function of the functional dimension of architectural and organisational objects, identical articulation of the levels (of the form dimension) of both kinds of objects through the articulations of the functional dimension, is essential. This tuning is called 'matching levels'.
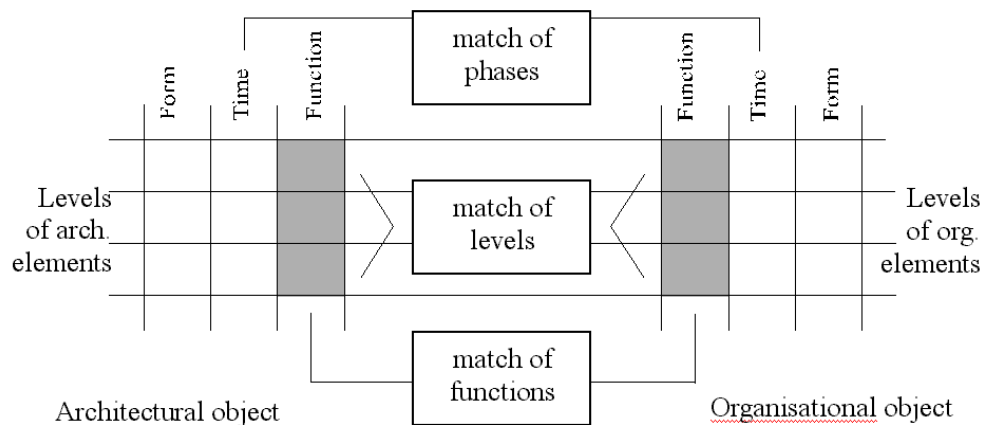

Figure 3.4: Match of levels, functions and phases. The principle of both types of matching is represented. The three dimensions of the architectural and the organisational object are depicted as three parallel (communicating) columns with the contents of Form, Function and Time.

The result of matching of functions and levels is that physical/spatial elements are arranged in levels, both in a formal and a functional sense, corresponding with organisational elements being authorised thereto.
In designing architectural design processes it is useful to join in with the traditions of the architectural discipline, i.e. that physical/spatial levels correspond with usual drawing scales. The articulation of the object's formal dimension is dominant with respect to the articulation of the functional dimension and also dominant with respect to the articulations of the organisational object.
If these conditions are fulfilled, the move may be made from objects to processes. The contents of the levels of the objects are then put on the same footing as the contents of the articulations of the design process, the phases. Next to the match of functions and levels, a match is made between the time dimensions of the architectural and the organisational object. The authorisation or mandate of each party is determined for each stage of the object. With this last step of matching phases, all dimensions of both objects have been tuned.

3.7 Processes and Activities

The design process consists of phases and phases consist of activities, which again may be composed of sub-activities. Activities may be considered the elements of the system; in this case not an object system, but a process system. There is no fundamental difference between phases and activities, although within a phase there is feedback between activities, which means that the result of an activity may have a preliminary and temporary status, while the result of a phase principally has a definitive status.

The contents of an activity is determined by a set of physical/spatial elements, their functional features and the parties deciding about them. As the activity is a building stone of a process, an activity is also characterised by an 'input' and an 'output', or an initial situation and a final situation. Moreover, management, monitoring and evaluation of all occurring manipulations should be carried out, in which prevailing rules, regulations and norms are taken into account. These subjects are also referred to as 'controls' of the activity. Next, the process should be provided with instruments, tools and resources, necessary for the execution of the operations; often somewhat deceivingly referred to as 'mechanisms'. According to the IDEF0 method input, controls and mechanisms can be output of other activities in an overall approach of the total design process. Again, output can be input for other activities and numerous feedback loops can be observed in the process. Activities can be split up into sub-activities, etc. (IDEF0 1993).

Pairing parties and physical/spatial elements determines the parties' mandates. Furthermore, in a process it is necessary (insofar the 'mechanisms' do not provide such) to determine the period within which the activity should be completed, the position of the activity in the course of the design process and the budget available for carrying out the process.

A phase consists of a number of activities, partially or completely connected in parallel or in series. The design process in principle proceeds from global to specific; i.e. from a low towards a high degree of specification. The contents of a phase consists of activities in which decisions are made about physical/spatial elements belonging to the same level. These decisions are made by parties assigned to a corresponding organisational level. Thus a direct relation exists between the contents of levels and phases, though levels primarily relate to objects and phases apply to the articulation of a process. Therefore, in designing the design process the resulting process phasing should be taken into account already in the first phases of that process, when levels are discerned.

In designing the design process fundamentally the same categories are used as in the design of objects: here programmes and situations, models and plans are involved too, although these categories now apply to a process and therefore concern activities establishing this process.

3.8   Design process: strategic choices

Though in the design process model several ways of phasing are conceivable, in this model a sequence is chosen in which successively an initiative-phase, a model- and a plan-phase are distinguished. These phases roughly correspond to the identification-, definition- and specification-phase as mentioned in the introduction. In each phase the architectural object, the organisational object and the design process are involved. Within these phases a sequence of programme and situation, model and plan sub-phases is discerned. In all (sub-)phases partial processes and feedback may take place simultaneously.

- In the identification or initiative phase (of the design of the design process) descriptions are made on a typological level. At this level the difference between the formal, functional and temporal dimensions of the object fades away, and the object is considered primarily as an entirety, as an image with its symbolically loaded meaning. Architectural as well as organisational objects and processes are considered as types.

- In the definition or model phase (of the design of the design process) descriptions are made on a systems level. At this level the form, function and time dimensions of the elements (objects and activities) are distinguished. This phase focuses on modelling the object and articulating it into levels.

- In the specification or plan phase (of the design of the design process) descriptions on a detailed level are made of the organisational object (the designing organisation) and the design process, aimed at the implementation of the design process. The object that was modelled in the previous phase, is now transformed into an object plan.

Specification of the architectural object takes place during the implementation of the designed process; this matter is beyond the scope of this discussion.

3.9   Design process model

Within the chosen strategy and based on the discerned categories: objects and processes, architectural and organisational objects, situation and programme, model and plan, it is now possible to describe a model of the design process in broad outline (Figure 3.5).

3.10 Design process as a plan

3.10.1 Identification phase

Identification of the kind of architectural of object
Global description of the requirements (and possibilities) of the programme and the situation. The description is made on a typological level (e.g. a regional hospital with 100 beds in the centre of a medium-sized town, a pavilion building type, etc.).

Identification of the kind of organisational object.
By analogy with the categories of the identification of the architectural object.

Identification of the design process
Global description of the requirements (and possibilities) of the programme and the situation. The description is made on a typological level (e.g. a serial or a parallel process, etc.).

3.10.2 Definition phase

The identified project is defined by modelling objects and processes according to a general description model.

Definition of the architectural object
Detailed description of the requirements and possibilities of the programme and the situation. Because of the heavy interaction between the two categories of requirements, no further systematic distinction into sub-phases is made here. The description is made on the basis of a structured analysis according to the description model of Domain Theory. Formal, functional and temporal dimensions of objects are described in qualitative and quantitative terms. Within the discerned (formal) spatial levels (and phases to be coupled eventually thereto) the analysis is carried out according to the (functional) concepts of the taxonomy. The analysis primarily concerns distinction of levels and subsequently decisions about the assignment of (functional) attributes to physical/spatial elements of the architectural object. Through this the identified object is defined and modelled. It should be reminded that the object is primarily determined as a functional design. This phase is concluded with synthesis of the analyses (of programme and situation) in a schematic model, articulated in levels.

Definition of the designing organisation (as an object model)
By analogy with the categories of the definition of the architectural object. This phase is concluded with a schematic model, articulated in levels, defining the mandates of the parties involved: the position structure.

Identification phase (Initiative phase) of the design process
1) Identification of type of architectural object. 2) Identification of type of (designing) organisation. 3) Identification of type of design process.
Definition phase (Model phase) of the design process
4) Definition of the architectural object (as object model) • Programme analysis. • Situation analysis. • Synthesis into a model of the object. 5) Definition of the (designing) organisation (as object model) • Programme analysis. • Situation analysis. • Synthesis into a model of the organisation. 6) Definition of the design process (as process model) • Programme analysis. • Situation analysis. • Synthesis into a model of the process.
Specification phase (Plan phase) of the design process
7) Specification of the designing organisation (as object plan). 8) Specification of the design process (as process plan).

Figure 3.5: Design Process Model

The architectural object to be designed and the organisational object to be designed mutually define each other. Several options arise: the architectural object imposes an organisational situation, or the opposite; adaptations are made on both sides. In the latter (most common) case iteration takes place. This iteration ends if a match is achieved of the functions and levels of the architectural and organisational object.

Definition of the design process (as a process model)
The definition is a further specification of the process type from the initiative phase. Based on the definition of the already functionally and formally tuned architectural and organisational objects (physical/spatial elements and positioned parties) activities are defined and arranged in the phasing of an architectural design process. To the design of the process as a model the same rules apply as to the design of objects. Hence there is a process situation and a process programme in terms of mandates, budgets and time limits. Thus a process model is defined

that is still open with respect to specification into a process plan in the specification or plan phase. This plan is a further specification and interpretation of the model.

3.10.3 Specification phase (plan phase)

Specification of the designing organisation
This concerns principally filling in the names of agencies and bodies belonging to the designing organisation and the detailed regulation of their mutual relations.

Specification of the design process
The model of the design process is filled in. Activities are architecturally and organisationally specified. This means that architectural elements are named, that intended changes are determined and that is decided which parties have which mandate to perform this task. The input, output, controls and mechanisms of the activities and the phases of the process are determined (e.g. according to the IDEF0-conventions). Also time limits and development budgets are laid down.

3.10.4 Implementation

After the design process is specified the implementation of the design process may be started. During this process the architectural object model is specified into an architectural object plan.

3.11 References

Aken, J. E. van (2001). Domain-Independent Design Theory, in: Achten, H. and Vries, B. de and Hennessey, J. (eds.) *Design Research in the Netherlands 2000*, Eindhoven University of Technology, Eindhoven, pp. 9-17.

Bax, M.F.Th. (1979). Domain Theory, Scope and Structure of Building Science, *Open House*, **3**, pp. 30-43.

Bax, M.F.Th. (1989). Structuring Architectural Design Processes, *Open House*, **14**, pp. 20-27.

Bax, M.F.Th. and Trum, H.M.G.J. (1993). A Taxonomy of Concepts in Architecture: A New Tool for Analysis and Synthesis in Architectural Design Processes According to Domain Theory, in: Behesthi, M.R. and Zreik, K. (eds.): *Advanced Technologies; Proceedings Fourth EuropIA International Conference on the Application of Artificial Intelligence, Robotics and Image Processing to Architecture, Building Engineering, Urban Design and Urban Planning*, Elsevier, Amsterdam, pp. 53-64.

Bax, M.F.Th., and H.M.G.J. Trum, (1996). A Conceptual Model for Concurrent Engineering in Building Design according to Domain Theory, in: Timmermans, H. (ed.) *Proceedings 3rd Design and Decision Support Systems (DDSS) in Architecture and Urban Planning Conference, Spa, Belgium, Part 1, Architecture Proceedings*, pp. 527-546.

Bax, M.F.Th., H.M.G.J. Trum and D. Nauta jr. (2000). Implications of the Philosophy of Ch.S. Peirce for Interdisciplinary Design – Developments in Domain Theory, in Timmermans, H. (ed.) *Proceedings Design Decision Support Systems in Architecture*, Nijkerk, 2000.

IDEF0, 1993, *Integration Definition for Function Modeling*, Federal Information Processing Standards Publications, National Institute of Standards and Technology, Gaithersburg, USA.

Jones, J.Ch. (1992). *Design Methods*, 2nd ed. Van Nostrand Reinhold, New York.

Trum, H.M.G.J. (1979). *Over het Normbegrip in de Bouwkunde*, Ph.D. thesis, Technische Hogeschool Eindhoven, Eindhoven.

Trum, H.M.G.J. and M.F.Th. Bax (1990). The Applicability of Domain Theory in Technological Design, in: McCabe, V.J. (ed.) *Design in Engineering Education, Proc. SEFI Conference*, Dublin, pp. 397-402.

4. Improvement of the Design Process

By Integrated Information Management and the Use of Computer Mediated Communication

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Keywords
Data web house, computer mediated communication, information handling, information exchange processes, information ecology, integrated information management.

4.1 Abstract
In this paper the changes in information handling within architectural design teams are explored as well as the attempts to improve information exchange processes within architectural design teams. The proposal for defining a model for integrated information management is worked out with the use of computer mediated communication.

4.2 Characteristics of information-handling in architectural design processes

Within temporary, project based organisations as well as permanent, small, medium sized or big organisations, the handling of information should be as important as the organisation of the team and the management of it to produce results. Handling of information concerns the generation-, transmission-, publishing-, receiving-, storing- and retrieval of information of an organisation verbal as well as non-verbal, synchronic or a-synchronic (Den Otter and Prins 2000). Within temporary project based organisations for technical complex building projects information exchange is of growing importance because of the following reasons:
1) Technical complexity as well as volume of these projects is growing.
2) Time pressure is growing for reasons of organisational as well as real estate concerns of the client.
3) More and different organisations are participating in the project.
4) Design teams for designing the artefact are growing because of the higher technical demands and the higher quality demands.

4.2.1 Design processes
Design processes in these kinds of projects are especially important concerning information handling because in the design the needs and expectations of the Client (The Client's brief) are translated into sketches, images, drawings and schemes. Designers use this kind of information exchange together with verbal information exchange (Donker 1999) to represent the volumes, masses and materials of the building they design.

Architectural design processes are creative, multidisciplinary, iterative processes, consisting of structured sequences of activities, directed to solve complex, ill-structured architectural problems.

Design is a reflective continuous whirling process in which 1) interpretation, 2) generation, 3) comparison of 4) design choices is important:

1) Interpretation: What's the shape of the problem? A definition of the problem.

2) Generation: What are the alternative solutions? A range of alternative solutions.

3) Comparison: What makes them different? A set of comparisons and preferences.

4) Choice: Where do we go from here? A decision about policy and action.

On the other hand the building that is designed and represented by drawings, images, sketches, schemes and documents has to be realized by building contractors, sub-contractors and suppliers. The design information produced for the participants mentioned above has a totally different focus and purpose. That is why in the design phase all the information and knowledge to realize the building in the most economic way should be available.

Design teams for technical complex building and design projects mostly consists of different designers coming from different organisations with different ways of handling information. Design teams are growing because of higher quality demands of the design for the building produced by the team. A lot of design specialists come into the team as van Loon (1998) stated. Design processes are whirling processes and consists of problem finding as well as problem solving processes (Rutten and Trum 2000, Friedl 2000) in which information handling between the design partners within the team is essential to produce the solutions for the design as formulated in the Client's brief. Participating designers and design organisations are highly depending on the exchange of each other's information to design their own solutions to the Clients brief (Heintz 1999). In most design processes, several design organisations with specialized knowledge are hired by the client for the development of the design; architectural designers and specialist designers for structural design and engineering, building physics, installations HVAC, facility planner, ICT, building cost adviser and others.

4.2.2 Design teams

The configuration of the design team for a Building & Construction project is mostly as unique as each Building & Construction project is. The information handling process within such a team is primarily a whirling information exchange process between the participating designers about the artefact to design. Sketches, images, drawings and schemes are key information carriers for the handling of design information. The information handling between the architectural design team and the Client's organisation mostly is an important aspect of a decision taking process as well as a negotiation process with several stakeholders in different settings. The designers have to convince the client that the design they produced is the best solution to his needs and demands as formulated in the Client's brief.

For the purpose of this research an architectural design process for a technical complex building is seen as an information exchange process, processing multi disciplinary design information: object information as well as process information.

The information handling within design teams is complex and difficult due to reasons mentioned above. The different partners in the design team do have, apart from that, different information needs. Those needs can roughly be separated in the information needs of the client and the stakeholders and the information needs within the design team that generates the design. When building contractors are participating in the team up to date technical construction- as well as construction experience information exchange becomes available for

the team. This is especially important in fast-track projects in which there is a great time pressure on the design team to work as concurrent as possible (Den Otter and Prins 2000). The information needs of the client and stakeholders are focused to choices made in the design. The focus of the information needs within design teams is to get the right information of the client and his organisation and to exchange the generated design information between the design partners as efficient as possible to keep progress in the design process.

4.2.3 Information media

All the time new media for information exchange are entering the market. But the old media (books, paper mail, newspapers) don't disappear (Davenport 1997). Continuous developments in ICT are strongly influencing the way processes in the building industry give new dimensions to the notions: information and communication. Recent developments in the building industry lead to the need for ICT implementations op project level. However implementations of ICT- tools are implemented market driven per organisation instead of in the temporary project organisation.

Recently, web-based ICT tools: "Project websites or Data web houses (DWH)" entered the market. These kinds of tools can open the door to interactive, digital information, extranet environment for a collaborating team of design organisations in a building project. This digital environment looks ideal to use also within the design information environment because of the transparency, the openness, the collaborative, the safety and the dissemination aspects of such an information system.

- Transparency makes it possible that everybody has a clear site of the complete flow or flood of information and the changes in design.

- Openness makes it possible that everybody has access to all the information needed for designing.

- Collaboration makes it possible that the tool increases the collaboration in working together on the same object, see the progress of the design and the missing parts as well as the changes made.

- Safety makes it possible to put information in the DWH that can be traced at all times, protects the owner and protects the information by digital keys.

- Dissemination makes it possible to use specific information earlier in all parts of the designed object.

However, effectiveness of ICT-tools and efficiency of information flows and processes depend only for a part on the tools and the systems themselves, as we all know! In the Netherlands, and not only in this small country design teams and organisations are still facing major problems with their CAD-systems in regard to effectiveness and efficiency, and the exchange of information, the libraries and the codes for elements.

Design organisations; architectural offices as well as adviser's organisations, still aren't used to work usually in their projects with 3D-CAD systems for design work as we expected so many years ago! They are working mostly in 2D with all lot of different systems. They produce different stored and coded information, in different formats, and work only some-times in 3D.

Davenport (1997) writes about this subject: "Better computers and communications networks do not inevitably lead to better information environments". It involves people working in organisations: "Human factors are the keys"! The following statement could be added to these lines, specifically for architectural design teams in the Netherlands: "There are as much information systems as there are architectural design organisations".

For the above reasons this paper is specifically focusing to people working in the design information environment, working with all kinds of information systems in design teams and design organisations, digital as well as non-digital. That is why the main question about this subject is: What do we know about the design information environment, this specific information landscape with sketches, drawings and images as key information carrier?

Other questions following are: What do we know about the information behaviour and the information culture in the design office and the design team? How is the information environment managed and controlled? Who is responsible for it?

4.2.4 Information landscape

Davenport writes about the changes in the information environment, behaviour and culture in all kind of business offices and business organisations. He writes about the information politics and the way we usually inform other people: verbal, by writing or digital. However Davenport doesn't write about or did research in the permanent, design organisations as well as in the temporary, multi-disciplinary, design teams in the building industry.

Verbal information has the highest percentage for chief executives and managers. Designers inform other people by sketches, images and drawings and, most of the times, together with a verbal, explaining story. Designers information attitude were not investigated by Davenport.

It is important to get a clear view on the information landscape within design organisations as well as in the design teams to know what can be improved, the importance of it, and the chances of success for the aspects and matters that are intended.

4.3   Problems with information handling

Because of the growing team, the growing pressure in time, the growing technical complexity as well as the volume of building projects the improvement of the management of information handling: information management is of great importance to get a better control and steering on the growing team, the growing etc. etc.

The use of computer mediated communication promises to solve a lot of these problems by the use of so called Data web houses.

4.3.1 Information handling

Better control as well management of information handling in architectural design processes for the design of technical complex building projects is of great importance for the improvement of the performance of those processes. The need for this on the one hand arises from the growth of design teams for big complex building projects in which more different design organisations are participating (Heintz 1999) as well as designers with specialist knowledge (Van Loon 1998). The need on the other hand arises from the growth of the volume, the size and the technical complexity of big building projects. Together with the growing building volume and technical complexity the number of participating design organisations is rising (Heintz 1999). Van Loon (1998) writes about these designers: the number of involved specialists is rising faster than the number of architectural designers.

The information handling within design teams is complex and difficult due to reasons mentioned above, all the more because the different partners in the design team do have different information needs. Those needs can roughly be separated in the information needs of the client and the stakeholders and the information needs within the design team that generates the design.

The focus on the information needs of the client and stakeholders (Donker 1999) has to do with the choices made in the design. The focus on the information needs within the design

team is to get the right information of the client and his organisation and to exchange the generated design information between the design partners as efficient as possible to keep progress in the design process. Designers are depending strongly on the generation of information of the participating designers to develop their own part in the design (Heintz 1999). Parts of the architectural design often are designed simultaneously or concurrent under the influence of the growing time pressure on the design process.

4.3.2 Influences to information handling

The information handling within the design team is influenced by a number of aspects: 1) The arrangement and control of the architectural design team (den Otter 1999), 2) Differences in the working methods concerning the exchange of information of architectural design organisations as well as designers themselves (Heintz 1999), 3) Changes in the suitable information-exchange media in which electronic media like Internet play an ever growing role.

Arrangement and control of the architectural design team (den Otter 1999)

Architectural design teams for the design of complex Dutch building projects are mostly temporary, multi-disciplinary design teams with a client and several stakeholders within a project based environment. The arrangement of a design team is mostly as unique as a complex Dutch building project is. For architectural design often the client hires several design organisations with special knowledge: architectural designers, specialist designers and technical advisers. The selection of design partners often is based on the best economic offer instead of based on criteria for collaboration and teamwork. The control of the architectural design process is strongly focused to co-ordination of the design partners (Heintz 1999) and is depending to the way a project is managed by the client and/or the delegated client.

Within the project environment and the design team of a complex building project on the one hand the control of information is an important aspect as stated for instance in the PMI-BOK (1995) and on the other hand there is a certain, continuous desire to communication and information exchange as (Donker 1999) argues. There are big differences in the way designers exchange design information. A characteristic of designers is the inimitable way of working they have and visualize their design results in different ways (de Bruijn 1999), amongst others by means of sketches, three-dimensional images, collages of existing images and so on. Due to that aspect the information exchange between designers is multi-interpretable. That is why often face-to face communication is needed to prevent misunderstanding and mistakes in perception of the design. Within the context of advisers who are designers as well as the architectural designers are, also have to be included the technical engineers who translate the final design into the detailed design by choosing building products and materials that fits within the design.

Differences in the working methods concerning the exchange of information (Heintz 1999)

The differences in working methods for exchange of information of design organisations arise from the differences in applied information systems within design organisations especially for CAD. These systems mostly need different working methods. As there are a lot of different CAD-systems in use in design organisations there are also a lot of different offices depending or application depending working methods.

Changes in the suitable information-exchange media

Due to the appearance of the Internet as well as email communication tools the information exchange is strongly influenced. The speed as well as the a-synchronous character (transmitter

and receiver do not necessarily have to be in contact with each other at the same time) of this type of communication is of importance for the users. From the preliminary design phase visual readable information like sketches, images, drawings and schemes often are as important as verbal information.

The improvement of the handling of information within architectural design processes for technical complex building projects can lead to:

5) Decreasing of throughput time of the design process decreases the total project time.

6) Expectations as well as needs of the client and the users can be suited faster as well as better.

7) Accelerating concurrent design and concurrent engineering processes that causes earlier start of realization of the building.

8) Improvement of the overall quality of the product.

9) Decreasing cost of design failures caused by design changes.

10) Improvement of the output of electronic information exchange.

11) Magnifying the chances to collaboration and teamwork between the concerned parties in the process.

4.3.3 Implementation and application of ICT - tools

To improve the efficiency of information-exchange processes for architectural design almost continuously, new, improved, as well as better ICT-tools are being implemented in design organisations (BNA 2000). The market of ICT-tools is rich in providing different tools with different possibilities as well as different prices. This makes it hard as an organisation to make the right choice so it is even harder and almost impossible to implement the right tools within a temporary design team that consists of different design organisations using different ICT-tools. This is a well-known phenomenon called island automation. Earlier attempts to buy the same tools for a specific purpose branche-wide within architectural design organisations failed (VCA 1984-1986) because organisations are used to make their own choices based on their own needs and budget. Usually they wait for the right time to implement the tools within the organisation when the organisation is ready for this.

Because of the described phenomenon, design organisations created their own information environments with working methods based on the possibilities of the ICT-tools, the knowledge and experience of the organisation as well as the supplier with the specific ICT-tools. The implementation and use is very less based on norms and rules defined by branches because up till now these norms and rules are not available branche-wide and didn't pass even the definition phase (B.A.S.). Only attempts to define rules within user-groups for specific ICT-tools were successful like the organisation "Geïntegreerd Bouwen" for the use of AutoCAD within design organisations. The use and implementation of different CAD-systems in design organisations in the past fifteen years is the best example of this fragmented implementation and caused new and other problems in the exchange of design information.

Because of these reasons it is reasonable to expect that the implementation of new communication tools within design teams to solve information exchange problems faces problems as well as causes new problems we are not aware of at the moment. On the contrary the implementation and application of these ICT-tools goes much faster then the implementation of other ICT-tool because this implementation is more or less market-driven. A lot of design organisations like to profile themselves with new Internet tools being an up to date high tech as well as dynamic firm ready for the job. The branche organisation of

architectural designers in the Netherlands: BNA expects that within one year time (in 2001) 70 to 80% of all the architectural firms will use Internet and email (BNA 2000).

The latest ICT-developments concern Internet-tools for the application of Extranet environments in which all the project documents can be stored, updated and used by all participants in the design team (so called Data web houses). However these tools are promising in terms of solving information exchange problems, the effect and profit of using these tools is highly depending to the organisation and control of the information environment in which this technology will be implemented (Den Otter en Prins 2000).

4.3.4 Information environments

An information environment can be defined as the total structure of implicit- and explicit information exchange processes permanent or temporary organisations uses to reach the defined targets of the organisation. Implicit information exchange processes are mostly verbal, person depending exchange processes without vast procedures. The information environment of an architectural design organisation can be defined as the total structure of information exchange processes this permanent organisation uses to achieve continuousness in the generation of designs for building projects.

The information environment of an architectural design team can be defined as the total structure of implicit and explicit information exchange processes this temporary organisation uses for the generation of a specific, client-oriented, architectural design as well as to realize this design within an approved budget.

The information environment of a design team depends on the configuration of the project and the participating organisations. The design, arrangement and control are depending on knowledge and opinion of the project organisation in:

1) The project information environment.

2) The information environments of the participating design organisations.

3) The views on the possibilities of information exchange.

There are differences as well as similarities in the targets of the architectural design team and those of the participants in the team.

One of the most important targets of a design organisation is to continue the organisation after a design is finished and realized to be able to design other projects. Generated knowledge of realized designs is important for application in future projects as Weggeman defines within his book "Knowledge Management" (1997). Re-use of generated design information, knowledge and experience out of realized designs as well as design processes.

The most important target of the design team is to generate the design in conformity with the requirements and expectations of the client and within the specifications of time, budget and quality as confirmed with the client. The interest of the organisation of the design team is focused on collaboration and information exchange within the team to deliver specific knowledge of the concerned design organisations in time at the right location for application in the design and to prevent failures due to new, outdated or changed information.

Information environments of design organisations differ from each other as described before. As an example the information environment concerning CAD information exchange will be described in this paragraph. This part of the information environment is different within design organisations because of the implementation of different structured CAD-systems with different possibilities in 3D as well as in 2D. This development in design offices has lead to a discipline as well as office focused organisation and control, which from the perspective of the information environment of the design team can be seen as a nasty form of island automation. The lack of general norms, appointments and references within the Dutch

building industry for the structuring, storage as well as exchange of information is an important reason why this development could take place. Already in 1994 branche-organisations (BAS 1994) finally took the initiative to define a rule-system Building Industry-wide. However, until now this system is still in the definition phase and is not implemented in the building industry or in design organisations.

4.4   An information ecology model for the overall design process

To get a clear view on the information ecology of the design information landscape seven different components are distinguished: 1) Information architecture, 2) Information strategy, 3) Information systems, 4) Information processes, 5) Information management, 6) Information politics and 7) Information Culture / behaviour.

These seven components for the model are based on the components of the ecology model of Davenport (six components) as well as on the 7S model of McKinsey as well as own observations and experiences in the architectural design- and drawings environment (Information systems).
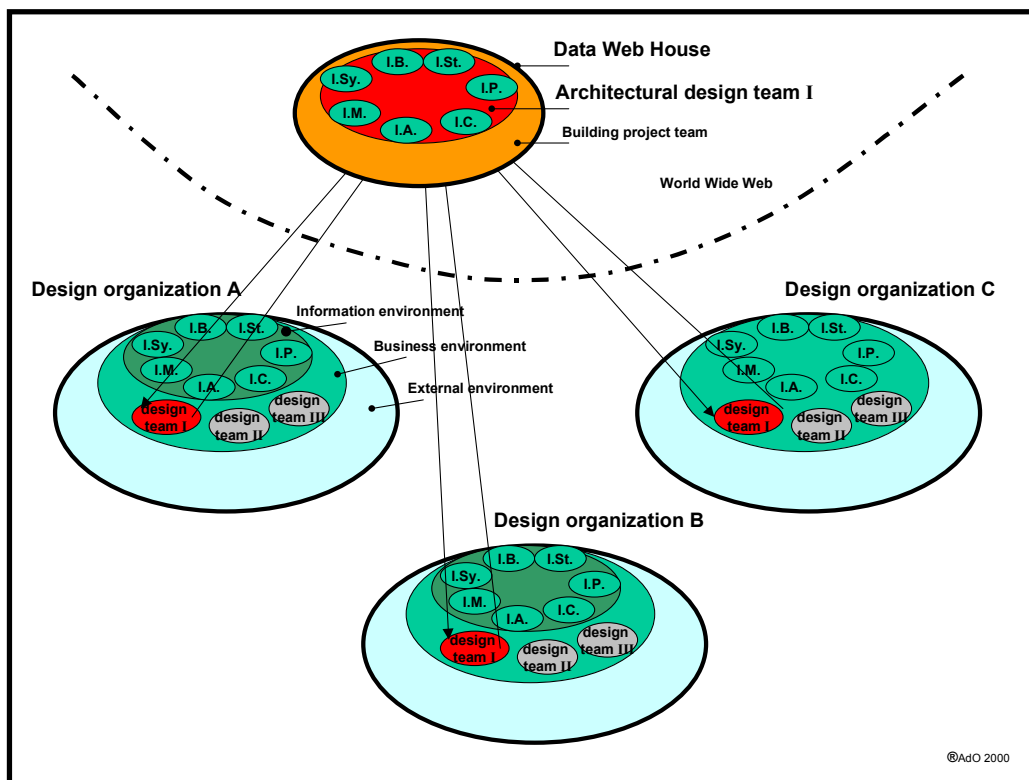
Figure 4.1: Components of design information landscape.

4.4.1 Problems in the information exchange of architectural design processes

As stated by Den Otter and Prins (2000), important problems in information exchange processes within architectural design teams are caused by problems due to the design object, to the design team and by tools (ICT included). Design object aspects:

1) The complexity and the volume of building projects.
2) The growth of the volume of the design related information.
3) Changes and risks of mistakes in the design.

Team aspects are:

4) The growing time pressure of the design process.

5) The growing number as well as globalisation of design partners.

6) Differences in information handling of design partners.

ICT aspects are:

7) The number of applied electronic as well as non-electronic information systems

8) Double, incomplete and not updated information in different information systems as well as changes in information systems

9) The speed of technological changes.

As described in section 4.2, the information exchange is becoming more complex and difficult by the growth of the architectural design teams and the growing complexity and volume of building projects and besides that the application of different electronic information exchange tools and the lack of standardisation and norms for the procedures and exchange processes. For instance: There are standards and prescriptions for the design products that are delivered in specific design stadiums starting with the Client's brief, the Structural Design, the Conceptual Design, the Final Design and the Technical Design (NEN 2574). Design solutions have to be approved by the client, the users as well as the local authorities and concerned groups. But information processes, needed to communicate about design solutions or to exchange, integrate, compare information produced aren't standardized or even described. Chances to delays in the progress of the design are enlarged as well as the chances to mistakes and failures due to continuous chance-procedures in the developing design process.

4.5   Research into improvement of information exchange processes

In the recent past most efforts to cope with these developments were directed to setting up a prescription of a building as a collected assembly of information entities (object modeling). In the Netherlands for instance we have had BIM (with Idef technology) and COMBINE (with ISO-step technology) as the two major efforts. Apart from these attempts to improve information exchange also attempts were taken to model information exchange processes, based to object modelling theories: Electronic Data Interchange (EDI) and Product Data Interchange (PDI).

These attempts were successful within the Civil area as well as in mechanical installations but not in the Dutch building industry and in the design area. De Vries (1996) tried, by means of a vast protocol, to model the communication within the building process while Donker (1999) by means of a design language called Scaffold tries to improve the communication between all the stakeholders involved in the design and building process.

Bälter (1999) did comparable case studies to the use and application of email as information exchange system. He concluded amongst other things that apart from information-overload there is also communication-overload. He argued that it isn't only of importance what to exchange but also how and why. Email communication is positioned within a total framework of information exchange systems that an organisation uses as well make their choices out for her primary work process, depending on situation and circumstances.

As stated before the multi disciplinary architectural design team often has a fickle and unstable information environment. Davenport (1997) has done research to the improvement of information environments in business organisations and describes an approach for improvement by the holistic approach of 'Information Ecology' in which the human being is positioned centrally in an ever-changing information environment. Based on the 7S-model of McKinsey an "Information Ecology Model" is developed with three levels: the information

environment, the business environment and the external environment. Three aspects are dominant to the opinion of Davenport: 1) Information overload, 2) Information politics and 3) Multiple meanings.

This might be an interesting approach for the environment of design organisations however it is not applicable for temporary design team not directly. The project environment in which the information environment of the design team occurs is not defined in Davenports model. Den Otter and Prins have defined this in their article "Design management within the Digital design team" (Den Otter and Prins 2000), where they made a distinction between the following aspects:

1) Information strategy.
2) Information staff.
3) Information-architecture.
4) Information processes.
5) Information systems.
6) Information politics.
7) Information culture and behaviour.

4.6   Conclusions

The holistic attempts of object modelling as well as process modelling were not successful. That is why it can be stated that solutions have to be found within the management of the information handling of the design team as well as in the information management within the design organizations. For that reason the first exploring research by case studies (Yin 1994) about information handling finds differences as well as similarities in the information handling at workflow level as well as the management level (Gummesson 1991). The goal is to define the design parameters for the design of an Integrated Information Model to manage and control the information handling within the design process. By means of defining a classification system an insight view can be given to the information environments of the participating design organisations within the design team.

For the definition of the design parameters the next list of aspects is of concern:

1) The differences as well as the similarities in the information environments of the design partners.
2) The design of the architectural design management system and the level of self-control of the design partners.
3) The complexity of the design.
4) The application of the information systems for CAD and documents as well as the project management- and Internet tools.
5) The different information exchange systems.
6) The application of a Structure of rules (GB, VG-bouw or concept of the BAS).
7) The knowledge and experiences of the participants concerning the use of Computer Mediated Communication Communication (CMC).
8) The management and control of rights of ownership of information.
9) The information politics and information behaviour.
10) The technical information management (management of ICT-tools).

4.7 References

BNA-ACCIS (1999). Benchmark Investigation About the Use of ICT-tools as Well as Internet Amongst Members BNA (Bond Nederlandse Architecten).

BAS (1999) 'Bouw Afspraken Stelsel', *Central Rules for the Dutch Building Industry*, Release of Vereniging Bouw Afspraken Stelsel, Jan. 1999.

Davenport, T. (1997). *Information Ecology,* Oxford University Press, Dover Publishers.

De Bruyn, R. (1999). *Creativiteit, Alfa-Omega , Visie-Vorm,* De Bruijn Antwerpen.

Den Otter, A. (1999). Ontwerpmanagement en Project Management, *De Bouwadviseur*, **Sept.** 1999.

Den Otter, A. and Prins, M. (2000). Design Management Within the Digital Design Team*, Proceedings ECAM*, Atlanta, July 2001.

Den Otter, A and Prins, M. (2000). High Performance Teams in Fast-Track Projects, paper to present at the *International CIB conference* Wellington 2001, proceedings.

Donker, P.A. (1999). *Structuring Communication in the Architectural Forum, Scafford,* Delft University Press, Delft.

Drucker, P. (1988). The Coming of the New Organization*, Harvard Business Review* **66**, Jan-Febr., Pp. 45-53.

Friedl, G. (2000). *Modellering van het Ontwerpproces - Een Proces-Choreografie* (Modelling of the Design Process - A Process Choreograpy, TU/e Press, SAI-ADMS publication, Eindhoven.

Gilbert, E. (1975). *Technical Communication and Writing - Managers Perspective,* University of Michigan.

Gummesson, E. (1991). *Qualitative Methods in Management Research*, Sage Publications.

Heintz, J. (1999). *Coordinating Collaborative Building Design*, Ph.D. thesis, Delft University Press, Delft.

Loon, P.P. van (1998). *Inter Organisational Design,* Ph.D. thesis, Delft University Press, Delft.

PMI-BOK (1995). *Body of Knowledge for Project Management,* Association of Project Management U.K. (APM).

Rutten P.G.S. and Trum H.M.G.J. (2000). *On the Innovation of Buildings,* Internal Publication, TU/e FAGO, Eindhoven.

VCA (1985). A*ttempts for Collective Buying and Implementation of Software-Packages for Financing, Administration, and CAD.* Vereniging Computergebruik Architecten (VCA), release 4.

Vries, B. de (1996). *Communication in the Building Industry,* Ph.D. thesis, Eindhoven University of Technology, Eindhoven.

Weggeman M. (1997). *Kennismanagement, Inrichting en Besturing van Kennisintensieve Organisaties*, Scriptum Management, Schiedam.

Yin, R.K. (1994). *Case Study Research - Design and Methods,* Sage Publications.

5. Design Methodology for Building Products

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5.1 Introduction

In this paper the Organogram for Product Development is described for standard products. The Organogram describes in sequential and parallel activities with feedbacks, the main lines of a design and development process for a new standard building product, completed with the necessary marketing phases. In view of the design results, students would benefit more when these and other methods are taught from the very start of their education. The handling of design methods should therefore, as far as it is lacking in the basic years, be brought to that basic training. Not only students need to be educated, teachers also have to become aware of that, in order to make explicit their individual design methods from their subconsciousness and then carry it through to students. Actually three types of building products can be mentioned, separated from each other by the influence of the project or the consumer/project architect, versus that of the product or the producer. In that tense field are: special, system and standard products. Reasoning from the project architect's point of view, who used to draw all component parts of his building himself in former days, this is (extremely put) the sequence of 100% to 0% of influence from special to standard products. From the producing industries' point of view (for instance glass production industries, also working for the automobile industry) the preferential sequence with the intermediate form of products (of which the characteristics also lie in-between the three main lines) is, of course, the other way around: from standard to special products:

- Standard product.
  - Systematized standard product.
  - Standardized system product.
- System product.
  - Special system product.
  - Systematized special product.
- Special product.

The sequence reflects to the producer the sliding down of mass production at a large scale to the workplace productions at a small scale. In view of the normally relatively small serial sizes in the building industry, a much used intermediate station is that of the system products, as greatest common divisors to be put in with more projects and which can be made suitable with relatively little trouble for individual projects in production. The three main types of products have enough different characteristics to scrutinize all of them separately and also to follow a different development process strategy in each of the three cases. Although the following process organizations are very analytical, there is also a holistic vision at the basis. Out of the holism the total is always reflected in the parts. With this is not meant the

connections of parts, but the character of the whole. This influence is especially strong at the synthetical activities like the design synthesis of phase 1 and the research activities of phase 3, by which these will always maintain the guarantee of putting them into the whole.

5.2   Organogram standard products

As a work method to control the entire process, the Organogram for standard products describes the entire process of steps and activities from the initiative up to the actual regular production. The Organogram is a reflection of the sequence of process activities as the author has experienced it as a model for a smooth running process in designing and developing in his company Octatube. These activities, however, are described in a generalizing manner to have a broader validity. The sequence of the various steps or activities is serial (one after the other) or parallel (one next to the other). The specific project circumstances, like the completion of the concerned development project, the capacities and insights of the participants in the process, the time pressure from outside and such worries, cause a different interpretation of any of the three general Organograms up to a specific project Organogram or process Organogram, over and over again. But this does not in the least alter the validity of the Organogram as a general method for product development. Certain sequences are very consciously placed in the shown framing, like firstly Objective and Strategy, after that Evaluation Criteria and only then the working with the Analysis, Brainstorm and Synthesis of partial aspects, then the entire product concept and behind that the evaluation activities. Actually it concerns the sequence of four clusters of activities blocks:

- Objective and Goal.
- Analysis and Synthesis of aspects.
- Clustering for product concept.
- Evaluation and Feasibility.

The order of these four blocks can not be altered, but there is more freedom within the blocks: the partial aspects can be gone through serially or parallel, depending on the subject. Serial working means to be able to concentrate on one single problem at the time, while parallel working means the shoving around of information in one mind, or the simultaneous working of more division groups of process participants. The price of parallel working is a higher complexity in a structured chaos with an inherent loss of costs, the advantage is a more frequent feedback and a faster result. Parallel working is fierce and more expensive, but faster. No more waiting, but anticipating. The increasing demand for parallel working is expressed in the notion 'concurrent engineering'. We must take into account that principals will want to work through design and building processes ever faster. One of the activities which is hardly to be shortened, is the building permission trajectory. In the beam chart of the entire (preparation and realization) building process the length of the beams of the building permission procedures are hardly alterable. The longer the building permission beams become, the less time is left for engineering and building. In the future the building process will become ever shorter. Concurrent or simultaneously working with all its dexterity to double activities as few as possible, should belong to the intellectual luggage of the engineer.

These types of products are mainly directed at the industrial market and at industrial manufacturing. They are distinguished from the special and system products because the project architect (practically) has no influence on the creation of these products, their manners of production and therefore, the actual resulting product. All he can do is choose: whether or not to apply a certain product. Sometimes minor interventions in the product can still take place per product, like the tangling of bricks, the cutting to fit of tiles or glass plates, but that

is not an influence which is related to the nature or the production manner of the design. The Organogram for standard products is built up of five characteristic phases:

- Phase 1: Design Concept.

- Phase 2: Preliminary Marketing.

- Phase 3: Prototype Development.

- Phase 4: Final Marketing.

- Phase 5: Product Manufacturing.

5.2.1 First phase: Design Concept

The first phase of the Organogram is titled 'Design Concept', and is comparable with a Preliminary Design in architectonical designing. First we will globally explore the steps in this phase before going deeper into each phase. Especially head and tail of this phase, first and foremost deserve our attention.

The Organogram was based upon the entire project being viewed as a 'project'. Logical in activities, but rather confusing in connection with the titles of project architect and product architect. Therefore we will henceforth rather speak of process, instead of project, and in that sense the adjacent Organogram has been adjusted. It is of the greatest importance to correctly define the process objective, the start of the process, the process strategy, the process goal and the evaluation criteria. One could compare this with the importance of a good programme of requirements for an architectural design. If the programme does not meet the actual needs, then much energy is wasted and false expectations are raised which can only lead to disappointment. Firstly, this initial cluster of steps is important because from this the direction the process is heading for is determined and from this the product will be developed in the process. Secondly, it is important to build in the expectation beforehand and the scoring rate afterwards. If the result of the process does not meet the evaluation criteria, the process has failed, unless halfway by a genius turn a consciously different route is taken. When this happens, it is good to realize that the initial goal is not achieved and the goal halfway (that is, after the genius turn) must be adjusted consciously and motivated. It has happened more than once that so-called coincidental discoveries in a research process led to radical results at a worldwide level, while from the original process only an anecdotal mention remained. But this can be looked upon as the exception to the rule that the process must be gone through very accurately. The danger of 'drifting about' in a product development process with all its inherent loss of energy is many times greater and more frequent than the chance of an unintended brilliant side-product. It is a matter of efficiency of human resources.

The end of the first phase must be concluded with the economical step of feasibility, which can also be looked upon as feedback for the evaluation criteria. When this first phase is thus concluded by a positive result, only then the second phase will be entered.

The initiative of a producing company to complete the company's assortment with a new product is derived from the unbalanced relation between changing demands and the set supplies. This new product shout fit in the current assortment, be produced by the existing, available equipment and channelled through existing marketing routes. From this initiative the specific product process comes about.

Start of process: 1

The start of the process is set up by the commission to develop a certain standard product, mostly a material product or also immaterial (like 'virtual') products. The motivation behind this commission can be formed from questions from the practice (= market) for a yet non-

existing product, or an improvement of an already existing product which, by altered usage circumstances is no longer seen as a sufficient answer to the demand. It is also possible that this motivation contains a hidden theoretical objective (for instance in an academic study), leading to a hypothesis without a direct control on the practice. In that case the process must be understood as a product development game, where the end results not necessarily can be or have to be realistic. For instance, the development of Zappi, the famous research topic of tough new and unbreakable structural glass-like material at the Faculty of architecture, TU Delft.

Since, in the case of a hypothetical starting point, common sense and insight are capable, indeed, but personal practice experiences (knowledge) and learning are not capable of making sufficient corrections, it is an absolute necessity to describe and document the process game properly, in order to maintain one's course at this outside world level, in order to communicate with the persons involved in the game. This goes for the student, as well as for the teacher. Well begun is half done. A false start is usually noticed late in time and means loss of energy, much displeasure and friction. The very first question one has to ask oneself at the start of the process and the choice, respectively the acceptance of the product commission, is if this required product is in accordance with the market demand behind it or if it will be so in the future.

Process goal: 2

After the above, the first thing to do in the process is to describe its goal. When it concerns a building, which usually comprises a multiplicity of functions, a programme of requirements describes which functions a building must have. Such a programme of requirements is very extensive for a building. It also changes with time. For the smaller components of the building, however, each of them having less complex functions it will, of course, be simpler.

According to Roozenburg et al (1995) the programme of requirements must in any case mention how many identical numbers of the product must be manufactured, what the price will be and for what market the product is meant. Besides, a design commission has to contain a product basic idea, given by the commissioning company.

Here the question is if the objective or the programme of requirements is set clearly enough, if any inconsistencies have crept in, if there are too personally coloured visions processed in it (that is to say: hobbyism) which would not be just and would lead to a product which somebody may like to see, but would not be a realistic answer to a demand from the market. Enclosed in the company's brief to the designer is the notion that the required product is likely to get a sound receipt at the market. So, this has everything to do with the initial estimating of the characteristics of the product at this point, in order not to become saddled with an unsellable product after the development process. This market notion can be described and controlled by, for instance, making inquiries into a small group of professionals at the very least, or by dedicating a market inquiry on a large scale to it, completed with evaluation reports and a well-reasoned objective of the product. Since the danger of an initial deviation of course in the process, set in at this point and later to be corrected, does not seem hypothetical, it is of the greatest importance to document and elaborate one thing and another, so that afterwards, when there is a correction of course, feedback can be applied. All these activities are the client's responsibility, before commissioning the designer.

Process strategy: 3

Next to the process goal it is good to already map out a route towards the achieving of this goal. Estimated at this stage is how many steps or activities have to be to put in, one after the other or simultaneously. The exact progress of the process is in the dark, but it is good to

make an overall survey before actually starting to work. To students who are confronted with a plan like this for the first time, it is good to set up their own process diagram of assumed steps or activities: their own Organogram. There must be no fear that all steps will not be mentioned or that the emphasis is put on other things when executing the process: the process diagram can be kept up and altered all the time, so that it can serve as a reference book of process management. A second time it will definitely be easier. After this, for instance, the standard sequence will be maintained and from the standard schedule the specific process alterations are brought in automatically. After the first exercise, a certain knowledge should arise in the guidance of oneself and in the reasoning on what activities have to be processed first, followed by what others, respectively what activities must be done simultaneously.

At first sight the alternation of the technique and marketing phases in the Organogram is very striking. To the building technology student it is a clear sign that two marketing phases have been built-in between the three technique phases. To the building management student it is clear that the marketing activities need an intensively developed technical process in three phases to come to a technically suitable product.

Evaluation criteria: 4

The fourth step in the process is already a small running start towards the result, taken by putting down the wishes and requirements a successful product must meet. To set these criteria at this point already, is indeed a precarious matter, because a great advance has to be taken on the process. But it helps to define the exact expectations and when they are expected to be fulfilled. If wished for, returning to this step a couple of times during the process is also possible, as is the well-reasoned adjustments of the evaluation criteria. The pattern of these adjustments also tells, of course, something about the purposefulness of the start and the drifting about of the process afterwards. However, if criteria are not set at this point, it will not be known if the process after having ran through an amount of steps, is the right one or if it will lead to the desired results. Obscure or ill-defined evaluation criteria may lead to simultaneously moulding of expectations and solutions. In the worst case, designers tend to adapt the evaluation criteria to the developed product or process result instead of the other way around!

Process Assurance: 5

As is mentioned above the process consists of a contents part (at the right in the diagram) and a steering and assurance part (at the left). In this process the progress of the process is regularly compared to the previously set process plan, the agreed time schedules and the financial budgets. To this entry consequently belongs a financial estimation of costs beforehand, according to the process and previous experience, from roughly budgeted to, if possible, more refined at set time units, unit costs or total costs. A normal course of events covers the refining estimation of the next steps to follow, up to and including the roughly approximation of further remote steps which, in their turn are being refined from approximation to estimation when the actually processing activities are becoming better known. Since the specific product development process is mostly directly initiated from the company's top management, the reporting of the contents process part is also management directed and the process assuring is a management related activity. The process assurance sets partial goals as well and controls these regularly by watching the actual progress. It almost goes without saying to neglect this financial activity in a study situation, if only a mark-reward did not go with this. Time is essential, even for contemporary students.

Study aspects: 6

After the objective, strategy, evaluation criteria and assurance as conditions have been determined, the core of the process begins with making a distinction in the main problem by a number of partial problems. These are more or less autonomous, or for a short while as autonomously considered aspects of the subject, they can be studied separately. In some processes there will only be a few aspects, in other there will be more. It is clear that with the development of a complex machine or building, many aspects can be studied next to one another, while the designing of a simpler part, for instance a system of new glass blocks, will have fewer aspects. This step also distinguishes the different study aspects in their independence, semi-dependence and total dependence. One thing and another of course leads firstly to the independent study and after that to the combined or integrated study of the distinguished aspects. This hierarchy is later also used again to combine aspects with each other in their interim and final results. After this, the various aspects are given a (identification) number, like in the standard schedule, or they are named. Every aspect is started with the respective (sub) goals and evaluation criteria and, if necessary, also with the aspect strategy. Then the distinguished aspects can begin to be looked upon as clusters, as collections of steps belonging to each other, around a certain aspect. In the following the characteristic steps of each aspect cluster will be mentioned in succession.

Once more: the Organogram looks deceivingly simple, but a process of a complicated product can hold a complex of aspect clusters, which are here marked, for the sake of survey with the first numbers 1, 2 and 3 etc. Each cluster consists in principle of four steps: analysis, brainstorm, ideas, synthesis and the combination of the latter two in an aspect concept. The concepts of the various aspects are then combined into a complete product concept (whether or not after sub clustering in sub product concepts).

Aspect analysis: 7

The first step of an aspect cluster is to unravel the aspect until it has become a combination of indivisible parts, which are studied through literature research, competitive examination, research of existing designs, model research and the likes. In this phase the preliminary product concept is concerned, not yet the final product, so these analyses do not have to be exhausting at this point. It is, of course, also a matter of not losing the overall view, despite continuous feedbacks. 'Better broad than profound' is the motto here. Rather process all aspects than leave a few (later perhaps crucial) aspects out for ignorance or unfamiliarity. With the aspect analysis much actual information is gathered as well.

Brainstorm ideas: 8

It often happens in an analysis like this that a kind of research blindness occurs. Apart from this, it happens with every long lasting study. That is why an unceremonious brainstorm step is introduced which, taking distance of the facts from the analysis, enables the designer or students to bring forth all sorts of ideas, ripe or green. The usual tactics then are to have a group of students improvise with each other and lay down all results, with the intention to judge them only later, throw them out if need be, or to combine them. Often such a brainstorm session is necessary to challenge unconsciously living ideas and, with the help of the fearlessness of the one, have them filled up with the responsive ideas of the other. Naturally it also occurs that a step like this can only be taken after a weekend of sailing, or during a long journey when the mind can quietly order the thoughts and is not burdened with all the heavy information of the analysis. Sometimes a spontaneous 'Eureka' moment occurs, a flash which also pushes others to go on. At this step the hope of many designers and architects is directed. Not unjustly, because this is where the creativity of the designer has to come from. And there

is always the matrix of the actual analysis which lies at the base of the brainstorm. Brainstorming without a preceding analysis often leads to cycling in the air. Therefore, there is an unsteady balance between conscious and unconscious (or subconscious) steps in this process. Designers are mostly well equipped, compared to many technicians who are hindered by the profundity in which they work in their technical environment.

Aspect synthesis: 9
The factual information and the free flying of the brainstorm session are now being combined by hard and creative work towards a synthesis of the aspect in question. Here an attempt has to be made to give one or more solutions for this aspect. Preferably more solutions, because in the course of the hereafter following combinations many will perish because they will not be compatible with the synthesis of other aspects.

Aspect & Product concept: 10
The results of the aspect studies are laid down in individual aspect concepts. These are now combined with each other, be it in a free form, or in a number of clusters of aspects belonging to each other, or in a tight combination through, for instance, a matrix where each aspect is combined with all the others. This will produce an overdose of combinations of which many will not be practicable, or clumsy, and others perhaps feasible or even very promising. Hopefully, a number of combinations will come up which were never thought of before. It is, of course, a matter of cautious handling of these combinations. All too quickly a disapproval may occur, because it is difficult to recognize the quality of a combination which has never been seen before. From all these combinations it could emerge that the best does not answer to the set total requirements. In that case it is sensible to get feedback with the now acquired knowledge for the starting points, the analysis, the brainstorm and/or the synthesis of aspects, before submitting to this definitively. These feedbacks lead to doing the entire process, or a (major) part of it, all over again. These concentric circles also tend to show a progressive match of the total solution of the problem. It is like swimming around in ever decreasing circles towards the buoy. A good product concept is the factual as well as the intuitive result of studying all aspects, with alternating degrees of success. Designing is looking for compromises.

Technical feasibility: 11
For these reasons it is good to decide now if the resulting product concept is technically feasible. Strictly speaking it must be at this point in the process, as this decision must not be made too early in order to not ruin potentially creative ideas too fast. Of course it requires some 'enlightenment' of the reviewer, in order to prevent the feasibility of using one's everyday spectacles, and having new glasses put in for a change. Perhaps new product techniques must be developed, or raw materials or basic materials may need a different pre-treatment than usual, and so on. It is clear, when in this stage an absolute and final 'no' is heard from the production department, and that after repeated explanations and further discussions, the process should be cancelled. If it is, however, not good enough yet, then it is logical to have yet another feedback towards one of the previous activities in order to thoroughly study one of more aspects for alternatives. When the result is positive, only then the next step can be taken.

Preliminary market analysis: 12
The next step is the market, directed to comparing the resulting product concept in the market for which the product is meant (starting point), with the market for which it seems to be suitable (result). Are all the characteristics of the product experienced as being positive? Are

there any favourite and tolerated qualities? What are the attractive qualities? Perhaps market segments, reacting differently to the product, are to be distinguished. If this short feedback of the product concept to the market is positive, or if the client (when known) is positive, then the process can be continued.

Economical feasibility: 13
The last step in the first phase is the financial feasibility. If things were done correctly a global cost-price was proposed in the evaluation criteria. With the help of the proposed production techniques, belonging to the product concept, evaluation is now possible. With technically pioneering products it is not unusual that this economical feasibility step is moved far to the back in the process, simply because many unacquaintances darken the sight completely. In the building industry the sight is mostly obstructed as it is, but yet it is slightly present. The financial allowable margins products must meet is mostly rather limited, since it usually concerns new products which must perform in the same manner as existing products, and those have an actual and known set price. It is like developing an alternative with many set side-conditions. This makes the work sometimes very fascinating, but also hazardous and disappointing. In the case of a complete economical disappointment, the project has to be cancelled. Sometimes hard work must be done to come to a hardly noticeable result. There is no getting out of the way the building industry works with poor materials and low cost-prices per mass, surface or length belonging to that, in order to result in low cubic metre prices of the building practice as a whole. In other cases the products are even concealed and the surplus value is merely the flexible use in time, so in the further away future.

5.2.2 Second phase: Preliminary Marketing
At the very first start of the process a marketing indication must have been given. One does not start a product developing process without further ado. So a global notion of the market attainability must already have been there. This market suitability is also involved in the study at the end of the first phase. Now that there is an elaborated concept after the first design concept phase, it is advisable to first try the concept at the market: is this the product the market segment is in urgent need for? Or does the product perhaps not completely answer to the expectations of the market? Did, on the whole, something maybe go wrong in the first phase, through which a product, as such being very potential, was created for a totally different market than was aimed at? In such a usually expensive product development process a keen eye has to be kept on the goal, as well as on the evaluation criteria. This in order to not get off the track or have a product result which can be added to the average 95% of failures with product development.

It is also imaginable that the activities of phase 2 'Preliminary Marketing' run more or less parallel with the activities of phase 1. Especially when the total of the number of weeks the process is allowed to take up is extremely short, phases 1 and 2 would be possible to pass nearly parallel for those products for which the marketing people know all the routines. Designers must then be mindful that the marketing department will not start to dictate the design department. In general a marketing vision is directed at a short term, where a design vision has to be long term directed. Many designers are not at all amused with marketeers.

Goals: 14
The goal of all activities in phase 2 is to control if the design concept of phase 1 meets the needs of the market, respectively if the product concept has to be adjusted to the requirements of the market. In this phase designers must work together with marketing people of the company, where the help of designers often can be called in to estimate certain architectonical

and building possibilities of the market. For instance, product applications for the various building designs of project architects who operate on the market. Besides, product designers can get, and also take, the opportunity to anticipate on product applications under many different architecture signatures and architectonical styles. By sketching alternative product applications with a piece of transparent paper, on project publications of recent buildings, it is even possible to make an architectonical marketing analysis. Finding applications and recognizing differences in them, naturally requires marketing skills as well as architectonical skills.

Process Assurance: 15
Like activity 5 from the first phase, process assurance enters into the organisational and financial aspects. And here also goes that alert students must handle their time efficiently in order to let knowledge, learning and social education mature.

Marketing analysis: 16
An analysis of the market for the intended product has to be made. How often, under what circumstances can it be applied, in what different performances? Can a distinction be made of different types of buildings or through different offtake channels? Then market segments can be mentioned, each with their own Product-Market characteristics.

Market properties: 17
The market characteristics for which the product is thought suitable need to be described in all their particulars and peculiarities. Distinctions must be made in functional, building technical, architectonical and commercial aspects, and also the approximation of the market, the accessibility, the type of determiners and the determination hierarchy, and the geographical differences per country or countries and continents.

Market segments: 18
The entire application market could probably be distinguished in market segments which, in their characteristics, prominently differ from each other. There will be strong mobile markets as well as more static markets. Market segments are also often to be approached differently among themselves. There will be interesting and less interesting market segments, fast to be conquered short-term markets and slowly to be penetrated long term markets.

Tactics: 19
The various market segments probably know their own determiner, or determination hierarchies. Nature and conduct of these determiners also arrange the most suitable manner to approach the market segment of these determiners, via which route, by which means, people and timing. Distribution and sales channels are also of importance. Tactics will be clearly different for the various geographical market fields. Tactics are the philosophy of approach to get the product to the market.

Promotion strategy: 20
When the different market segments, their determiners and the general tactics are described, then from this follows the strategy to draw the determiners' attention to the product.

Product & Market goal: 21
With this the combinations of types and quantities of products for the various market segments are qualified and quantified, distinguished in short, medium and long terms in time.

Product & Market concept: 22
The characteristics of each desired type of product, in certain required qualities, should be taken to the customers in a specific manner.

Testing product & market concept: 23
The combination of product and market as is set above, is tested for the time being in a small circle of customers, by means of individual presentations, a small group presentation or a presentation lecture, coupled with other events. Do not rouse the expectation yet that the product will soon be available on the market.

Process evaluation: 24
The total process with technical and marketing aspects must be considered as being successful, or maybe there are reasons to adjust it. Other tenderers may have appeared on the market in the mean time. The total need for the new product must be determined at the end of this phase.

Product & Market concept acceptability: 25
The product-market combination should have sufficient potential market opportunities to enter the next technical phase. If not, the process should be cancelled. If not entirely, another feedback is needed again for one or more suitable activities before this step.

5.2.3 Third phase: Prototype Development

Formulation of goals: 26
After the subject of the phase is set, the goal is determined. For example: for study module B3 this means the further designing and developing of the initial concept of the façade scenario up to a prototype on an actual scale, approximately 2 x 2 metres and with the actual materials, manufactured in the workshop by the students themselves. The prototype must be assembled as a technical piece of work. The requirement is added that the prototype is presentable, that it is coated and that a minimum of one glass panel is applied. It must be transportable through access doors and it must fit in a service elevator. At this stage a global description of the goal to be achieved, befits. This description consists of minimal three parts:

- A technical or material part in which the kernel of the product idea is set.

- An economical part in which the required financial achievement is set (numbers, price).

- A marketing part in which the intended market is set.

Process assurance & Financial management: 27
At this point in the process the setting of the financial budgets is extremely important, as there will be much energy involved in all kinds of research activities and development activities, which in themselves are hardly calculable. Involved in this is the investment in time for the product, of persons times the costs of labouring hours. In the total process assurance this activity monitors all the different development activities of phase 3.

Evaluation criteria: 28
A proper programme of requirements is, in fact, a description of the criteria the product will have to meet. Completely different criteria can be summed up per product. The continuous intention, especially at the end of the third phase, is the feedback for these criteria. The criteria can be quantitative, as well as qualitative. It is good to also distinguish stronger demands and weaker wishes. Because a solution which does not meet a demand is not acceptable while, on the other hand, a solution which does not meet a wish, can still be usable. Furthermore, it is important to remember that there is a certain hierarchy in the programme of requirements or in the list of criteria.

Product market identity: 29
A realistic product development does not start just like that, with an imaginary idea. The realistic validity must be analysed. A suiting answer, to the assumed question or a proven problem, has to be found for the product. For instance, for which applications, types of buildings and architecture, for what kind of climatological, functional, architectonical, technical and economical circumstances has such an answer to be found? Do different applications, like market segments, have to be distinguished? To what extent do these division markets influence the qualities of the product? How will the product distinguish itself from existing products which ought to be replaced by it? How would the product finally be introduced at the market? How are the information flows from the building industry? Who are the intended customers, who are the producers, which functions in-between them can steer the usage of the product? By these considerations the programme of demands and wishes is filled up or adjusted. To conclude the provisional marketing phase 2, a market product identity comes about for the time being which provides, as it were, the required image of the product at the desired market segment. This to control that no undesirable products are developed for other market segments which, in themselves can perhaps be very useful. But they leave the original principal empty-handed unless, in the mean time, the starting point has proven to be an unjust assumption. (If such an unintended side-product comes about, then one must document, describe, sketch and store it for possible later elaborations in a different field of study).

Preliminary marketing plan: 30
This will not be discussed here, because it actually comes down to a reflection of the process activities from phase 2. It is, however, sensible to discuss it here if that study does not catch up with this second phase. In the following activities 31 up to and including 37, a number of aspects of the design to be made will be further explored. These activities can take place one after the other with feedbacks, but also simultaneously with strong inter-relations. In any case, each aspect in itself must produce a result which must be brought to a synthesis in activity 38. In general it will not be sensible to choose a material in activity 31, to only study the production possibilities of that material in activity 35, and so on and so forth. All activities have strong inter-relations. Analysis separates the different aspects, but cannot be without the synthesis of once more assembling and combining.

Material research: 31
From the chosen subject and design follows, initially, the research of the most suitable materials. These are compared to one another on aspects such as chemical characteristics, physical characteristics of the separate elements, the components, as well as the capability of combining them. This study is processed simultaneously with the production research and the technical research. The chosen most suitable materials are then once again and far more thoroughly gone over for their chemical and physical qualities. The preference approach is not 'bottom-up': starting with the chemical structure, up to the component, but rather a 'top-down' approach from the design: by firstly specify the behaviour of the product in question in the shape of a component, then that of the sub components and subsequently to come to the material qualities of these elements themselves.

Technical shape research: 32a
The hierarchy between element, sub component and component must be explored in the shape which arises from a certain material and certain production techniques, to be used for a specific function. Continuous reasoning has to be done here from small to large, from element

to component, from building part to building, and the other way around from large to small. The relation between product and architecture has to be studied in depth at this point.

Technical assembly research: 32b
This is the exploring of the way in which the various elements are connected into a sub component and the way in which several sub components are connected into a component, which perhaps in its turn influences, as a super- component, the shape of the separate building parts, the means and methods of connection and the resulting manifestations. Transport has its influence in the form of limitations of weight and sizes, hoisting points and possible transport reinforcements, while the hoisting crane can also have its influence. Sometimes specific mounting methods can have a dominating influence on the appearance.

Production research: 33
The raw material is usually in bulk and out of reach of the designer, outside the building industry, purified and transformed into material. The material is transformed into usually standard marketable, intermediary products, in professional language normally called 'semi-products' or 'pre-manufactured product' (in the view of the processor, one step before him in the product hierarchy. Metal window-frames are, for instance, called 'basic profiles'. In the case of window-frames there are, fitting in extended window-frame systems, assortments of basic profiles in the available materials of wood, steel, aluminium and PVC. They can be used as a starting point for further development, respectively serve as examples to design and develop an entirely new series of profiles. The question that has to be answered first and foremost is how many running metres window-frame profile of a certain section will be used in the future. For the various materials the material costs and mechanical writings-off with the production of the basic profiles are very different. The ascending line from low to very high shares in the production costs per m1 profile, respectively the economical attainability of small to very large series in wood, aluminium, steel and PVC. These production techniques are about basic profiles. In the further processing of these basic profiles into elements a choice must be made from a number of processing techniques that are specific for the material and for the desired element shape. Although the material is normally strictly limited, the number of processing techniques is large and the number of element shapes (= the result) is, if possible, even greater. But it is ever clear that the product designer draws a great amount of inspiration from the product techniques. Knowledge of the facts is therefore indispensable and essential when new product techniques must be contrived to obtain special process effects. Here, the definite relation between basic material and production techniques and element shape is laid down.
Here could also be considered the various production techniques, as yet unknown to the building industries but surely in vogue with other industries, like car, bus, train and aircraft industries. In mechanical or civil engineering these are: gluing, laminating and casting.

Application research: 34
The three main types of building products, namely: standard products, system products and special products all have a different, yet clear relation with the application of products in the building industry. Standard products can either be put into practice in many applications without alterations, or not be applied at all. System products need a game of question and answer to get their qualities filled in per project. Special products only exist in separate projects. Therefore, the influence of the project architect runs from zero, via partly, to fully. The mentioned main types of products are, to project architects, 'closed', 'half open', or 'open'. Applications, in their turn, can thus have a very penetrating influence on product development. In fact, an amount of technical and architectonical marketing sinks in here, at

the level of the development process. The study of various application environments is in this phase of the project important enough to already give an advance on the multi-launching of the product system, in order to do research on the various locations for the project product. On the other hand, a standard product in a varying context or country environment, can also have an ever surprising effect. Imagine a new car, photographed in the Sahara desert or in the snow. The application research of the ready to hand standard product is seen through the glasses of the product designer on the producing side.

Design prototype: 35a
Out of the combined facts of the designing research activities of phases 34 up to and including 37, follows a prototype design. Perhaps a couple of times feedbacks have to be made for preceding activities (especially the technical research activities, but also the objectives and product market identity are self-evident), extensively described, sketched, further drawn and elaborated at the level of workshop drawings. In this phase (the synthesis) all the gathered knowledge must in a creative manner lead to a design. Remember that most innovations prove to be essentially new combinations of already existing or familiar techniques!

Building prototype: 35b
Depending on the type of product a decision must be made in which form, scale, size and materials the prototype will be built. The prototype serves, in first instance, as a control of the design and development process for the product designer, in second instance as a confrontation model for the market or the principal. Ideally a functioning prototype is made on an actual scale with the intended materials in the manner of the workshop, but to do this in many cases the room, time and budget may be lacking. In that case it is better to manufacture crucial details, or to make a product on a somewhat smaller scale, respectively a form model on a full scale in non-realistic materials.

Testing and evaluating the prototype: 36
In the workplace, the factory or the laboratory performance experiments can now be carried out on the prototype. If the prototype is of an actual size, in actual materials and assembled in a final manner (independent of the fact if it is manufactured by the definite production technique), then it must be possible to carry out a global performance experiment, with sufficient profoundness to have feedback for the functioning of the prototype at design level. Concerning the quality of this test simple devices must be considered, ran through with common sense in a short time. The aim of testing, if it concerns a technically challenging prototype at least, is to be able to view the reliability of the prototype's behaviour with relatively little effort, roughly for 80%. In a more accurate situation (laboratory) the remaining 20% is studied. This usually involves more sophisticated equipment than available in the workshop. After this phase follows, as a rule, a feedback for preceding phases if they do not sufficiently meet the set criteria.

Cost price calculation: 37
Estimating the necessary costs of a zero series, a small series or a large series of identical products after the model of the prototype. Dividing the costs into the costs of the preparation trajectory, the production trajectory and those of the sales trajectory. This is done in order to actually sell the products, to get an adequate sense of these mutual relations. Then a comparison of the resulting cost price + margin = market price with the market price of the intended products to be replaced by the new product. Finally there is the drawing of conclusions, in relation to the financial feasibility at the market, of the new product.

Prototype acceptability: 38
The prototype should answer to the specified expectations and to the specified respects.

Prototype evaluation: 39
The manufactured prototype is evaluated according to the initial evaluation criteria (see activity 31). These are ranged in the order of functional, architectonical, technical and economical criteria. The measure of fulfilling these criteria is set, so is the possible non-fulfilment and the reasons behind this. It will be determined if the prototype will sufficiently meet the specified expectations. Next to that there is also a feedback for the provisional marketing and the product market identity.

Process evaluation: 40
The entire process route is evaluated, besides the individual final results of activity 42. One and another is set and presented by students to module attendants and the external viewers in a, to them, convincing manner.

Approval of progression: 41
In the study situation the study attendance is responsible for the approval of progressing into a next phase. The management of the company for which the product is developed will, on a basis of the technical results from the preceding activities and with a feedback for the provisional marketing phase 2, occupy themselves with the progression of the project. If the opinion is not entirely positive, then perhaps a feedback for further activities of phase 3 may follow. When the approval is granted, the following activities are those of the definite marketing from phase 4. If the management is of the opinion that the process must be stopped, then a reflection on the market position of the prototype product in activity 42 will follow first, before the plan is postponed, put away or thrown away and all costs are written off.

Continuation of marketing: 42
This phase will only be ran through if the management's opinion is that the project has to be stopped. It is to be considered as a summary of the definite marketing activities: are the data of the provisional marketing still correct for the now developed product? For there is a great chance that the technical product development and the marketing plan pulled a totally different track. The marketing opportunities of the developed prototype must be evaluated. This activity does not have to be processed when the management agrees with the continuation of the process, since the fourth phase holds a far more extensive set of marketing activities.

5.2.4 Fourth phase: Final Marketing
After the product is further developed up to the prototype stage, and so physical examples of the product can be shown, photographed or filmed for presentations, the fourth development phase sets in: the definite marketing. In the second phase, with the data of the concept design, there already has been a provisional exploration of the market reaction to the concept product. It is, by the way, not unusual that the marketing phases are not linearly linked after the technical development phases, but are (partly) overlapping, where the danger of marketing pressure and force from the marketing department towards the product development, holds a risk for balanced development. In view of the second phase, 'preliminary marketing', which states requirements, the fourth phase is a more determining one.

Goals: 43
The goal of the fourth phase is threefold. Firstly, the product related activities to definitely determine which possible production methods would be suitable to use (internally and/or

externally) to have the product manufactured. Then the resulting cost price and the final choice of production need to be determined. Secondly, the prototype related activities to definitely determine the marketing opportunities of the prototype product. And thirdly, the marketing related activities to make a marketing plan with a strategy to introduce the product at the market, to have it conquer a place and keep it.

Process Assurance: 44
A budget has to be estimated, time-planning and staffing must be scheduled, as well as external costs be estimated or offered if a part of the activities are executed by others than one's own staff. These activities together form the process assurance of phase 4.

Production techniques: 45
The possible production techniques are now being definitely studied for the component parts, the sub assembling techniques for the joining of elements into sub components and the assembling techniques to manufacture components from elements and subcomponents. Also the transport possibilities and the super assemblies at the building-site, being the mounting, installing and finishing at the building-site, also are a part of this.

Building prototypes for marketing: 46
A number of prototypes have to be built now in order to present them on the market. This must be done in a manner which makes a sensible presentation possible, and which must bring in enough data for a final marketing plan to be based on. The making of presentation material, like photos, videos, presentation folders of the prototype with possible application varieties and sufficient technical support, is part of this activity as well.

Cost-price evaluation: 47
From the data of the most suitable production methods of activity 45 and the required materials and series sizes, a cost price calculation for the product can be set up. The marketing activity 48 will give the reaction to the market price, so that the profitableness of the product can be viewed.

Test market reaction: 48
From the presentation of the prototypes in a physical form or in the shape of images with descriptions, personally (visits), as a group (part of the day presentation in a symposium manner or such) or per branch (exchange introduction), reactions of potential consumers can be recorded. These persons are approached after a hierarchy is set of the route the decisions concerning the application of the product will follow. For instance, firstly the project architect as the determiner of the type of product, then the principal for the sake of the product budget, after that the building costs adviser and possibly a building management office which once more controls the quality and price for the client. After the tendering and contract awarding it is mostly the main contractor who is allowed a semi-autonomous decision as to which of the competitive offers he will agree. He will do so in the knowledge that the architect (sometimes) has a preference and he will be thinking of his own profit position. In this stage the subcontractor or producer are rather often financially squeezed out, without the initial determiners knowing about this, or can do anything about it. To the architect only a management position holds a greater say.

Positive reaction: 49
The marketing test as mentioned in activity 48, which can be processed on various market segments, is evaluated. If an insufficient success is scored, a feedback can take place for the activity in phase 3: which seems the most sensible, or the most probable. If an absolute negative reaction follows, then a reconsidering of the progression of the development project

must take place, or a reconsideration of the market segments and the determiners. Perhaps the manner of presentation has to be altered, or a better occasion must be waited for, in order to create the chance that potential clients can reflect better or more profoundly on this. If the reaction is positive, as is suspected, then activity 51 can be entered.

Choice of adequate production: 50
From the surveys of the most suitable production methods, plus the tenderings and the suitability of side producers or subproducers to perfect the product simultaneously ('co-makers' with technical assistance and high-standing), follows the definite choice of production techniques and production routes. Some of these choices have an artistic design consequence which has to be related to the market reaction, for instance the replacement of a fluently shaped casting by a cheaper, but more angular mechanically manufactured component.

Determination of final product: 51
From the feedback of the market reaction, the cost price determination, the market price determination and the final production techniques, follows the final determination of the product.

Final marketing strategy: 52
Now that the product is final, the market and market segments are known, the routes and hierarchies of decisions have been scheduled, the marketing plan must be rounded off with the marketing strategy. This must map out how, where, to whom, when and with what the product will be introduced to the great (professional) public. The first activities have to be determined, the following ones and the safety net activities when something threatens to go wrong. It must be considered if there will be an introduction at a large scale, or rather a more project directed one, or a 'pilot project' with substantial reductions to ensure the entrance to the market.

Product evaluation: 53
Yet again the definite product with the definite marketing plan is evaluated, in the presence of the management, the technical developing team, the marketing staff, the production staff and anyone who later on must spend their energy to make the product a successful one.

Approval of the management: 54
As a summary of the preceding evaluation, the management will have to give the sign to enter the fifth phase of the actual production. This 'go-ahead' in the car industry holds the starting sign to mostly extended investments. For less specific products, like in general in the building industry, normally the aim is to making the most of an existing machine fleet with a couple of additions.

5.2.5 Fifth phase: Product Manufacturing

Formulation goals: 55
The fifth phase consists of a first production, whether or not directed at a specific project. This is seen as the final test of the technical product, plus the market reaction. Also the definite production of the product (which is ready to be launched after this) is a part of it.

Process Assurance: 56
The financial and organizational management must be accommodated in the regular management tasks of the company in this phase. They should no longer be a separate development process watching. In this phase even the test production is considered to be a part of the factory production, with all aspects connected with it.

First product application (zero series): 57
This activity consists of the production and application of the first, whether or not paid for, test production, which needs to be attended with the necessary care of the technical development team and with the gentle assistance of the marketing team.

Reactions of clients: 58
As a feedback after the first zero series application of the product at an actual scale and in a building, the reactions of the clients are once again gauged and viewed, in order to find if these reactions bring about any alterations in the product-marketing plan.

Production plan: 59
The final production environment is organized as an alteration in the lay-out of the existing production, or only the assembly room is reserved if the production of elements takes place outside and only the assembly takes place inside, or a new facility is being created, with all the architectural, financial and social consequences involved. Location and logistics of production and transport also must be determined in this phase.

Acceptable results: 60
The results of the clients' evaluation of the first zero series application are likely to be positive. If not, the product, the market, the strategy or anything else must be adjusted. It seldom occurs that no feedbacks for preceding activities are needed at this point. However, with a skilfully directed process the 'loops' will be short.

Start of production: 61
The actual production is started with a small and slow running up or an approach at a larger scale if the management and/or clients ask for it. Also this activity will require an Organogram of different activities as such, a discipline which should follow from the discipline derived from the following of this Organogram. The matter will not be further discussed here.

Sale of first application: 62
The contract for the first official commission of an entirely paid-for product. It is open for decision whether or not to inform the clients of the fact that they are the first consumers.

First application: 63
The producing of the first product application shows for the first time all the subactivities which have to be run through to get the product eventually delivered. This single activity 63 consists in itself of dozens of subactivities.

Engineering application: 64
For system products an input of engineering activities will be necessary in order to prepare the product application. For that matter, a different Organogram for system products is in existence, including a system design level and a system applications level. The system application needs engineering.

Production and assembly: 65
The actual production of elements, assembly of elements into components and subcomponents, and the assembly of elements and subcomponents into components. After transportation to the building-site the super assembly, the mounting and/or the installation and the finishing off takes place there.

Alterations: 66
From the first application the need for alterations of the product, the process, the marketing or anything else may come forth.

Improvements: 67
The supplied suggestions are being studied, with feedback for the responsible persons and carried through as improvements of the product, the production process or the marketing.

Start of official sale and production: 68
The official sale and production can now get started via the, in the mean time, set linear organization, the dealer net or whatever route: producer - sub contractor - main contractor - principal.

Launching the product: 69
This is the starting signal for all sorts of activities concerning an adapted publicity campaign and all that is necessary, according to the marketing plan to get the production going and keep it going.

5.3 Conclusion

The previous sections have given an overview of the Organogram that describes the entire process of steps and activities from the initiative up to the actual regular production for standard or new products.

5.4 References

Roozenburg N. F. M. and Eekels, J. (1995). *Product Design: Fundamentals and Methods*, Wiley, Chichester.

DESIGN PROCESS

6. Information Processing in Design

A Theoretical and Empirical Perspective

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6.1 Introduction

The research mentioned in this paper has been conducted in the sub-Faculty of Industrial Design Engineering at Delft University of Technology during the last seven years. This research belongs now to a big research program called "Ambition". Ambition is a program focused on three main topics: Product Conceptualisation, Intelligent Products and Sustainability. Information Processing is part of the Product Conceptualisation topic.

Product Conceptualisation has a special focus on the designer's thinking and behaviour in the conceptualisation of a product. Design thinking in the conceptual phase of the design process is aiming at the development of concepts through analytical, visual and conceptual activities. Although these activities are part of one process, they are seen here (for methodological reasons) as three parallel processing elements, i.e. (1) information processing, (2) visual thinking, and (3) conceptual thinking. The three elements all show a common ground and are linked together in focusing on the initial phases of the design process, dealing with aspects of one and the same activity: optimising the process which develops from the definition of the design task to the conceptualisation of a design solution.

Optimising the conceptualisation phase, being the main focus of the Product Conceptualisation research topic, should contribute to:

- The enlargement of knowledge and insights into the designer's knowledge and behaviour in the conceptual phase.

- Offering models and methods that will support the designer, with special attention to the visualisation of ideas and the use of visual media. Media that will include both traditional and electronic tools.

- The application of the knowledge acquired through developing machine-based strategies for information search.

Regarding the scope of Information Processing, this optimisation can be achieved through research focused on: i) how designers process information during the conceptual phase of the design process, taking into account the designer's expertise, and the communication with the design environment: stake-holders, users, society, etc.; and ii) the type and extent of (contextual) information considered during the design process.

While the designer or the design team needs information in identifying the 'problem' and looking for 'solutions', both internal and external information are rather diffuse, incomplete and unstructured. Moreover, information processing will strongly be influenced by the designer's expertise and by his social and cultural background and, as the member of a design team by the group communication and interpersonal relations. Hence there is a need for knowledge and insights into information processing so as to create a design environment that is conducive to innovative conceptualisation. It is also necessary to create a good support, in

terms of knowledge and technological media for designers and researchers to handle and include in practice diffuse and unstructured information, namely, contextual information. The main research questions are:

- Which aspects of the design environment are conducive to information processing allowing the designer to break through his schemata (knowledge frames) and to generate creative and innovative concepts? Some of these aspects include the accessibility of information, the communication within the design team (social behaviour within the team) and with the environment and the 'format' in which information is provided.

- Given the differences in designer's knowledge frames and experiential backgrounds, which evolutionary and adaptive tool-based strategies can be defined? An assumption is that the interaction with these strategies will result in explorative processes leading to a redefinition of the design environment and, at the end, to creative and innovative design solutions.

- What are the effects of the type and extent of the information processed, the support in which it is stored/presented to designers, and the strategies used to process such information in a designed object, in the satisfaction of stake-holders expectations?

In the next paragraph, some theoretical notions about the topic will be offered, which will illustrate the methodological approach of our group at Delft University. The content of this paragraph is mainly based on a recent paper by the authors (Restrepo et al. 2000). Then a number of empirical studies from our group will be presented, which has been conducted since 1993, focused on information processing in design. Although all of these studies cover only a small part of the entire field, partly due to their limited operational definitions of the relevant variables, together they form an interesting body of knowledge. Finally, conclusions for future research will be drawn.

6.2   A theoretical approach

From the point of view of design methodology and design education, it is important in design research to focus on the role of knowledge in the design process, and on the role of the information processed. Questions like how problem solvers (designers) select relevant information and how they represent and retrieve expert knowledge should be solved.

Research through observations of design processes has provided some relevant data on the role of knowledge. Firstly, designing is not just regulated by preconceived goals, but it remains more or less vague, ambiguous and conflicting. Secondly, the interplay between individual designers, design teams, and the environment, influencing each other, affect the outcome of the design process. Designing requires interference of several 'knowledge cultures' and is multi-perspective. Thirdly, the designer's perspective as an individual seems a cognitive one: the designer will reason and act based on knowledge 'frames'. Frames are imposed through tacit background knowledge, habits of perception etc., acquired through experience or enculturation into a community of practice. Designers' knowledge and ideas are filtered by these frames, while they will process external information to the extent that it conforms to their knowledge structure or ways of knowing. As a consequence designers can be blocked by past experience or fixated by information offered in a particular situation. In contrast, the role of the (contextual) information processed or needed during the design process has been scarcely studied.

Literature in context or contextual information related to design is rare. This suggests a disregarding in research and practice of the roots of motivational aspects that make the creation process of designed objects possible. A process that is always contextualised and

socialised. To expose this aspect it is necessary to discuss the concepts of context and contextual information.

Context can be understood as the reference frame in relation to which a linguistic expression (semantic context), an event of the phenomenological reality (cultural context), an intersubjective situation in the time-space relations (situational context) or an object of the reality (physical context) acquires, or is able to acquire, one, and only one particular sense. The reference frame consists of a set of conditions that pertain to different elements in relation to which an event, or an object, is acquiring sense: the creator, the interpreter and the milieu. Recognising that this frame depends not only on environmental conditions (economic, social, technical, natural, etc.) but also on actors, as the creators and the interpreters (designer, manufacturer, client, final user, etc.) empowers the notion of context, because it gives the opportunity to study and act on subjects as well as on objects. Finally, it is important to annotate that the notion of context, as the entity that gives ground to shared understanding of representations among individuals, cannot be individualised. A generally accepted cognitive approach tends to regards the social context as an external stimulus field (Restrepo et al. 2000). However, a shift in attention from an individualistic to a more social approach should lead to the opposite conclusion, by considering that the interpreter is implicated and is part of the context, and that perception and interpretation are structured by virtue of the involvement and interests of the perceiver or interpreter (Spears et al. 1997).

All the information required and processed by a subject in relation to his intentional objects, in order to interpret initial states of the world and to create representations of the aimed states of the world, is what constitutes what here is called contextual information (see Figure 6.1). In an even broader sense, the subject could be just a person (user, designer, etc.) or a group of persons (a society, a design team, etc.).

Observing the research methods and design methodics, it can be said that designers (and design researchers) have put the object (object understood as the product of a design process) –as economy did– in the centre of the discussion. The goal of most methodics is too focused on the embodiment of a concept into an object and the meeting of all the economic facts around it. The object's finality (its effects in the world or in the users), as well as the motives of the subject that made the requirement are not explicitly considered, seriously restricting the amount of contextual information a designer is able to handle and embed in the object and in the design process itself.
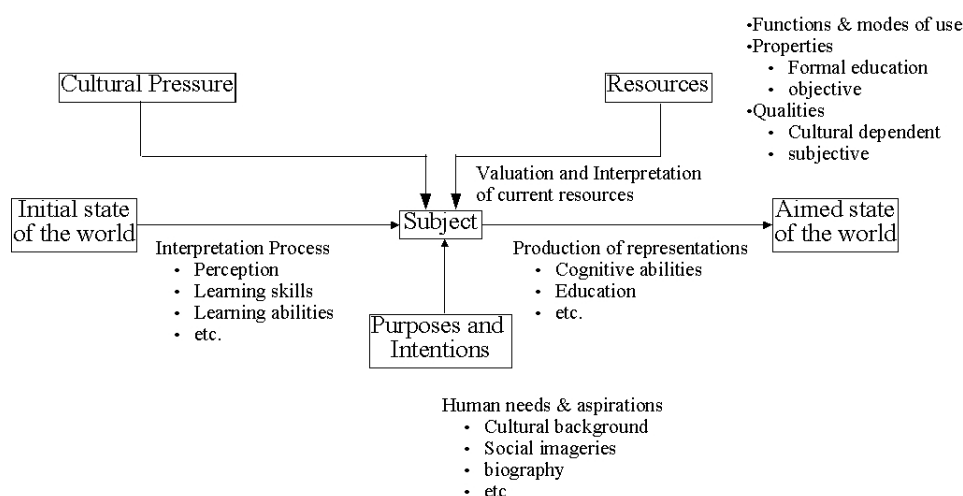

Figure 6.1: Social and cognitive factors and processes involved in the interpretation and production of representations of initial and desired stated of the world.

Even though designers in practice could be aware of the necessity of introducing such contextual information into the design process and into the object itself (and say they already do), they often fail to do so, due to its vast extension and the lack of both epistemological and technological support.

The claim is then, that a clear understanding of the generation process of aimed states of the world (see Figure 6.1), and its associated information, as well as the mechanisms that make possible its flow throughout the whole (design) process (see Figure 6.2), could lead to the creation of (technology and knowledge-based) means to support designers in the inclusion and handling of contextual information.

The framework (see Figure 6.2) proposed shows, in a very rough and yet-primitive way, some aspects of the information involved in the construction of representations of possible (better) worlds and its translation into objects that (could) make those worlds possible.

The potential applications of this framework are: i) The creation of means (technology and knowledge-based) that can provide the support designers need in the inclusion of contextual information, not only on the design process, but also on the designed objects themselves; ii) The generation of new research methods on society-product (instead of human-product) interaction, given the non-individual character of the information involved; and iii) The generation of new (design) methods that start, not from the idea that there is an object to be configured, but from the idea that there is a mental state, a need or an aspiration to be achieved or satisfied, so the pressure on designers (natural) ability to do that is eased.
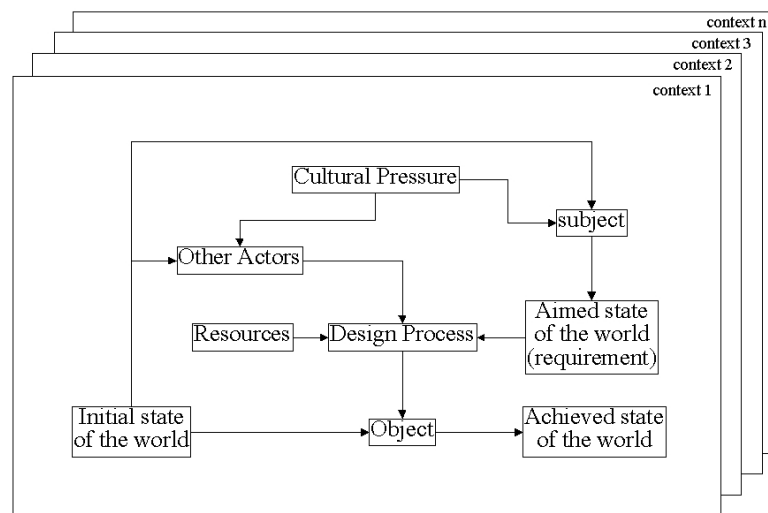

Figure 6.2: Information flow framework. Note that (design) representations are the communication conduit among the levels (contexts)

6.3   Empirical research

The theoretical approach goes hand in hand with gathering empirical data about parts of the hypotheses. Within the project on "Information processing in design" several studies have been conducted and published over the last seven years. All of the four studies mentioned here have contextual information as their main focus. Although the definitions used slightly differ between the studies, quite a clear picture is presented of the area of research they are focusing on.

6.3.1 Study 1: Impact of information mode on the design outcome (Christiaans & Van Andel 1993)

The first study was concerned with the question under what conditions relevant contextual information from external sources would be more accessible for designers as measured by the design output. The contextual information concerned the psychological aspects of the child's playing behaviour in using different kind of toys. Designing a go-cart (in The Netherlands called a 'Flying Dutchman', see Figure 6.3) was the assignment for a group of 21 second-year students of the sub-faculty of Industrial Design Engineering at Delft University of Technology.

Figure 6.3: A Flying Dutchman

Two different ways of presenting this information were compared. In the control situation, students received only general information on six psychological topics related to the design assignment, while in the experimental condition, students received more detailed information using verbal and visual examples. In this way, and by stimulating the students to actively 'work' with the information, compilation of the transferred declarative knowledge was supposed to take place. Knowledge compilation, or proceduralisation is defined by Anderson (Anderson 1993) as the creation of task-specific knowledge through practice. Pictorial information together with an active way of using this information on designing was expected to have a greater impact, although this impact might result in mimicking behaviour.

The study showed that the experimental condition, using visual information together with verbal information, had a strong effect compared to the control condition. Not only in the designed prototypes but also in the technical reports the differences were obvious. A second finding of this study was a fixation effect in the experimental group; some students in the group mimicked one of the examples offered during the experimental instruction.

The introduction of behavioural or psychological aspects in the design assignment was a rather new phenomenon in the design course of the sub-faculty of Industrial Design Engineering. In spite of that, the results of this study showed that, if (student) designers are taking into account that part of the knowledge from the domain of psychology, which is relevant in the design activity, they are able to design objects which are closer to the users' expectations.

6.3.2 Study 2: A cognitive view on information processing (Christiaans & Van Andel 1998)

The aim of the second study was to explore what typical strategies designers use in their information gathering behaviour; if designers would mainly look for technical information in using external sources, while user-related information is given low priority; and to prove if a database, offered to a designer, could be more accessible when it is adaptable to the designer's idiosyncratic way of processing information.

In order to tune the information system to a design problem a design assignment was defined, that would force the use of external information and come close to the core activity of industrial design (engineering): bringing together the intentions of the designer, the user's needs and experiences and the system image of the product to be designed. A bicycle for people of 55 years and older (55+), a topical subject in The Netherlands, was chosen as the design assignment. Both technical and functional information and specific knowledge on the users were essential in the development of this design assignment. Subjects were student designers working in teams of three people. They worked on the task for two days, full-time.

An 'Internet' hypertext information system was developed with information on several aspects regarding the assignment. According to expectations about how designers should look for information the main menu started with three general categories: (1) Information on the manufacturer and the market; (2) Information on bicycles; and (3) Information on the user. Both text and pictures were used.

As an example, in Figures 6.4 and 6.5, the type of information asked for is presented for team I and team VII. Each team showed one's own specific graph, representing the way they go through the information system and also indicating what information is most important for the team. The two teams differed not only in the amount of information consulted on both days, but also in the choice of the topics. On the other hand, teams also showed some similar behaviour.
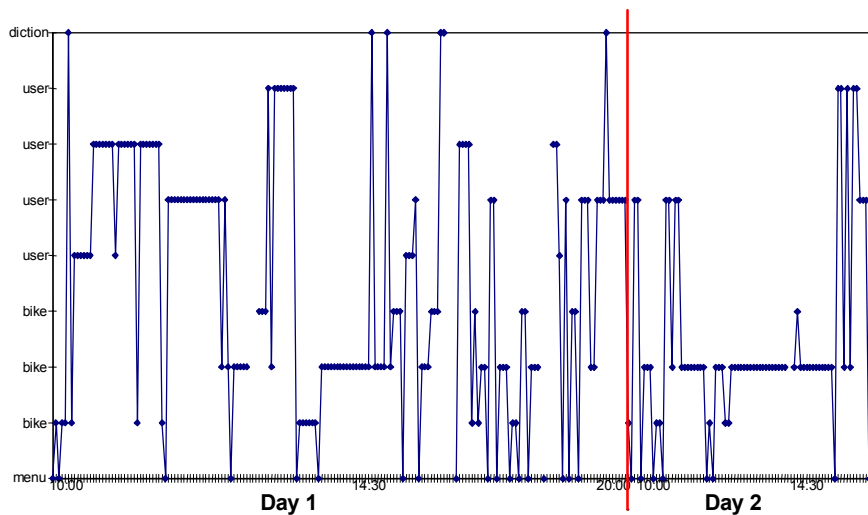

Figure 6.4: Information asked for by team I. y-axis: menu = navigation pages, bike = bicycle category, user = user category, diction = dictionary, edit = pages edited by the team.
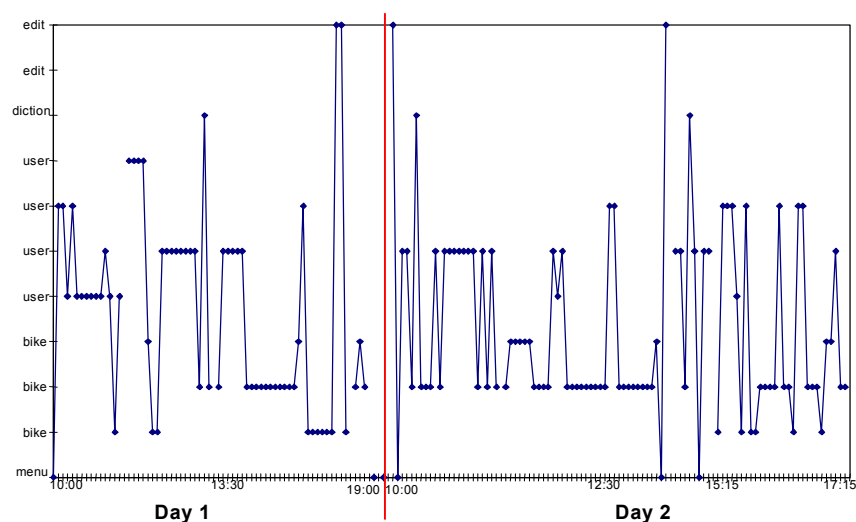
Figure 6.5: All information asked for by team VII. Values on the y-axis: see Figure 6.4.

The first conclusion of the study was that the information system played a very relevant role during the design process. All teams, except for one, made extensively use of the system and were very positive about the usability and efficiency. Another way to test the relevance of the information was to consider the design specifications, as reported by the teams, and to look for data that was derived directly from the information system. The application of data from the system was evident.

Data from the system was used mostly in the analysis phase and in defining the design specifications. Although there were differences in the way the teams went through the information, most teams started with user-related topics. Later in the process, the type of information asked for seemed very typical to the phases of the process the teams were involved in. These phases can be defined as conceptualisation, decision-making and evaluation. During these phases the two sources mainly looked for, were technical data (such as geometry of the bicycle, materials, and production methods) and legal norms and standards. While on the first day teams looked for user information, this was hardly the case on the second day.

One hypothesis was that the possibility to adjust the database to one's own wishes and preferences should have a positive influence on the processing of knowledge from the information system and thus on the influence of this knowledge in designing. However, as the results showed this possibility was hardly used by the experimental teams. The most important reason was that the editing facilities offered were not user-friendly. Hence, this hypothesis could not be tested in this study.

6.3.3 Study 3: Implicit knowledge of the designer (Trousse & Christiaans 1996; Christiaans 1999)

In the study discussed here the aim was to understand the nature of the design process as a communication process modelling the argumentative knowledge of the individual designer or the designers in a team. Design was viewed here as a meaning-construction activity.

A theoretical framework was introduced based on argumentation theory, proposing that the problem-solving actions of the designers are performed in one of three specific spaces: (1) A structural space in which the action-based and linguistic skill of the designer(s) manifests itself; (2) A socio-linguistic and socio-action based (ritual) space related to the context in

which the designer(s) and the design assignment are situated; and (3) A discursive space in which the designer implicitly pre-constructs his cognitive devices that will be used for design purposes in the two other 'meaning-construction spaces'. The more the discursive space is based on relations between the two others spaces, the higher is the discursive skill of the actor (designer).

The actor knowledge in the 'socio-linguistic and ritual space,' validates and guides his argumentation. If actors do not share the same space, then a valid statement of one actor can be of no meaning for another actor who has to interpret it. For an actor performing an activity and using the three spaces (in a variable way) the argumentation will be the way to orient and modify the real world.

In this study two teams of designers were analysed through the written transcript of the protocol. The design brief for two design teams and two individual designers (all professionals) was to develop an artefact that connects a backpack to a bicycle (see Figure 6.6).
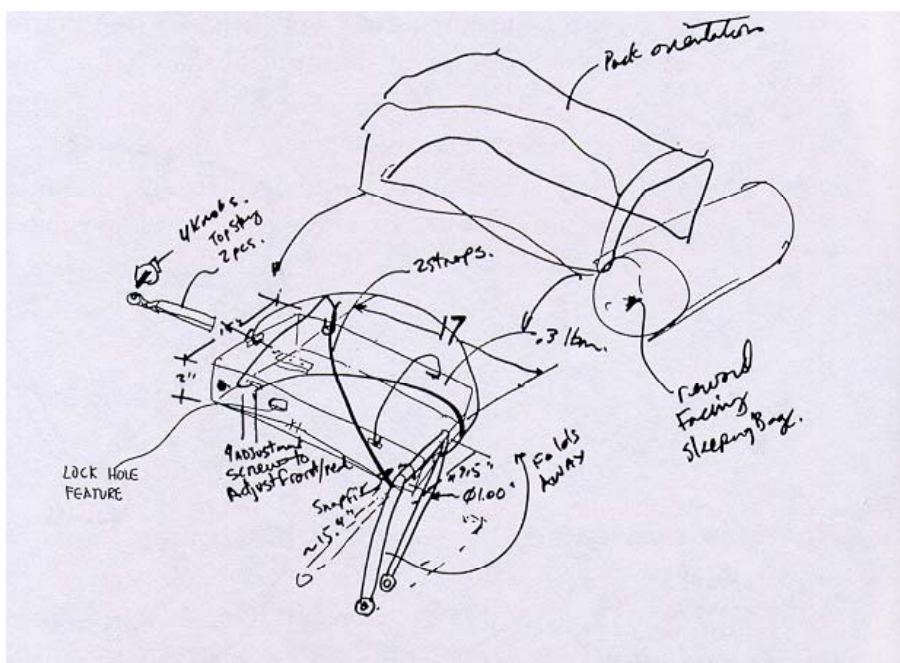
Figure 6.6: Strapping the backpack on the bike.

The conclusion was that argumentative knowledge seems to be an important component of design rationale by contributing to a better understanding of the design activities and to the specification and development of real co-operative knowledge-based design support environments.

All designers gave their information mainly in the structural space, technical aspects regarding bicycle, backpack and joining device. It means that the socio-linguistic and socio-action based (ritual) space hardly place a role. This is quite a dramatic conclusion, because it holds for professional designers.

The content of the 'topical' models was based on not only explicitly expressed meanings but also implicit ones. The expectation was that every model shows the underlying knowledge base and structure of the designer. Examples of these models gave indeed differences between the designers in their problem approach and their knowledge input. One of the conclusions of

this study was that the better the discursive skills, both structural and 'contextual', of designers are, and thus the larger the topical fields, the better the design results will be in terms of creativity, potency and distance.

Studying the role of argumentation in team design makes clear that the design process is not a mere knowledge-based activity but also a confrontation of belief systems and attitudes, and of social roles. Finally, fixation effects were disclosed, especially fixation on arguments or ideas as a consequence of the background knowledge (Mey 1993) and the knowledge structure of the designer(s) or by social factors.

6.3.4 Study 4: The influence of contextual information on the design outcome (Snoek, Christiaans & Hekkert 1999)

The goal of the most recent study regarding the overall research theme in information processing was to test the hypothesis that application of certain information, i.e. not directly related to the (design) problem at hand, contributes to an enlargement of the (metaphorical) solution space. In turn, such an enlargement of the solution space should offer more interesting starting points for an original design solution. In performing a design task individually, subjects were offered information by means of an information system containing traditional, i.e. domain information, and contextual information. It is important to clarify that the sense given here to the definition of contextual information is different from the definition given in this paper. These empirical studies, together with reflection on to which extent contextual information should be considered, have lead us to the conclusion that the scope and sense given to contextual information in the past, in our own studies in particular, and in literature and other studies in general, is limited, inexact, shows a disregard of the contextual information as an indispensable piece in the design process and therefore, must be broadened. Analogous to the aforementioned study 2 (Christiaans and van Andel 1998), an 'Internet' hypertext information system was developed, which was available to the subjects during the design process.

A 'search engine' was available enabling subjects to search on any word in the system. In using the information system, standard facilities of the browser could also be used by the subjects, such as the buttons 'back', 'forward' and 'bookmark'. However, the access to other sites of the WEB was blocked. In the information system, both text and pictures were used.

The system contained two types of information, traditional 'industrial design' information, and 'contextual' information. Traditional information is defined as information that is directly and obviously related to the problem domain. Subjects were 23 senior students from the sub-faculty of Industrial Design Engineering at Delft University of Technology.

The design assignment given to the subjects was designing a new concept for a modern office environment. This assignment was further explained by a text of about 500 words. The text stressed information on the changing environment, due to a variety of factors such as developments within the area of information technology, globalisation, and a knowledge-base increase in general; the rise of a dynamic environment that forces companies to change both on an organisational level and in respect of their accommodation; the change in work culture that can be characterised as 'flexible'. The core of the design assignment was formulated as: "The problem is that an employee must have at his disposal the things he needs for his specific task at any time and in any place. Also, he wants to be able to adapt the desktop to make it his own personal work station at any time and in any place."
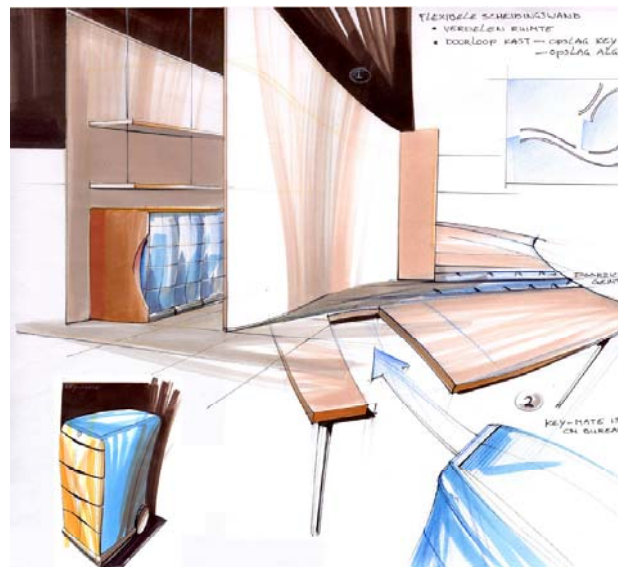
Figure 6.7: A new office environment.

At two points in the design process, the subjects were asked to report their conception of the problem, which is considered to be a reflection of the solution space. It is demonstrated that the originality of the (second) problem conceptions and consequently the final design solution were affected positively by the relative amount of contextual information processed. Since this latter measure had a negative effect on the appropriateness of the concepts, it is concluded that students should be trained in translating contextual information into creative design concepts. Appropriateness can be understood as the feasibility and constructibility of the designed objects.

6.4   Overall conclusions and discussion

From observing literature in design and in design research, it can be concluded that there is not a consequent definition of context or contextual information related to design. This is upheld by methods and methodics that appear to be more helpful in pruning the information than in introducing it into the design process, and by the amazing human ability to manipulate large amounts of fuzzy information based on cognitive economics strategies. As a result, potentially valuable contextual information is missing in the design process.

There is no strong evidence on how the inclusion of contextual information can help in making an object (a product) more easily accepted into a community or by an individual, or how to make it fit better the stake-holders aspirations. This is probably because there is not (yet) a strong understanding of the relevance and real extent of this information, and because of the lack of a suitable support to handle it.

On the other hand, there is strong evidence, from the studies mentioned in this paper, that the inclusion of contextual information in an appropriate way has a positive effect on the design process, leading designers to break their own fixations. There is a direct relationship between the amount of contextual information processed and the creativity, potency and distance of the resulting concepts. However, the relation between contextual information processed and the appropriateness of the concepts is still in doubt. It seems that the more contextual information is processed by an individual, the less appropriate his concepts will be. A possible reason for this is the lack of a good training of designers in translating contextual information into

feasible products. Hekkert and others have already proposed a way to overcome this weakness (Hekkert 1997).

The studies also confirm the claim that too much effort is being put in methodology and in design in the consecution of means to allow designers to generate a concept and to embody it into a product. The scope does not go beyond this point, missing the information related to motivators, needs and aspirations, motivators that appear in every creation process, consequently missing the contextual information that comes with them.

6.5 References

Anderson, J. (1993). *The Architecture of Cognition*. Harvard University Press, Cambridge, Massachusetts.

Christiaans, H.H.C.M., and 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* vol. 14, **1**, pp. 58-74.

Christiaans, H.H.C.M., and Andel, J. van (1998). Information Processing and Storage During the Design Process: The Use of a Flexible Information System, in: Frankenberger, E. and Badke-Schaub, P. and Birkhofer, H. (eds.) *Designers - The Key to Successful Product Development*, pp. 233-248, London: Springer-Verlag.

Christiaans, H.H.C.M. (1999). Designer's Kowledge Base and Structure: An Analysis of Argumentation in Design, in: *Proceedings of the International Conference on Engineering Design ICED*, Munich, 1999.

Galle, P. (1999). Design as Intentional Action: A Conceptual Analysis, *Design Studies*, vol. **19**, 20.

Hekkert, P. (1997). Productive Designing: A Creative Path to Design Solutions, in: *Proceedings of the Second European Academy of Design Conference*, Sweden. [available online] http://www.svid.se/ead.htm.

Mey, J.L. (1993). *Pragmatics: An Introduction*. Blackwell, Oxford.

Restrepo, J. and Christiaans, H. and Rodríguez, A. (2000, in press). *The Finality Argument on Design Methods. A Theoretical Approach From the Social Sciences*.

Snoek, H. and Christiaans, H. and Hekkert, P. (1999). The Effect of Information Type on Problem Representation, in: *Proceedings of the 4th International Design Thinking Research Symposium on Design Representation*, Massachusetts Institute of Technology.

Spears, R. and Oakes, P. and Ellemers, N. and Haslam, A. (eds.) (1997). *The Social Psychology of Stereotyping and Group Life*, Blackwell Publishers, Oxford.

Trousse, B. and Christiaans, H. (1995). Design as a Discursive Activity, in: V. Hubka (ed.) *Proceedings of ICED 95*, pp. 436-443, Heurista, Zurich.

Trousse, B. and Christiaans, H. (1996). Design as a Topos-Based Argumentative Activity: A Protocol Analysis Study, in: Cross, N. and H. Christiaans and K. Dorst (eds.), *Analysing Design Activity*, John Wiley & Sons, New York.

Wallace, K (1992). Some Observations on Design Thinking, in: Cross, N. and Dorst, K. and Roozenburg, N. (eds.), *Research in Design Thinking*, pp. 3-10, Delft University Press, Delft.

7. Developing NPD-Process Knowledge

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7.1 Introduction

This conference on Design Research in the Netherlands 2000 gives us a nice opportunity to show the results of design research which is being carried out at the Delft School for Product Design (officially the Sub-faculty of Industrial Design Engineering at the Delft University of Technology). Since the 1995 conference a lot has happened. In those days the Delft School of Product Design was the independent Faculty of Industrial Design Engineering. Now we have merged with the Schools of Mechanical Engineering and Naval Architecture into the new Faculty of Design, Construction and Production (DCP). The number of students and staff for product design stayed constant for all those years (ca. 100 fte staff and 1600 students).

Originally we had five organisational units: four "Vakgroepen" responsible for teaching and research in the fields of respectively Construction, Ergonomics, Formgiving and Management Sciences, with one shared "Werkgroep" responsible for teaching design.

Now we have three departments ("Afdelingen"), responsible only for research: Industrial Design (ID), Design Engineering (DE) and Product Innovation & Management (PI&M). All education is separately organised, headed by the Director of Education. Design teaching is an integral part of this organisation (although it is separately organised as the Institute for Design Teaching (= IvOO = Instituut voor het Ontwerp Onderwijs) and has the same budgetary status as the three research departments ID, DE and PI&M. The Department of Industrial Design is the combination of the former Ergonomics and Formgiving groups, Design Engineering comes from the former Construction group and Product Innovation & Management comes from the Management Sciences group. Design Methodology was part of the Management Sciences group and is now part of PI&M.

7.2 Design research

It could be argued that all research carried out within a school of product design is a form of design research, but that would be much too pretentious. For instance within the Department of Design Engineering research is done in the field of material sciences on plastics, and within Industrial Design researchers look at the physical limitations of elderly people in order to design better suited products for them. Within the Department of Product Innovation & Management research has been done on market introduction strategies for new products. These and other research projects are not considered as design research projects though.

It would be difficult to make a sharp distinction between what is design research and what is not, especially considering the multi-disciplinary character of design itself. I will limit design research to only those research subjects that are aimed at the development of process knowledge of the New Product Development (NPD) process and not covered by other

traditional mono-disciplinary domains. This gap partly exists because the other disciplines are not interested in them (i.e. intuition and creativity by psychologists) or because they are unable to do it within a mono-discipline (i.e. real protocol analysis of product design projects needs both designers or engineers and psychologists).

I will also limit myself to the research work of the Department of Product Innovation & Management. Others at this conference will take care of the research work that is being done in the other departments.

By doing so I will not go into the research carried out within the Marketing group (a sub group of PI&M), because their research is part of the mono-discipline of marketing. Even though they have, besides marketeers, economists, psychologists, communication scientists and even product designers in their staff. I will only report about the developments within the two other groups of PI&M, the Design Methodology Group and the Management & Organisation Group.

7.2.1 The Design Methodology Group

(Permanent research staff per May 1st 2000: ir. Norbert Roozenburg, dr. Peter Lloyd and 2 vacancies. Temporary research staff: 2 vacancies).

This has been the core design research group at our school, right from its beginning in 1964. Design Methodology is one of the key elements in the curriculum of Delft School of Product Design. According to the research of Hanny de Wilde (1997), about the history and development of this school, explicit attention to design methodology was one of the key elements to start the first product design school in the Netherlands at a university level. The founder of our school, an architect called Joost van der Grinten, borrowed the ideas about design methodology both from the Royal College of Art in the UK and from the Hochschule für Gestaltung in Ulm, Germany. The work of Bruce Archer was quite influential.

The graduation work of our first graduate (Norbert Roozenburg in December 1971) was about the application of a specific design method in product design. He still works at the school and is, not only, very active in the design methodology and design research field, but is also the Director of the School's Institute for Design Teaching. He is unable to be here because he is currently guest professor at the Danish University of Technology in Copenhagen. So I will be his humble representative.

The first professor in Design Methodology was Johannes Eekels (he became emeritus in 1987). Together with Norbert Roozenburg he produced numerous books and articles. The latest Dutch version of their book was published in 1998 (Roozenburg and Eekels 1998). An English version was published in 1995 (Rozenburg and Eekels 1975).

Besides this traditional emphasis on the prescriptive and normative ways of designing, which is still of concern, the research in this field now also embraces empirical studies.

The publication of the book on the Delft workshop on protocol analysis is a landmark in this respect (Cross, Christiaans and Dorst 1996). The workshop was organised to discuss, among leading scholars in design research, the results of different analyses from shared data.

The shared data consisted of a protocol study on both individual and group design work. It was based on the same design brief. The experiment itself has taken place at Xerox PARC in California. The experimenters were Nigel Cross (at that time part-time professor in Design Methodology in Delft), Anita Cross, Henri Christiaans and Kees Dorst; the participating designers came from IDEO, the leading product design firm in the US.

The workshop offered a great deal of insight into how designers actually work. At the workshop invited scholars shared their results, ideas, objections and doubts. It was interesting to watch the discussion because every attendant of the workshop had used the same original

data. It proved to be a very effective way of having detailed discussions about both the content of a design process as well as the way of doing protocol studies.

Another interesting project of this group has been the research of Kees Dorst. This empirically based study proved that the use of different paradigms within the design research field could be used to study different aspects of design. Traditionally within the design research domain the rational problem solving paradigm, based on Herbert Simon's ideas, is dominant (Simon 1967). Kees showed that this paradigm has its limitations, and looked for another paradigm. Donald Schön's idea of "design as a reflective practice" proved to be this interesting other paradigm (Schön 1983). Kees showed that using both paradigms to interpret the same empirical data leads to different views and different conclusions about how designers are really working (Dorst 1997). It is my opinion that this multi-paradigmatic analysis of product design will produce more interesting results.

The arrival, last year, of Peter Lloyd from the UK, an ethnographic oriented design researcher, is the next step to continue the current new stream of conducting further empirical studies.

The teaching of this group is focused on a fourth year course in Design Theory and Design Methods for all our design students. Of course the group is very active in the design studio work within the "IvOO".

7.2.2 The Management & Organisation Group

(Permanent research staff per May 1st 2000: prof. dr. ir. Jan Buijs, ir. Frido Smulders, ir. Rianne Valkenburg, dr. Hanny de Wilde, and 2 vacancies. Temporary research staff: ir. Danielle Hendriks, ir. Remko van der Lugt, and 2 vacancies).

The main objective of the Management & Organisation Group, the group I am responsible for, is to study product design processes in their natural environment, that is in the competitive situation of design projects, within companies, working together with suppliers and customers. Its focus is on design as a business activity. We usually refer to it as "design in context" or "design in business"

We are looking into product design as the result of teamwork. We are interested in both the communication within the team, as well as the influence of the project leader on team behaviour. This approach looks at team behaviour not in terms of group dynamics, but in terms of design work. Of course design work and group behaviour are intertwined, but we are primarily interested in the content of the product design work.

This shift from individual designers towards design groups has been caused by the very practice of industrial product development. Few product designs are the work of just one lonely designer. Nowadays complicated consumer- and industrial products are always the results of multi-disciplinary design teams. However we are not only interested in the teamwork itself, but also in the interfaces between those design teams and the rest of the organisation.

We are continually conducting case studies of product development in real corporate situations. This allows us to compare empirical studies with theories of product development and has resulted in two books on Integrated New Product Development and a new course for our first year product design students (Buijs and Valkenburg 1996 and 2000).

During the discussions of the aforementioned Delft workshop on analysing design activities we discovered big differences in the ways psychologists and design researchers were looking at design behaviour. For example two researchers were looking at the same type of a group design activity. Both looked at a specific action on the videotape. However the psychologist looked at body language and group dynamics, while the design researcher looked at the

content of the discussions within the design team. So for both there was something interesting to see, but the results were completely different. More surprisingly, some times the conclusions were completely different or even opposing.

This has led to some very intriguing research projects. Helga Hohn, a psychologist, started to look at the behaviour of team leaders in helping teams with innovative tasks. She questioned more than 75 international working professionals on how they inspire their (design) teams, how they keep them on track, and how they deal with the company pressure to perform better, quicker or cheaper. Once again process and content were very closely related with "playing" proving to be very important in keeping teams alive and kicking (Hohn 1999).

Rianne Valkenburg, a design researcher, is looking at team design work on the content level. She is comparing two teams of students designing during the Philips Design Competition, and two professional design teams, which took part in the earlier Delft experiment at Xerox PARC. Inspired by Kees Dorst's work she is using Donald Schön's paradigm to compare these different design teams. She has operationalised Schön's theory and is heading towards some interesting conclusions about shared understanding and team communication based on the content of the design project (Valkenburg and Dorst 1998). Her thesis will be published at the end of this summer.

Within this team-based research Danielle Hendriks and Hanny de Wilde are doing research about the role and influence of project leaders on the results of the product design team. Besides interviewing project leaders in Dutch design consultancies, they were also allowed to study the archives of one of the leading Dutch design firms. From a knowledge management perspective these archives have not proved useful. However, they have shown that if designers want to learn from their past they have to be more accurate in what and how to file their actual design work. Recently, an e-mail-based way of making weekly diaries has been developed. In analysing these diaries they hope to find some of the heuristics, project leaders use to solve their professional problems (Hendriks and De Wilde 1999). They are helped in this by a research student, Sjors Witjes, who is doing empirical research in cooperation with Stanford University. He is observing and interviewing project leaders of product development teams in the US high tech industry. Hopefully we can compare the results from the Netherlands with those from the US. These results will be integrated in our recently developed fourth year course on Product Development Management.

In our attempts to study the real life of designers we have discovered that most designers talk about intuition as an important element in their work. Although intuition is difficult to study within the traditional way of doing scientific research, we have taken up the challenge. Robin Groeneveld has interviewed about twenty professional designers. Most of them are very explicit about the influence of intuition and about the way they can rely on it. Hopefully his PhD thesis will be published the end of this year.

Finally within the Management & Organisation Group we are interested in stimulating creativity in product design. Not only have we developed a fourth year course on Creative Problem Solving (CPS), we have also started a research project in this field. Creative Problem Solving (i.e. brainstorming or synectics) is usually verbally based, while product designers tend to be visually oriented. The research project of Remko van der Lugt is trying to bridge the gap between the original CPS-rules and the more visual attitudes of product designers. The first results are promising (Van der Lugt 1998). An extended version of braindrawing, as opposed to brainstorming, seems to be an effective tool for product designers. His PhD thesis is scheduled for early next year.

Beside the already mentioned courses we are also teaching a third year course on Strategy and Organisation (Frido Smulders is responsible) and we all participate in the design studio work.

7.3   Final remarks

The research in both the Design Methodology Group and in the Management & Organisation Group is aimed at getting better insights into the process of New Product Development (NPD). With this insight we hope to improve the quality of product design work.

By sharing a selection of our work with other design researchers in the Netherlands we hope to get enough energy not only to continue, but also to improve.

7.4   References

Buijs, J. A., and Valkenburg, R. (1996). *Integrale Produktontwikkeling*, Lemma, Utrecht.

Buijs, J. A., and Valkenburg, R. (2000). *Integrale Productontwikkeling - Tweede Geheel Herziene Druk*, Lemma, Utrecht.

Cross, N. G. and Christiaans, H. and Dorst, K. (1996). *Analyzing Design Activities*, Wiley, Chichester.

Dorst, C. H. (1997). *Describing Design: A Comparison of Paradigms*, PhD thesis, Delft University of Technology.

Hohn, H. (1999). *Playing, Leadership and Team Development in Innovative Teams*, PhD thesis, Delft University of Technology.

Hendriks, D. and Wilde, H. de (1999). *Project Management for New Product Development Projects: An Empirical Study*, in: Proceedings ICED '99, München.

Lugt, R. van der and Buijs, J.A. (1998). Creative Problem Solving in Product Development: An Exploration Into the Use of CPS in Design Practice, in: Dingli, S., *Creative Thinking, Towards Broader Horizons*, Malta University Press.

Roozenburg N. F. M. and Eekels, J. (1995). *Product Design: Fundamentals and Methods*, Wiley, Chichester.

Roozenburg, N. F. M. and Eekels, J. (1998). *Produktontwerpen, tweede druk*, Lemma, Utrecht.

Schön, D. A. (1983). *The Reflective Practitioner*, Basic Books, New York, 1983.

Simon, H. A. (1967). *Sciences of the Artificial*, The MIT Press, Cambridge MA.

Valkenburg, R. and Dorst, K. (1998). The Reflective Pratice of Design Teams, in: *Design Studies*, **19**, pp. 249-271.

Valkenburg, R. (2000). *The Reflective Pratice of Product Design Teams*. PhD thesis Delft University of Technology, forthcoming in 2000.

Wilde, H. de (1997). *Passie Voor Productontwikkeling*, Lemma, Utrecht.

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8.   Product Development and Design Research

Research Into Architects as Component Designers

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8.1   Introduction

In Design Research, a lot of energy has been put in the generalisation of the design process. Practising designers however, state they do not see much profit from this knowledge. As a response to research aimed at generalisation, Lawson (1994) started to describe individual design processes of architects. This research showed that besides general conclusions, clear differences in work methods can be distinguished.

From these experiences with generalisations on design processes, I drew the conclusion that describing a general outline for a product development process does not serve practising design professionals accurately. A certain event will never repeat itself exactly (Waldorp 1992). But certain elements form similar events that can be lumped together as themes or patterns. Themes are elements in events that can be seen as resource or constraint for product development processes. Patterns are reactions on a theme, or actions from other persons, affecting product development processes.

Within the frame of my PhD research I reconstructed effective development processes of new building components initiated by architects. Themes and patterns found were used to construct a theory. Architects can profit from the knowledge accumulated on themes and patterns. Elements from this theory that they feel are relevant to their approach can be integrated into their private work methods. The aim is to stimulate architects to develop more new building components and come to a more effective and efficient way of component design. Before going into the results, I will outline the research methodology and the theoretical framework.

8.2   Methodology

At first the aim of my doctoral research was to catalogue and describe the product development processes in the building industry. First a case study research was carried out that focused mainly on manufacturers. Six initial cases revealed that architects play an important role in initiating product development by requesting manufacturers to supply special non-existent components to realize their projects. It also turned out that manufacturers use some of these ideas to generate new standard products. In contrast to the development processes of standard products in the building industry, special product development initiated by architects is a virtually uncharted territory. I therefore decided to make this the central subject of my doctoral research.

8.2.1 Cases and additional research data

Since very little research had been done into special product development in the building industry, the obvious choice was to use an exploratory research method. In principle, it would

be possible to use exploratory, descriptive or explanatory research strategies. On the other hand, these strategies have different characteristics which makes the one more suitable for a particular study than the other. The decision to opt for case study research was based on Yin's (1989) considerations.

Semi-structured interviews were held with employees of manufacturing companies and architectural practices. The sensitising concepts underlying the interviews came from business administration literature on innovations and design research. The literature study produced tools to get to grips with product development in the building industry. An overview is to be found in a state-of-the-art report (Oostra 1996). The case studies investigated to what extent the sensitising concepts could be applied to component design. This approach is based on a long tradition of the grounded theory methodology that originated in the social sciences (Glaser and Strauss 1967).

The case study results will be supplemented with statements made by 118 architects, manufacturers, contractors, constructors, project developers and researchers who were not part of the case studies. The research results were linked together using the game theory.

8.3   Theoretical basis

In the first instance it is important to make a distinction between two product categories: standard products and special components (inspired by Eekhout (1997)). A standard product can be manufactured independently without a client being involved. All products are identical, even though a manufacturer can include a number of varieties in his range, differing for instance in colour or measurements. He will know for certain precisely what requirements the product in question must comply with. In the case of a special component a manufacturer may get a request from a client that he cannot resolve with a product from his range. A completely new product must be developed for a specific building task.

There is an essential difference between the parties who take the decision whether or not to make a product. A manufacturer decides on the making of a new standard product. In the case of special components it is the client who decides that he wants to use a non-existent product. Clients may play different roles in the building process, for example a principal, contractor, consultant or an architect. This paper focuses on the situation in which it is the architect who decides whether or not a new product should be made. From now on, I will use the term component design to refer to an architect's contribution to the development of special products.

For present purposes an architect is defined as someone operating alone or on behalf of a group of individuals, usually a firm of architects, who designs a plan for a building and looks after its realization. The aim of an architect is to design or redesign and realize buildings or other objects in cooperation with people outside his own firm. The building process is the process by which an initiative towards a building project is converted into a physical building. The achievement of this goal requires many different types of expertise, generally represented by individuals from different companies. This paper proceeds from a 'traditional' building process in which an architect directs the other parties involved in the project on behalf of a client. Participation in a building process is a precondition for being able to initiate the development of special components.

8.3.1 The manufacturer's perspective

The literature from the perspective of the manufacturer of standard products has a long tradition (Bruce and Biemans 1995, Hollins and Pugh 1990, Clark and Wheelwright 1994, etc.) This perspective is recently being broadened. Von Hippel has introduced the consumer

active paradigm (CAP) as a counterpart of the manufacturer active paradigm (MAP) (von Hippel 1988). His research suggests that clients in the business-to-business market usually look for a manufacturer who is able to make the product they have in mind. Clients thus respond to technology capacity in general and a company's capacity in particular (Hutt and Speh 1995). Something similar is also taking place in the building industry.

Also in the building industry manufacturers are seen as the ideal product developers (Pries 1995). However, other parties also make important contributions to product development. Architects for example play an important role in initiating the development of component parts in specific building tasks (Oostra 1998). Architects who come up with an idea and initiate product development fit in with Von Hippel's consumer active paradigm (CAP).

In planning a building, architects come across elements that cannot be realized with standard products. In situations like this they have the choice of adapting the design to existing products or initiating the development of new products. To achieve good results with the development of special components, an architect must be open to collaborating with others (Oostra 2000). He needs production facilities, and hence must collaborate with a manufacturer. In most instances he will also need complementary expertise in the preparatory phase from other people such as constructors or other advisors.

8.3.2 Game theory

The game theory perspective was used to interpret and link together the data generated in the context of this study. Historians date the origins of game theory as far back as 1654 (Colman 1995). Game theory initially began as an abstract mathematical invention, the theory of probability. Since then it has evolved into a model for all kinds of interdependent decision-making processes. The social sciences began to use game theory to explain and predict behaviour.

In their book "Actors and Systems", Crozier and Friedberg (1980) show that games provide an excellent frame to study companies and industries. According to the authors, the creation and use of structured games is one of mankind's more important inventions, making possible the achievement of common goals, which require the cooperation of many different individuals. Contributing to a common goal also allows each individual to advance his own interests. The way in which an industry and companies are organized, however, has an important influence on the behaviour of the individuals involved. People are not controlled by the rules of the game but by its structure. In other words, there is scope within the rules for the players to determine their own strategies that will allow them to play in the way they personally find satisfactory. Usually they will only be able to achieve their own goals as long as they go on contributing to the common goal.

Following Crozier and Friedberg, I have distinguished between resources, constraints and strategies. Architects have certain resources at their disposal to use in a product development process. They will encounter difficulties that they will have to overcome if the process is to be brought to a successful end. Deliberately or otherwise, architects use certain strategies to take full advantage of their resources, or to sidestep or get around any difficulties. How architects see their resources, constraints and strategies depends in part on the 'frame' (Schön 1983) they use to assess their own situation.

8.3.3 Project management

Architects employ strategies to manage the available manpower, means and information in the development process of a special product. They have to operate within the margins of the

building process. The general knowledge of these strategies comes under the discipline of project management.

Wijnen, Renes and Storm (1988), who are authorities in the field of project management, categorize the aspects to be controlled in managing a project into: (a) Time, (b) Money, (c) Quality, (d) Information, and (e) Organization. Other aspects that are emphasized in the literature are communication (Robbins 1996) and monitoring the work sphere in which trust among team members plays an important role (Bennis 1994). These aspects provide a basis to divide the strategies used by architects to direct project development into the following categories: 1) Time, 2) Money, 3) Quality, 4) Information and communication, 5) Organization, and 6) Atmosphere.

8.4   Research findings - themes

8.4.1 Resources
Important resources to help realise special products are time, money, information and access to facilities. Since an architect does not have extensive knowledge about the appropriate technologies to manufacture a special product, he needs other parties to collaborate with him. In this context, the aim of collaboration is to have knowledge and manufacturing and testing facilities at one's disposal.

Product development budget
There is a link between the commissioning of a building project and the budget allocated for its construction. The prevailing opinion among architects is that a higher than average budget for a building, or a higher than average fee for an architect, is a precondition for initiating the development of new components. An example to show that this need not be the case is a young product development company oriented towards the building market. The money that had been put aside to purchase standard light fittings for an office was used to develop new fittings. Development costs and the manufacturer's fee came well within the budget reserved for light fittings.

Time
The time allocated to a building process may in part be spent on developing new components. The planning of design work determines the time available for product development. It could be that a building has to be completed in such a short space of time that there is no room left for an architect to design a new building component.

Information and facilities
An architect depends on the support of other parties, those who have the knowledge and facilities that are needed to realise a new product. For this, an architect needs at least a manufacturer who is willing to make a new product. One of the cases proved that this collaboration is not always as obvious as it seems. A manufacturer, who specialised in sports goods, was not interested in delivering building products. It took much power of persuasion to move this monopolist to collaborate.

Because the parties involved in a building process do not see the development of new products as an essential part of it, an architect will have to motivate the parties whose collaboration he needs to develop a product. Money can play an important role in this respect. But other reasons could also motivate a person or an organisation to contribute to product development.

The following motives for cooperative behaviour towards architects have been observed:

- A client organisation: Because product development is appropriate to its declared aims.

- A researcher at a university of technology: Because he is involved in research into the material in question.

- An institution concerned with the development of steel structures: Because it is prepared to subsidize a project where it sees the possibility of encouraging the use of steel in buildings.

- A structural engineer: Because he is very interested in applying the material in buildings, or because he enjoys thinking about something new.

- A supplier: Because he would enjoy being involved, while he does not see the project as an immediate financial success for his company ('hobbyism').

- A supplier: Because he sees opportunities to increase his turnover.

Since the crucial role of having relevant information available, this study looked into the matter of information exchange in closer detail. The exchange of information relevant to component design has different characteristics depending on the sort of information. In this connection two sorts of information mentioned by Colin Davidson (1998) are interesting: (1) project-related information and (2) general information. He defines them as follows: "Project-related information, as its name implies, denotes information that is particular to an individual project and is accumulated during the project-related processes of design, manufacture and construction. General information is, at least in principle, available to nourish the processes of any construction or any research project; it is accumulated constantly as more and more is learnt about building-related technology, and about the application of the human and natural sciences to building."

These two systems of information are found in different contexts and time scales. In the case of standard products it is in the producers' interest that potential specifiers are aware of the existence and advantages of these products. It is of his immediate advantage to make his new product known as widely as possible among those involved in the building industry who exercise an influence on the choice of building products. His aim is to make knowledge of his products part of the reservoir of general information of the industry.

The different members of the building team build up project-related information at the start of a building assignment. These members also have to find a common form in order to communicate for the duration of the project. When the project is realized and all decisions concerning it have been taken, this information largely disappears. Only a part is stored in archives or kept for maintenance purposes. The same goes for a part of the information linked to the development processes of special products. This information has not disappeared but it only remains in the form of experiential knowledge for the people concerned.

The information needed for developing a new product is a combination of these two sorts of information. As a result a distinction needs to be drawn between these two sorts of information in fostering innovation in building. Architects use general information in the development process for special products as a step to find producers. Besides drawing from their own experience, they use trade literature with this end in view. This literature is however inadequate for this use. To stimulate the development of special products by architects additional information has to become available. That is now mainly part of the project-related information reservoir. Because of the fact that is reservoir is hard to access, there is a need for an intermediary between architects and producers. This role is being taken on by a number of newly emerging firms, but these only reach a small group of architects. To encourage product

innovation on a larger scale, relevant information needs to be made generally available. A database via the Internet is ideal here. An independent body would have to make an inventory of the various projects using special components already realized. Information would need to be provided about the parties concerned together with a short description of the product developed. Ideally there should also be a survey available of the production facilities of the different producers involved in the building industry, with an assessment of their technical knowledge. In Holland the firm of Boosting has the potential for this. They have the proper contacts and objectives even though they do not yet have the financial means to realise such a database.

8.4.2 Constraints

When architects design components, they will for instance have to check for the codes and standards of the industry that might stand in the way of the development and application of new products. Insurance companies, clients, financiers, producers, contractors, politicians, project developers and even fellow architects may place obstacles in the way of architects' initiatives to develop new components (Oostra 1999) Innovation goes hand-in-hand with uncertainty (Crozier et al 1980), particularly in the initial phases. And innovation requires people to adjust their habits. In general the other players will try to keep such uncertainties under control and try to escape limitations that others try to impose on them (Crozier et al 1980). In a defensive reaction, a constructional engineer will stick to the usual methods of calculation, a manufacturer to the usual methods of production and a contractor to the products and constructional techniques with which he is familiar (Argyris and Schön 1996). Architects whose aim it is to develop special products need other parties to collaborate with them and to offer their expertise. However, the same parties could also obstruct the component design process. Architects should be prepared to anticipate and respond to possible obstruction in the product development process. Examples of such instances are the following:

- An insurer may impede the application of existing products in an unconventional way, let alone the application of new products.

- There may also be problems if suppliers have set up a cartel with the aim of dividing the market between them. Things can be difficult if there turns out to be only one supplier who can supply what an architect requires but that supplier is barred from doing so by the terms of an agreement with his fellow suppliers. As a consequence, the required products will not be forthcoming.

- One last example: Any attempt to cut out subcontractors will discourage innovation, as low prices do not guarantee the quality of a subcontractor's work. Particularly when a subcontractor contributes to a new component cutting him out can have an unfavourable effect. This situation may also result in a worsening of mutual relationships, which in turn would affect communication between the parties involved. The end result will be problems in the co-ordination of the various different activities and products.

8.5 Research findings – patterns

An inventory has been made of what made architects want to develop new building components in the first place and their roles in product development and strategies they use to steer product development processes.

8.5.1 Motivation

Although architects may initiate the development of new products, their main interest is not focused on the individual product but on the complete building project. Products are secondary in the sense that they are only the means by which (parts) of buildings are realised. But this central preoccupation with the realisation of the building can provide a motive to create new products. Frustration may be the trigger here. For example, it may not be possible to realise part of a building design using existing standard products in a way that satisfies the architect. If the discrepancy between the desired result and the available solutions is big enough and there is time available, then the architect will explore the feasibility of product development. The architect must consider product development to be an option in the first place, though. Some architects will only use products already available on the market.

Another motive to design new components can be the desire to distinguish themselves from their colleagues. Architects have to compete in order to get their building assignments.

A third reason to innovate among architect is interest in technology and their quest for new and improved solutions for design problems. In this case the architect is interested in exploring new possibilities and will try to gain more in-depth knowledge. He will look for occasions in a building design process to utilize these new insights and ideas.

8.5.2 Roles

Architects choose between possible solutions for their building designs and so are in a position to persuade their partners to cooperate in product innovation. Taking on the role of initiator of the development of project related product development makes adopting the role of motivator inevitable since other parties, such as the client and the contractor, have to be convinced of the need for the new product. The architect also has to find at least one manufacturer, who may or may not operate in the building industry, willing to develop and manufacture a new product based on his idea and at an appropriate price.

Architects usually play an active role as designers in the product development process. Although not responsible for all design tasks, architects make the final decisions concerning the appearance of new products. They can therefore take up a position as client or as co-designer (and occasionally as co-developer), depending on how much they rely on the aesthetic abilities of the manufacturer.

8.5.3 Strategies

Component design processes are incorporated in design processes of buildings. The development of a component is thus embedded, or in other words nested in another process (Kendall 1990), the building process. This imposes limiting conditions on a product development process. The fact that component design is embedded in the building process forces an architect to use his strategies at two levels and so exert a favourable influence on a development process, that is:

- At the level of the building process.

- At the level of product development.

Many architects find it difficult to manage product development. Embedding it into the building process is seen as a stumbling block. Although some architects would certainly like to develop a new product, a number of circumstances prevent them from actually doing so.

Architects can learn from the strategies their fellow architects use in managing development processes for special products and so achieve components which are better adapted to their own and their clients requirements and demands. A résumé of the strategies found in this study is presented in the following table.

TABLE 8.1

Strategies used in the building process to manage product development
Time   • Persuade a client to increase the amount of time for the creation of new products by convincing him of their advantages.   • Start the product development process as early as possible in the building process, so increasing the amount of time available.
Money   • Reserve part of the building budget.   • Reallocate costs in the building budget.   • Persuade a client to increase the budget by convincing him of the advantages of the new products.   • Inquire about possible subsidies.   • Look at different kinds of manufacturers when determining the price to ensure that the price is in line with the market. This means looking at the cost of alternative solutions. An architect who goes about this cleverly, by example by thinking carefully about the product description or the way in which he invites tenders, may achieve a more favourable price.
Quality   • Call on the knowledge of third parties - competing manufacturers or product developers - to overcome problems.
Information and Communication   • Have an open-minded attitude towards a manufacturer to make it easier to exchange information about a product's feasibility and the way in which it is composed.   • Ensure that a client remains enthusiastic not just about the building project but also about the component to be developed. This is important. If there is any uncertainty about possible risks he may reconsider his decision.
Organisation   • Consider whether product development can or should be kept separate from the building project.   • Come up with new forms for the organisation of the building process which are more favourable for initiating product development.
Atmosphere   • Involve people in the building process who are receptive to new ideas.   • Improve motivation in the pre-tendering phase by paying for any development work.

8.6   References

Argyris, C. and Schön, D. (1978). *Organizational Learning: A Theory of Action Perspective*, Addison-Wesley, Reading.

Bennis, W. (1994). *De Manager als Koorddanser*, Contact, Amsterdam.

Bruce, M. and Biemans, W.G. (1995). *Product Development: Meeting the Challenge of the Design-Marketing Interface*, John Wiley & Sons, Chichester.

Clark, K.B. and Wheelwright, S.C. (1994). *The Product Development Challenge: Competing Through Speed, Quality, and Creativity*, Harvard Business School Press, Boston.

Crozier, M. and Friedberg, E. (1980). *Actors and Systems: Politics of Collective Action*, University of Chicago Press, Chicago.

Eekhout, M. (1997). *POPO: Of Ontwerpmethoden voor Bouwproducten en Bouwcomponenten*, Delft University Press, Delft.

Glaser, B. and Strauss, A.L. (1967). *The Discovery of Grounded Theory: Strategies for Qualitative Research*, Aldine Publishing Company, Chicago.

Hippel, E. von (1988). The Sources of Innovation, Oxford University Press, New York.

Hollins, B. and Pugh, S. (1990). *Successful Product Design*, Butterworths, London.

Kendall, S. (1990). *Control of Parts*, unpublished Ph.D. thesis, MIT.

Lawson, B. (1994). Design in Mind, Butterworth Architecture, Oxford.

Oostra, M. (1996). *Productontwikkeling van Bouwcomponenten*, unpublished report TU Delft, Delft.

Oostra, M. (1998). Initiatives for Product Development in the Building Industry: The Architect as Product Innovator, in: Emmitt, S. (ed.) *Detail Design in Architecture 2*, pp. 35-44, Centre for the Built Environment, Leeds.

Oostra, M. (2000). Stimulating Innovation by Making Project-Related Information Available on the Internet, in: *Construction Information Technology 2000*, Reykjavik.

Pries, F. (1995). *Innovatie in de Bouwnijverheid*, Ph.D. thesis, Erasmus Universiteit, Delft.

Robbins, S.P. (1996). *Organizational Behavior: Concepts, Controversies, Applications*, Prentice Hall, Englewood Hills.

Schön, D. (1983). *The Reflective Practitioner: How Professionals Think in Action*, Basic Books.

Wijnen, G. and Renes, W. and Storm, P. (1988). *Projectmatig Werken*, Het Spectrum/Marka, Utrecht.

Yin, R.K. (1989). *Case Study Research: Design and Methods*, Sage Publications, Newbury Park.

DESIGN REPRESENTATION

9. Prolegomena to the Recognition of Floor Plan Sketches

A Typology of Architectural and Graphic Primitives in Freehand Representations

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9.1 The architect's papers

Despite being a mixed and transitional case (Goodman 1976), visual architectural representations have been extremely productive and expressive design tools. Drawings have replaced buildings as the primary product of the architect since the Renaissance, in what appears to be an attempt to elevate the status of the master builder to that of a scientific or artistic designer (Evans 1995; Porter 1997). This has resulted into not only many worthwhile buildings but also a huge number of images that document design processes and products from a variety of viewpoints. Our knowledge of world architecture relies more on published images than on personal experience (Evans 1989). In recent years our already highly visual culture has been further enhanced by social and technological developments, including the democratisation of the computer, the proliferation of the Internet and the popularisation related multimedia technologies. These have created an opportune environment for the digital dissemination of visual architectural information, uniquely suited as a repository of architectural imagery.

In most current information systems images are treated as discrete, integral entities. They are indexed through textual annotations and associated with other information items manually. Analysis of images, e.g. in the framework of content-based retrieval, can recover a number of important features, such as the number and shape of spaces or the overall shape of a floor plan. It can also produce the general topological pattern of such features. For practical reasons, however, image analysis is generally restricted to a small number of salient features. These form the basic classification criteria for the image in the framework of specific activities. Therefore, image analysis becomes a deterministic search for the most economical collection of features (Gong 1998). The approach underlying our research is fundamentally opposed to both manual indexing and basic feature extraction, on the grounds that they do not return a formal representation, which could be considered equivalent to the image itself. Drawing from computer vision and image analysis we aim at a comprehensive recovery of primitive parts, identification of relationships between these parts and recognition of emerging structures.

9.2 Floor plan sketching

Drawings of different types are used by architects for a variety of purposes, from freehand recording of visual experiences to design registration and communication. In these types and purposes we distinguish common characteristics, such as an uncertain grounding in geometry, systematic deviations from representational drawing, extensive (and at times redundant) annotating, analytical structure so as to specify form, behaviour and performance in detail.

These common characteristics make architectural drawings compatible to each other, generally flexible but also complex.

One of the most complex types of architectural drawing is the freehand sketch. Sketching combines subjective and objective drawing, in that it is characterized by variable emphasis on the designer's intentions/emotions and information conveyed in the drawing. From a technical viewpoint, sketches are not strictly bound by conventions of architectural drawing, in a way reminiscent of gesture drawing (Betti and Sale 1992). Their flexibility, availability and expressive power means that architectural sketches are applied to a variety of purposes: recording objects and designs (including visual investigations of the built environment), communicating design ideas and concepts, analysing how a design will fit a particular context, and studying building typology (Edwards 1994). Nevertheless, sketches are mostly associated with and venerated for the generation and exploration of central design ideas. This runs contrary to the wide application of sketches in design and analysis, but fits the elevation of the drawing to the level of a primary architectural product.

In our research, we approach sketches as a first step in a long path that leads to a complete design (Betti and Sale 1992), rather than as a self-contained design product. The function of sketching that interests us is the transcription of designs formed as mental images. Such sketches form external representations aimed at unloading/refreshing working memory, thereby also allowing the refinement of image through perception and ultimately communicating ideas to others.

Freehand sketches of floor plans are more schematic (conceptual) than other types of sketches. They follow more closely the architectural conventions of orthographic projection and add elements of diagramming, such as the use of symbols to denote objects, the application of emphasis on critical points and structuring of symbols through their interrelationships. From the viewpoint of recognition, floor plan sketches are arguably more challenging than perspectives, axonometrics or elevations because they are the farthest from pictorial recording. They belong to that intriguing category of representations that may be incomprehensible before one comes to grips with their structure, but become perfectly understandable afterwards (Lopes 1996).

9.3   Architectural primitives in floor plan sketches

9.3.1 Drawing dimensions

A sketch entails several dimensions. These are common to a number of representations, from writing to speech. Each dimension is a self-contained study area, central to one or more sciences or disciplines. The *syntagmatic* dimension concerns the sequential structure of the representation. In a drawing this is the sequence of graphic production, i.e. how the drawing comes into being as one graphic element after the other is added, for example through pencil strokes to a sheet of paper. In comparison to other representations, this dimension is relatively weak in drawings. In written text, for example, the sequence of words in a sentence reflects the syntactic and grammatical constraints of the language. In a drawing, on the other hand, the sequence by which strokes are added is not necessarily related to the two-dimensional structure of the described objects, not to the development of the design in the designer's mind. The *paradigmatic* dimension is complementary to the syntagmatic one, as it concerns the range of standard primitives used in representation. Drawing primitives are generally graphic objects such as lines, circles and dots. These can be analysed at their own level of implementation mechanisms, as well as at the level of representation symbols (Marr 1982), e.g. closed contours representing discrete architectural objects.

The mechanical dimension relates to the anatomy of the draughtsman in interaction with furniture and materials. Such constraints may seem trivial at first sight, but may determine several representation levels. For example, mechanical displacement of the arm may alter stroke matching. Also changes in starting position may affect direction of rotation around circles (Van Sommers 1984).

The *cognitive* dimension operates on the two interrelated levels of action and perception. Action planning and control constrains syntagmatic and mechanical aspects through e.g. eye movement in response to action, positive feedback, anticipatory pursuit, and eye, head and hand coordination in general (Kowler 1990; Miles and Willman 1993). Also relevant are issues of mental imagery and working memory. These are also involved in the perception and recognition of sketches.

Our research focuses on the paradigmatic dimension, that is, the identification of discrete, meaningful components and their relationships. This is a prerequisite to the analysis of cognitive and computational aspects. For instance, image segmentation into areas tentatively corresponding to known objects presupposes knowledge of the paradigmatic structure of architectural sketches. Other dimensions influence the formation of a sketch out of the basic graphic elements. For example, the sequence of adding graphic elements influences not only the total image but also individual elements.

Figure 9.1 illustrates such influences through three different sequences, A, B and C, for the same sketch. Each sequence consists of three steps, with each step adding one specific piece of information. Despite the near identity of the end products, differences -however subtle- are significant not only for the design approach but also for the drawing itself. In sequence B, step 2 shows the addition of the central circulation axes as a subdivision of the already placed overall form of the building. The same form in the other two sequences is added at the last step, as a way of constraining construction. In sequence C, the axes distort (in step 2) the building form and the relative position of the space bubbles. This happens prior to the introduction of the overall building form in step 3. In sequence C all four spaces are self-contained-bubbles, but in sequences A and B two spaces are partially defined by the external envelope against the backbone of the two circulation axes.
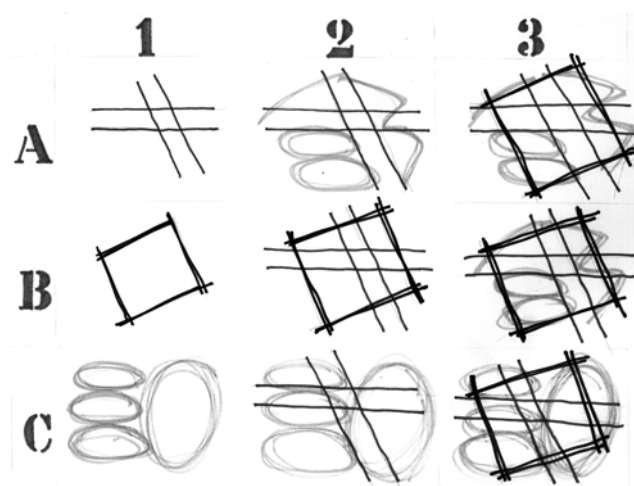
Figure 9.1: Alternative sketching sequences.

Mechanical constrains may also lead to differentiation in the paradigmatic dimension. When drawing simple geometric forms, such as the standard graphic elements of a floor plan sketch, the majority of strokes conform to the preferred stroke directions for the draughtsman's

preferred handedness. One important source of exception arises from a tendency to keep contact with the paper as the pencil moves from one linear element to another. The integration of this tendency, as well as the constraints of the drawing media (e.g. ink replenishment), results in a systematic even through variable approach to stroke length, direction and continuity (Van Sommers 1984). Differences and variations due to the syntagmatic and mechanical dimensions are generally impossible to trace in the end product (final sketch). Drawing style varies from person to person, but even the same person may variably use alternative styles with respect to drawing structure and media. Consistency in drawing style and technique is not a priority for floor plan sketching in the early design stages.

9.3.2 Organisational lines

Probably the most frequent type of information one draws in a sketch is organizational lines (Figure 9.2). These are implemented mostly by means of multiple lines as a framework of drawing. They organize composition by extending beyond the outside limits of objects and may cut through objects. Organizational lines are generally transparent -except where they overlap with object contours and relations.

Organizational lines are related to coordinating devices, that is, structures that determine the placement of spatial and building elements (Koutamanis 1996). Coordinating devices are either global (apply to a whole design or a distinct part, such as a wing) or local (refer to a specific component and its spatial relationship to its immediate context). Similarly to coordinating devices, organizational lines are a mixture of abstract spatial relationships, architectural elements and structural associations like grids. A compete sketch cannot consist exclusively of organizational lines. In addition to semantic guidance, organizational lines provide cognitive constraints to mechanical bias towards specific directions due to handedness: they guide strokes that follow a non-preferred direction (Van Sommers 1984). The same applies to relationship lines.
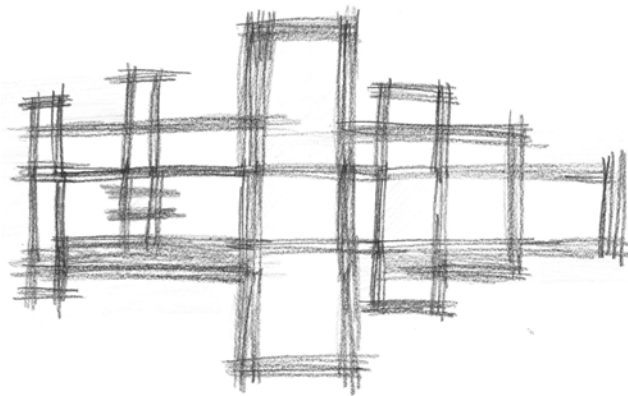
Figure 9.2: Organisational lines.

9.3.3 Spaces

Spaces are generally explicitly represented in floor plan sketches. Sketches consisting almost exclusively of spaces are not uncommon, especially as studies (Figure 9.3). Space contours normally are closed spaces or bubbles, even when the limits of the different spaces is not as sharply demarcated. The perimeter of a space is indicated by single or multiple lines.
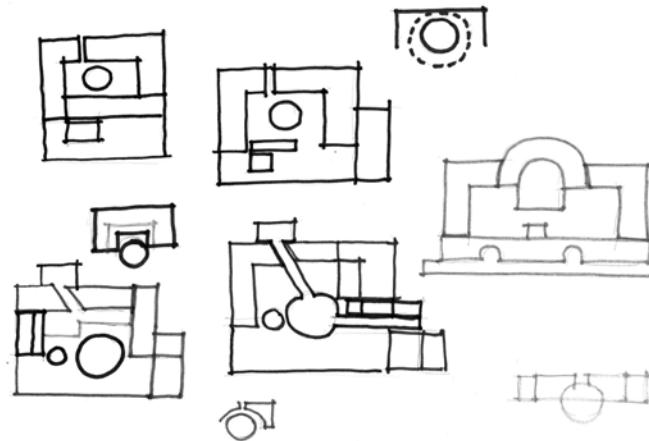
Figure 9.3: Space contours.

9.3.4 Relationship lines and building elements

Given the abstraction of sketches, building elements are seldom depicted as discrete objects. The obvious exceptions are building elements that contribute greatly to the spatial articulation or morphology of the design, such as a dominant wall in a flow space or a portico. More often, building elements are reduced to relationship lines that indicate arrangement (e.g. alignment in a line representing a colonnade: Figure 9.4). The same relation lines may indicate general principles of arrangement such as dominant axes. Relationship lines are related to coordinating devices and organizational lines.
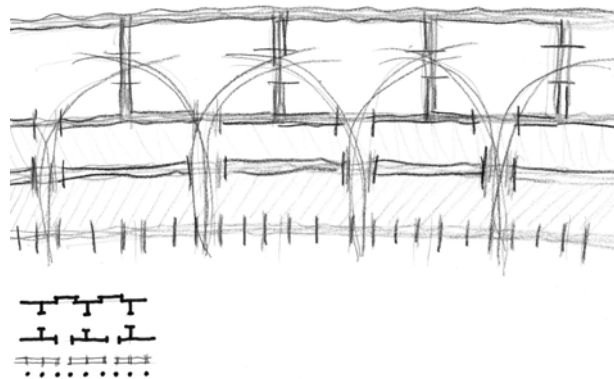
Figure 9.4: Relationship lines.

9.3.5 Positive and negative

Positive and negative, with respect to space and architecture, are charged concepts. In sketches of floor plans we refer to a sketch as being positive when the building elements are drawn (coloured) and spaces are left blank (similarly to conventional architectural drawings). The reverse: coloured spaces that leave building elements blank, is a negative sketch (Figure 9.5). This is frequently applied to so-called figure-ground drawings, which depict e.g. urban structure through the relationship between the solids (buildings) and voids (spaces) of the city (Edwards 1994).
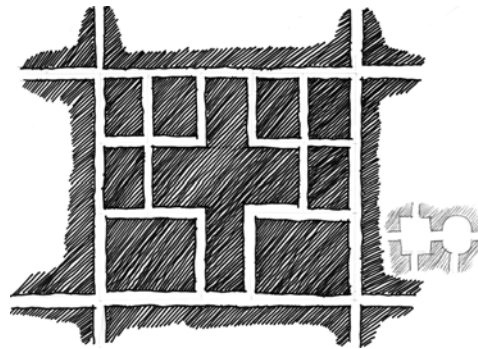
Figure 9.5: Negative sketch.

9.4   Implementation: graphic primitives

A sketch of a floor plan comprises organizational lines, spaces, building elements and relationship lines, usually in a positive manner. These types of information correspond with the level of basic architectural primitives in the representation. One level lower, we encounter the implementation mechanisms, that is, the graphic primitives used to depict the architectural entities. Implementation mechanisms vary with the implementation media and the mechanical constraints each medium affords. The following graphic primitives relate primarily to pen, pencil and paper.

9.4.1 Solid lines

The most general category of graphic implementation primitives is solid, continuous lines. These can be used for practically everything, from relationship and organizational lines to the contours of space or building elements. The arrangement of lines follows a number of general principles, which organize the image into generally discrete even though overlapping parts (Figure 9.6). These principles include:

• Continuation: Formation of closed or, less frequently, open shapes.
• Collinearity: Correlation of structurally similar or connected elements.
• Parallelism: Grouping of two or more lines into e.g. the contour of a path or a grid.
• Simple connection and cotermination: Two variations of the same relationship, which both indicate that the lines belong to the same form. In architectural drawing unrelated lines do not intersect or link, an element that, probably through training, has been carried over to freehand sketching.
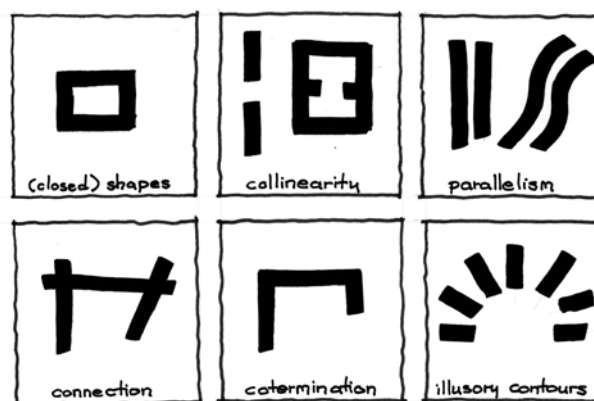
Figure 9.6: Line arrangement.

Under certain conditions unconnected lines combine to form shapes such 'negative' spaces, i.e. illusory contours. An illusory contour is produced by the grouping together of line terminations or by expectations linking together salient features of a nonexistent shape (Kanizsa 1979). Consequently, completion becomes a minor point of attention in recognition, not only for the identification of illusory contours, but also for the removal of local perturbations and other by-products of the mechanical dimension (Figure 9.7).
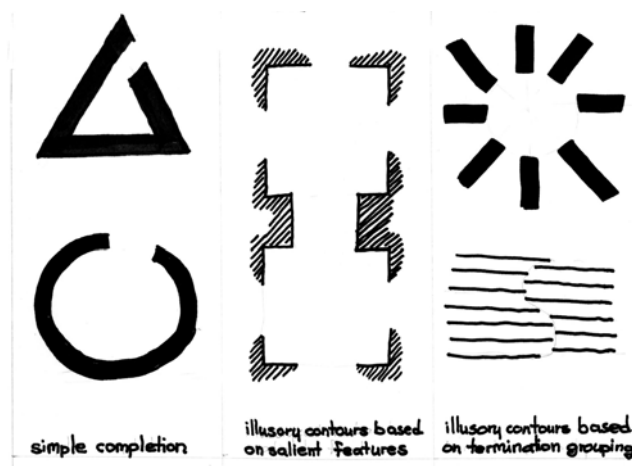
Figure 9.7: Completion

9.4.2 Multiple lines and bubbles

Multiple lines are used to depict organizational lines (Figure 9.2) or limits of spatial elements. Similarly to scribbled-line drawings, multiple lines make the outline of a form fuzzy and indefinitely stated (Betti and Sale 1992). This agrees with the reluctance to make hard commitments in the early design stages, as well as with the informality and metric flexibility of the sketch. Multiple lines may form closed shapes or bubbles, which normally signify spaces (Figure 9.8).
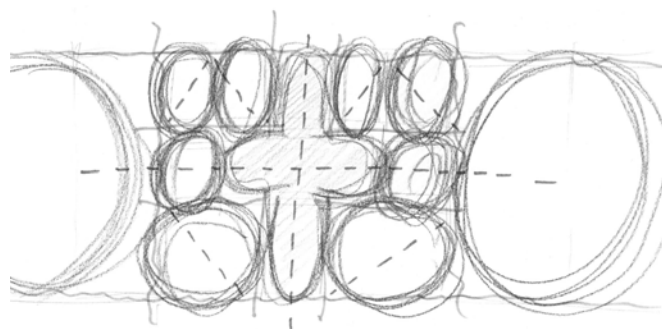
Figure 9.8: Space bubbles.

9.4.3 Broken and dotted lines

Broken and dotted lines represent a diversification of the basic solid line. They normally are used to indicate projecting elements, relationships between building elements (Figure 9.9) or (less frequently) spaces. In addition, they may be used as annotations, e.g. in order to illustrate proportions.
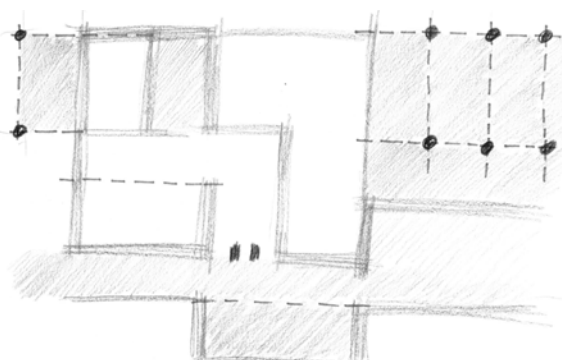
Figure 9.9: Broken lines and blobs.

9.4.4 Blobs

Blobs are small, usually filled surfaces or contours, which generally indicate an isolated building element, such as a column. The same graphic element is used to highlight a focal point of spatial articulation or construction, e.g. an important grid point (Figure 9.10).
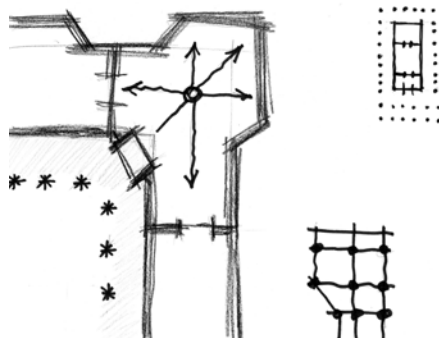

Figure 9.10: Blobs.

9.4.5 Textured and coloured surfaces

Texturing, hatching and colour are applied in order to accentuate spaces or space groups. These are also used to indicate subdivisions of spaces within bubbles or closed shapes, as well as graphic annotations of formal principles and activity patterns (Figure 9.11). Quite often, it is not possible to distinguish between a hatching pattern that indicates a space by filling it and a grid that applies to a yet unfinished area of the sketch (Figure 9.12). In such cases, a grid or web pattern is treated in the same way as a simple texture or hatching pattern. The addition of more information invariably transforms the grid into relationship or organizational lines.
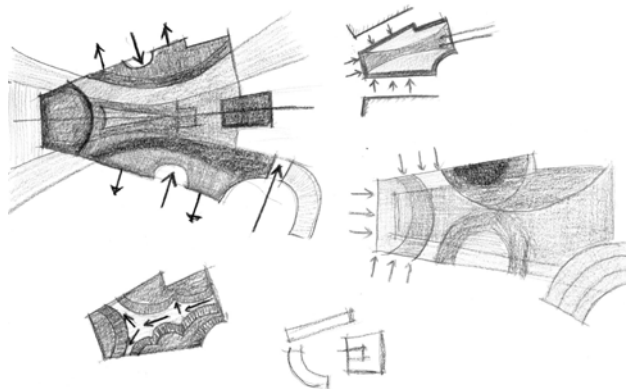
Figure 9.11: Graphic annotations.

9.4.6 Annotations

Annotations are used to indicate properties of relationships, building elements or spaces. They include graphic annotations, such as colour, texture and arrows (Figure 9.11), and alphanumeric annotations, which are placed in the proximity of the annotated elements. Rather than treating annotations as an information category, we have chosen to consider them as a notational shortcoming of the representation (or, at least, a weak aspect in the use of the representation). We consider this a reasonable solution of the pragmatic problems that arise in automated recognition of combined sketch and script, especially given the high redundancy of annotations in architectural drawings. With the exception of graphic annotations that signify a region in the image (i.e. filled spaces) and can be linked directly to an object as properties, our approach initially ignores annotations such as text and arrows. We are considering adding these at a later stage, as comments to either the whole sketch or part of it. In a limited number of cases, alphanumeric annotations could also be attached to objects as properties.
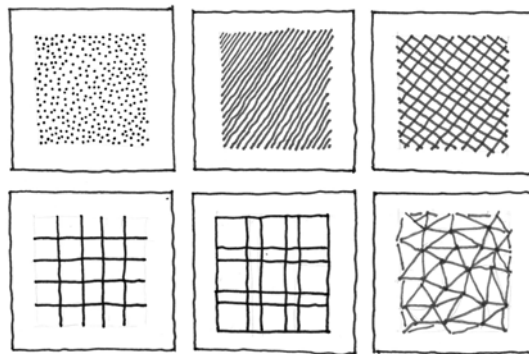

Figure 9.12: Texture, hatch, grid, web.

9.5   Flexibility, layers, and ambiguity

The matrix that emerges from the combination of architectural and graphic primitives reveals that floor plan sketches consist of a very compact set of basic symbols. Even if the set is expanded to allow for different geometries, it still remains manageable and unambiguous. For example, blobs may take a large number of forms, but always remain small, isolated regions that denote discrete building elements or focal points in larger coordinating devices. Architectural primitives are implemented in a small number of related graphic objects. Relationships, for instance, can be solid or broken lines. Multiple lines are used for a relationship if it corresponds fully with a collection of building elements. In such a case, however, it becomes more of an organizational line.

The notational flexibility offered by alternative graphic implementations has a limited scope, but can nevertheless be the cause of ambiguity. In sketching as communication, recognition is aided by the discussion between the designer and the reader of the drawing. Consequently, verbal clarifications frequently guide our perception and understanding of non-standard elements. Another related reason for ambiguity is the transformability of architectural objects in a sketch. What may start as a space contour may become an organizational line and end up as a relationship line. Even worse, designers are frequently uncertain about the type of a particular line and may use sketching to explore their ideas concerning it.

Final sketches are usually less ambiguous and come closer to the conventional floor plan. Most sketches, however, are not as straightforward. In the process of designing and sketching, a drawing may develop a number of superimposed layers, which contain the same information

in different variations and implementations. Such a layered structure makes even basic recognition tasks more difficult. For example, segmentation of overlapping organizational and relationship lines is only possible when the two have a difference in intensity or geometry. The use of multiple layers also extends to the carrier of the sketch. A sheet often contains several sketches, which should be read in juxtaposition. These sketches can be variations, alternatives or even complementary: the design is frequently the amalgamation of different parts from several sketches (Figure 9.13).
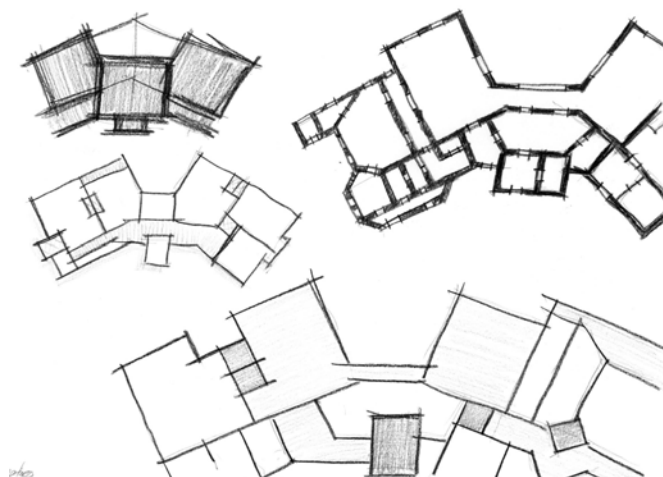
Figure 9.13: Multiple sketches.

The ambiguities and general fuzziness of sketches does not necessarily reduce the reliability and utility of automated recognition. If the recognition aim is to deterministically discover specific features for indexing or provide a single, unambiguous interpretation, as in e.g. conversion to CAD, the flexibility and layered structured of sketches can be prohibitive. If, on the other hand, recognition returns elements of spatial arrangement in terms of a neutral representation, the uncertainties of sketching provide a richer background for the formation and satisfaction of queries and the analysis of formal and functional aspects. A prerequisite to that is the use of multilevel representations, which can accommodate various aspects at different abstraction levels (Koutamanis 1997).

9.6 Discussion

Architectural sketches, especially those of floor plans, are undoubtedly one of the most subjective and mixed visual architectural representations. Yet, sketches have been an efficient medium for communication and design decision registration. This suggests that floor plan sketches contain, possibly with some ambiguity and deviation from the canonical drawing forms, the basic entities and relationships that exist in all structured architectural representations. Recognition of floor plan sketches is facilitated by:

1. The distinction between different types of sketches (floor plans, perspectives, gestural drawings, representational drawings).
2. The analysis of each sketch type, initially at the paradigmatic and semantic level. Other levels also contribute to our understanding of sketches, but only after the essential primitives, relationships and structures of a sketch type have been recovered and organized into a basic representation.

3. The interpretation of the analysis results as a symbolic representation of spaces and building elements, related to each other through overlapping networks of spatial relationships and multiple abstraction levels.

The layered structure of sketches, in combination with abstraction, results into a variable implementation of most entities. For example, relationships between elements may be implicit in the grouping or explicit as one or more relationship lines, as well as textual annotations. If recognition aims at deterministically identifying specific indexing features or at a single interpretation (as in conversion to CAD), the flexibility and transformability of sketch elements pose significant problems. If, on the other hand, recognition returns a neutral, general representation, the uncertainties of architectural sketching can be transformed into a semantically and structurally rich background for relevant queries.

9.7   References

Betti, C., and Sale, T. (1992). *Drawing: A Contemporary Approach*. Harcourt Brace Jovanovich, Fort Worth, Texas.

Edwards, B. (1994). *Understanding Architecture Through Drawing*, E & FN Spon, London.

Evans, R. (1989). Architectural Projection, in: Blau, E. and Kaufman, E. (eds.), *Architecture and Its Image*, Canadian Centre for Architecture, Montreal.

Evans, R. (1995). *The Projective Cast - Architecture and Its Three Geometries*, MIT Press, Cambridge, Massachusetts.

Gong, Y. (1998). *Intelligent Image Databases*, Kluwer Boston.

Goodman, N. (1976). *Languages of Art: An Approach to a Theory of Symbols*, Hackett, Indianapolis.

Kanizsa, G. (1979). *Organization in Vision - Essays on Gestalt Perception*, Praeger, New York.

Koutamanis, A. (1996). Elements and Coordinating Devices in Architecture - An Initial Formulation, in: Timmermans, H. (ed.) *3rd Design and Decision Support Systems in Architecture and Urban Planning Conference. Part One: Architecture*, Eindhoven.

Koutamanis, A. (1997). Multilevel Representation of Architectural Designs, in: Coyne, R. and Ramscar, M. and Lee, J. and Zreik, K. (eds.), *Design and the Net*, Europia Productions, Paris.

Kowler, E. (1990). *Eye Movements and Their Role in Visual and Cognitive Processes*, Elsevier, Amsterdam.

Lopes, D. (1996). *Understanding Pictures*, Clarendon, Oxford.

Marr, D. (1982). *Computer Vision*, W.H. Freeman, San Francisco.

Miles, F. A. and Willman, J. (1993). *Visual Motion and Its Role in the Stabilization of Gaze*, Elsevier, Amsterdam.

Porter, T. (1997). *The Architect's Eye*, E & FN Spon, London.

Van Sommers, P. (1984). *Drawing and Cognition*, Cambridge University Press, Cambridge.

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10. On Representation

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10.1 Introduction

The intensive computerization of architectural practice has been primarily motivated by the promise of increased efficiency in documentation processes, as well as by the sheer modernity of the computer. Consequently, the application of computerized instruments in architectural design is largely restricted to superficial but labour-intensive and time-consuming tasks such as technical drawing and specialized or novel areas such as rendering three-dimensional projections and animations.

Despite the relatively low level of architectural computerization, the production of architectural documentation and information occurs at such as scale that practice is confronted with two basic, interrelated problems:

1. Redundancy: The multiplicity of aspects and actors involved in architectural designing requires diversification of input / output for each separate task or activity. The mainstream approach is to produce different design documents for practically each task. For example, analyses of indoor climate are performed on the basis of different drawings and related documents than cost analysis or control of fire safety. Moreover, the results of these analyses are presented in different forms that are unconnected to each other and to the core design representations, i.e. the drawings that describe the spatial and building structure of a building. It is also noteworthy that most current design representations are mere digital transcriptions of analogue practices. This means that they include unnecessary structure derived from the implementation media of their analogue predecessors.

2. Consistency: The use of multiple documents for the various aspects of the design process and its products adds to their complexity in terms of consistency and coordination. Processing of drawings and other documents by computer does not guarantee that decisions taken on the basis of one document are correlated to other documents which may contain crucial, related information. The results of such a decision are normally registered in the documentation of the relevant aspect(s) but are not always propagated to other documents not directly involved in the particular decision taking process. These are usually updated only when and if it is needed and consequently may remain misinformed or incomplete. The overall picture of a design through the collection of such documents can be highly inconsistent and confusing, even to the members of the design team.

These two problems are becoming so obvious in practice that designers and managers are willing to invest in studies of their own processes and corresponding automation research and development (Leusen and Mitossi 1998). The ambition behind such development is to derive structural rather than ad hoc methods and techniques that improve design quality and performance. For research this frequently means new opportunities for already developed approaches and systems which can now be (re)applied to actual problems.

Academic research in areas such as architectural design methods and computer-aided architectural design has a long tradition of novel approaches that confront and attempt to improve mainstream ideas. Some of these approaches derive in part from pre-existing proscriptive methods. These approaches limit design products to certain a priori areas. A design is acceptable if it falls within the confines of the approach or conversely if it does not contravene with the specifications of the approach. Prime examples of proscriptive systems are architectural styles, where specific attributes become the sine qua non of the system. A classical building, for instance, must contain elements from the canonical orders. Otherwise it may fail to register as a classical building (Summerson 1980).

Other approaches can be classified as prescriptive. Rather than constrain the outcome of a process, prescriptive approaches imply that a (good) design can be achieved only when a specific sequence of actions has been followed. Such approaches are usually found in a theoretical or computational context, i.e. as deterministic formal models of designing or as algorithmic design instruments. Prescriptive approaches underlie many computational design methods, as well as recent data-driven notions of design.

Both proscriptive and prescriptive approaches may offer useful insights into the nature and structure of architectural systems and processes. However, they are too restrictive to cover the complexity of current architectural problems. Moreover, they are too inflexible to be popularly accepted and applied. For such reasons we are experiencing a shift towards descriptive approaches. These emerge from the necessity to tackle an ever-increasing number of design aspects and amounts of design information involved in architecture and building of today. Descriptive approaches rely on explicit information that is processed in a transparent way and provides decision support mainly through feedback. This takes place through techniques such as simulation and scientific visualization, which provide explicit, analytical information at an appropriate abstraction level and in relation to known, intuitively understandable visual representations. Also the notion of performance and performance evaluation are central to descriptive approaches (Kalay and Carrara 1996).

Descriptive approaches rely on well-defined representations that accommodate both the input and output of design processes. Earlier academic research as well as software development has been obsessed by the idea of a holistic representation that covers all design aspects and their facets with precision, accuracy and coherence. Unfortunately such representations are too cumbersome and demanding to be a practical proposition. Partial, coordinated representations are better suited for the representation of specific design aspects at a variety of abstraction levels that agree with the stage of design development.

10.2 Architectural representations

10.2.1 Symbolic representation: a definition

Our definition of a representation derives from David Marr (Marr 1982): A representation is a formal system for producing descriptions of a certain class of entities in a transparent manner, i.e. together with an explanation of how the system returns the particular description. Transparency is achieved by establishing a set of symbols used in the representation and a system of decomposition / correspondence by which the symbols are related to the described entity. Examples of such representations are abundant in daily life. For instance, quantities can be described using a set of Arabic numerals:

$S_A = \{0,1,2,3,4,5,6,7,8,9\}$

And the following decomposition rule:

$$n_n \cdot 10^n + n_{n-1} \cdot 10^{n-1} + \ldots\ldots + n_1 \cdot 10^1 + n_0 \cdot 10^0 \Rightarrow \quad n_n \cdot n_{n-1} \ldots n_1 \cdot n_0$$

Within which n_n, n_{n-1}, ... n_1, n_0 are members of the symbol set. A quantity such a 123 is produced as follows:

$$1 \cdot 10^2 + 2 \cdot 10^1 + 3 \cdot 10^0 \Rightarrow 123$$

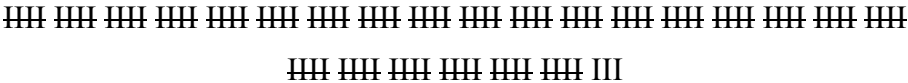The description changes if we alter the symbol set. Binary numerals, for example, use the following set:

$$S_B = \{0,1\}$$

The reduction of the symbol set is reflected by a corresponding change in the decomposition rule (2 replaces 10 as the base):

$$n_n \cdot 2^n + n_{n-1} \cdot 2^{n-1} + \ldots\ldots + n_1 \cdot 2^1 + n_0 \cdot 2^0$$

Accordingly 123 is described as:

$$1 \cdot 2^6 + 1 \cdot 2^5 + 1 \cdot 2^4 + 1 \cdot 2^3 + 0 \cdot 2^2 + 1 \cdot 2^1 + 1 \cdot 2^0 \Rightarrow 1111011$$

As the above example shows, there are many alternative representations for each class of entities. Each representation is better suited to different tasks and uses. Arabic decimal numerals appear to be more appropriate for general use by humans, presumably due to the correspondence between the base 10 with the number of fingers in both hands. Binary numerals are preferred for machines as the symbol set maps the two states of a basic device ("on" and "off"). For specialised tasks representations are altered to suit the processing information. For example, when registering incoming of outgoing quantities, humans frequently revert to ancient symbol sets that are handier for the procedural, additive character of the task. "123" Could be initially described by:

IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII

IIII IIII IIII IIII IIII IIII III

while the task is in progress. After completion it can be easily converted to the much more compact Arabic decimal numeral.

Representation should not be confused with the mechanisms used for its implementation, such as a relay or diode for binary numerals. The reason is that a particular representation can exist in various implementations with no change in content, structure or result. Binary numerals, for example, remain unchanged whether on paper, in a computer or in a calculator, despite the superficial differences in the implementation mechanisms. Nevertheless, as many representations are associated with dominant or canonical implementations, the symbols of a representation are frequently confused or equated with implementation mechanisms. In conventional architectural representations, such as floor plans and sections we read spaces, building elements and components (the actual symbols). However, the lines we draw and the surfaces these lines bound (the implementation mechanisms) are only too often discussed as the primitives of architectural composition. This testifies to the significance of geometry as a foundation of architecture and its representations and parallels the shift from the geometric object in Euclidean geometry to its images in descriptive geometry (Evans 1995).

10.2.2 Spatial and building elements

An underlying assumption in most spatial architectural representations concerns the choice of basic primitives for the description of a design. The currently dominant use of lines and other implementation mechanisms is clearly inappropriate for spatial representations, as spatial entities are only implicit in the perceptual grouping of implementation primitives. With

respect to such entities, the 'solids' and 'voids' of a building (i.e. the building elements or components and the spaces bounded by them) are the obvious choices. They are linked together by the fundamental relationships of adjacency, proximity and alignment into single holistic or multiple complementary networks that describe one or more aspects of the design in a coherent and comprehensive manner (Steadman 1976, 1983). These networks are generally sufficient for the description of a building at the macroscopic, normative level that characterizes apparent design thinking, including matching to the requirements in a brief, in legislated measures of performance or in a standard textbooks.

At the practical level, representation of a building in terms of its spaces and building elements is directly feasible as a straightforward improvement of current drawing practices. It amounts to a simple transformation of the geometric implementation primitives into more complex shapes and forms that exhibit a one-to-one correspondence with integral, identifiable spatial and building elements. Properties other than the geometry of an element are described by the clustering of the element (e.g. modularization by means of layers) and attached annotations. In the resulting drawings each space and building element is explicitly described but relationships between elements are only implicit. Most relationships can be recognized automatically on the basis of element properties. For example, access from one space to another if there is at least one door or similar opening adjacent to both spaces.
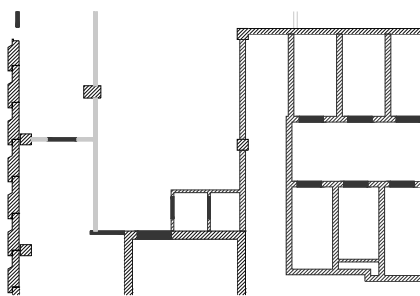

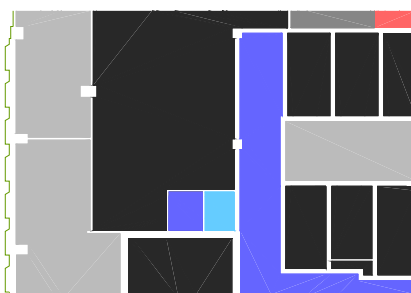*Figure 10.1: Building elements in floor plan.*

Figure 10.2: Spaces in floor plan.

10.2.3 Beyond solids and voids

The choice of spaces and building elements as the basic spatial primitives of a building is a sensible, relevant one. It allows for a closer correspondence between external design representation and design thinking, as well as for greater explicitness in design documentation, communication and analysis. For several design or analytical tasks building elements have to be subdivided into components, which in turn can be further subdivided down to the level of integral entities such as a brick or a steel bar. Spaces, on the other hand, are more difficult to handle. The transition from the implicit space, as in analogue drawings on paper, and the explicit space in a computerized spatial representation may create the

illusion that spaces have to be treated as integral entities, primary parcels of space that cannot be subdivided further.

Standard design tasks, such as the allocation of activities in a space, presuppose a basic analysis of the space into areas or zones, with distinct spatial characteristics. This analysis, however, is normally rather flexible and fuzzy. Consequently, little attention is paid to the explicit representation of the schemata used. Nevertheless, these schemata can be of significance for reducing the complexity of design information, e.g. as attractors in evaluations of environmental aspects. Two techniques that appear to hold promise as elaborations of the basic spatial representation are hierarchical adaptive segmentation (Samet 1990) and the use of activity surfaces in space (Nakayama et al. 1995). Both techniques are sensitive to local conditions within a space and permit identification of areas that relate to specific aspects in the geometry or structure of a building and the interaction between human activities and the built environment.

Another emerging elaboration of the basic spatial representation concerns the geometric precision of spatial and building primitives. In contrast to a freehand sketch, a computer drawing is normally very precise and allows for little flexibility in the spatial relationships between different elements. This, however, does not agree with the abstraction of the earliest design stages, or with recent interest in dynamic, transformable building materials and structures. Fuzziness in the geometry and position of spaces and building elements can be introduced by means of:

* Tolerances around canonical positions.
* Extreme states (e.g. minimum and maximum).
* Variable plasticity and adaptability (i.e. different degrees of hardness and response to adjacent or new elements).

10.2.4 Local co-ordinating devices

While the representation of elements in digital design practices is explicitly supported by symbolic techniques, less importance has been attached to the manner by which elements are integrated in a design. This is normally left to the designer who has to position and connect each new element in a building representation with little help from his instruments. For example, many drafting and modelling systems still fail to address the physical impossibility of two objects occupying the same space, let alone attempt to interpret the designer's intentions in overlapping objects. In analogue design media this is a logical consequence of their implementation structure. An analogue representation is perceived, recognized and interpreted by the human viewer. Computerized representations, on the other hand, should not be limited to human interpretation. On the basis of explicit relationships between objects the computer can provide meaningful feedback on the basis of qualitative and quantitative analyses which complement and support the designer's creativity.

The frequent absence of meaningful explicit relationships between elements in architectural representations does not imply lack of knowledge on the subject. Architectural and building textbooks deal extensively with the relationships between building elements and components. The positioning of one element relative to another derives from formal, functional and constructional decisions and has consequences for the articulation and performance of the building. Textbooks provide guidelines ranging from ergonomically sound distances between chairs and tables to the correct detailing of joints in roof trusses. The frequent and faithful use of textbook examples has resulted in a corpus of architectural stereotypes. Even though stereotypes may lead the designer to repeating known solutions, they help reach levels of reasonable performance in designing and in the built environment. By obeying the underlying

rules and reproducing textbook stereotypes the designer ensures conformity with the norms of building regulations, professional codes and general empirical conclusions.

A prerequisite to the computerization of such stereotypical configurations is thorough analysis of the formal and functional patterns they integrate in a single representation. In the framework of our research we concentrate on the representation of such patterns, based on the hypothesis that, once the overlapping constraint networks are untangled, we will be able to distinguish between properties intrinsic to an architectural element and wider relationships which focus on specific critical elements. These relationships form local coordination devices that apply to interchangeable elements, for example to different window or door types for a particular opening.

In textbooks, aspects of a recommended configuration are usually presented separately in a proscriptive manner, by means of sub-optimal and unacceptable examples. These are annotated with the relevant relationships and usually ordered from general to specific and from simple to complex. It is assumed that the reader of the textbook makes a selective mental aggregate on the basis of the aspects that apply to the problem at hand. Despite the fact that incompatibilities between different aspects and examples are seldom addressed in textbooks, forming an aggregate representation is generally a straightforward hill-climbing process. For example, in designing a door, one starts with basic decisions relating to the door type on the basis of spatial constraints and performance criteria. Depending upon the precise type, the designer proceeds with constraints derived from adjacent elements and activities. In the case of a single inward opening left hinged door of standard width (Figure 10.3), these constraints determine the position and functional properties of the door, i.e. the distance from elements behind the door, and the swing angle, orientation and direction which facilitate the projected entrance and exit requirements. These can be adjusted by other factors unrelated to the initial decision. For example, the existence of a load bearing element in the initial place of the door may necessitate translation of the door and hence a reformulation the initial design problem.

In the same manner as textbooks, drafting templates offer useful insights into the stereotypical interpretation of local coordination constraints. In templates, building elements usually appear as holes or slits. Each hole or slit is accompanied by annotations in the form of dents, notches and painted text. These facilitate the geometrical positioning of a form, as well as the geometric interpretation of spatial constraints. The configuration of forms and annotations typically represents a simplified fusion of parameters reduced to typical cases (Figure 10.4). Even though the superimposition of different patterns makes the template less legible than the more analytical textbooks, the template comes closer to the mental aggregate of the designer.
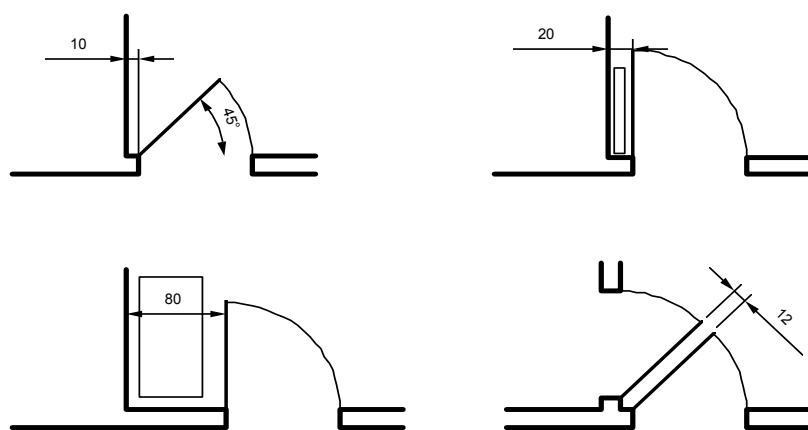

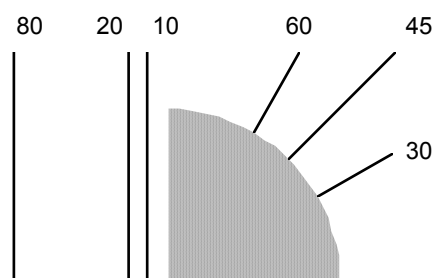*Figure 10.3: Textbook representation of local co-ordination constraints.*

Figure 10.4: Template representation of local co-ordination constraints.

The manner in which local constraints are centred on elements, the connections between elements, and their stereotypical treatment in designing suggest that mechanisms such as frames or objects would be appropriate for the representation of local co-ordination devices. In a frame-based representation the relationships of e.g. a door with walls and other elements of the immediate context can be described as slots and facets which link the door frame with the frames of walls, spaces and other elements. Such an implementation strategy has obvious advantages for the representation of local co-ordination devices, for example with respect to the interchangeability of elements by means of abstraction and inheritance. It is quite plausible that a single prototype would suffice for the representation of all kinds of doors. This could facilitate the manipulation of doors in computer-aided design, including the automated substitution of one door type with another if needed due to spatial conflicts or to a change in the designer's preferences. Another possibility is to distinguish relationships and constraints from elements altogether. By implementing elements and relationships/constraints with separate frames or objects it is possible to resolve a number of limitations in different techniques, e.g. by adding relationships other than IS-A in object systems and generalization/specialization to the links in a semantic net (MacKellar and Peckham 1992; Peckham et al. 1995).

10.2.5 Global co-ordinating devices

Global co-ordinating devices generally appear in two forms. The first is sketches and diagrams that explain the general spatial articulation of a design. Such abstract representations (even if devised post-factum) are commonly seen as the embodiment of the driving forces in the development of the design. For our purposes they form a useful 'précis' which can be placed at the top of a multilevel representation. The other form of global coordinating devices is as product of formal analysis. Being usually applicable to more than one design, it is expressed in more abstract terms, e.g. as grids and zoning schemes. Probably the most celebrated of such devices is the 5x3 grid proposed by Wittkower as the underlying grid of Palladian villas (Wittkower 1952). This grid has been universally accepted as the canonical formal expression of the intuitive perception of the Palladian villa's "triadic composition" of two symmetrical sequences of spaces laterally flanking the central series of spaces along the main axis (Ackerman, 1977). As a result, the 5x3 grid forms the basis of most Palladian studies, including the Palladian shape grammar (Stiny and Mitchell, 1978). In the Palladian grammar the first stage invariably concludes with the definition of the 5x3 grid which serves further as a template for the definition of spaces and the positioning of building elements.

Global coordinating devices can be derived by visual abstraction that eliminates the individual characteristics of elements and returns a skeleton, as in Figure 10.1. This, however, does not imply that these abstractions are accidental products of various, possibly unrelated design decisions. Another option is to treat devices such as the Palladian 5x3 grid as prototypical patterns that are systematically repeated in variations. Such a view underlies most computational studies, even though there is no historical evidence that Palladio set out to exhaust the possibilities presented by a single pattern. The 5x3 grid appears to be an fusion of different preoccupations and influences, from notions of harmony to the traditional centralized arrangement of the local house type (Ackerman 1977).

The representation of global coordinating devices relies on the distinction between contributing aspects. One good example is the analysis of the classical canon as a system of elements, relationships and coordinating devices that constrain design decisions (Tzonis and Lefaivre 1986). This system consists of three major levels: genera, taxis and symmetry. The term genera (preferred over 'orders') denotes the "well-determined sets" of architectural elements which are formed on the basis of fixed local relations. Taxis, is responsible for the overall organization of a classical building and contains two sublevels: the grid, which parametrically divides the building into spatial components, and tripartition. A rectangular grid and a simple tripartition schema produce a 3 x 3 pattern. The deletion, addition, repetition and embedding of parts in this generic pattern transform it into the layout of a classical building, including the 5x3 Palladian grid. Symmetry is the collection of relationships that constrains the positioning of a particular genus inside the divisions determined through taxis with respect to each other and to the overall structure of taxis.

The three levels in this formulation of the classical canon have direct correspondences with the division between elements and coordinating devices proposed in the present paper. The genera are the elements of classical architecture (spaces are treated as the final products of the taxis level rather than as separate entities positioned on the basis of taxis). Symmetrical relationships are closely linked to local coordination devices. Taxis the product of the generic general coordinating devices of classicism. Taxis patterns have the advantage of being visually and conceptually compact and coherent and at the same time the products of two distinct sublevels. The resulting flexibility demonstrates the superiority of such analytical global coordinating devices to sketches or diagrams depicting the central idea of a particular design. For example, choice of a different grid results in a direct transformation of a design into something different yet recognizable as related to the original.

Another advantage of analytical global devices such as taxis is their cognitive significance. An anthropocentric view of tripartition in classicism is closely related to spatial reasoning and, in particular, to the division of the world by projective prepositions, i.e. prepositions which convey information about the direction in which an object is located with respect to another. Such prepositions describe orientation and position on the basis of reference frames consisting of a division of the world in general directions (front, back, left, right, up, down), an origin and a viewpoint for the speaker or viewer (André et al. 1987). The affinities between the resulting spatial pattern and the 3x3 generic classical pattern imply that such reference frames can be applied to the analysis of classical buildings at the level of global co-ordinating devices (Koutamanis 1990).

10.3 Representation and analysis

Probably the highest priorities in architectural design at this moment are:

1. The precise and accurate geometric description of built form.
2. The intensive and extensive analysis of design products throughout the design process, with particular emphasis on the early stages.
3. The seamless transition from design to realization, including applications such as rapid prototyping and robotics in building.

Well-defined architectural representations are central to all three issues. In (1) and (3) we could be excused for assuming that geometric representations are sufficient, even though this would amount to diminishing the significance of the final product of the architect, i.e. space for the accommodation of human activities. For analysis, however, it is imperative that the spatial elements of a design are explicitly described. In descriptive approaches the role of analysis is to provide the designer with explicit, transparent information that enriches (rather than overloads) the definition and processing of a particular problem. This information contains the input and the constraints for the output of local processes. A multilevel spatial representation supports these processes and their integration in the total design process by making explicit relevant entities and facilitating a level of local intelligence sufficient for (partial) automation.

10.3.1 Static aspects

A rather large class of analysis concerns aspects that are evident in the representation as properties of specific entities. Examples of this class are comparisons of spatial quantities such as floor area and volume to the brief or legal norms, such as NEN 2580 in the Netherlands. The definitions in NEN 2580 follow generally established principles of position and function, such as the distinction between use and circulation spaces and between exterior and interior walls. Further distinctions are made on the basis of local cultural patterns, e.g. the ways usable or rented areas are calculated, and technologies used for measurement. The norm makes a point of eliminating relatively small perturbations in the form of a space, presumably because it assumes measurement of areas on a drawing on paper rather than in a digital drawing, where complexity of form does not normally make measurement more time-consuming and labour-intensive.

Analysis of a design to a brief or norms such as NEN 2580 on the basis of a well-defined spatial representation amounts to (Mitossi and Koutamanis 1998):

1. Identification of relevant entities e.g. circulation spaces on a specific floor. This normally takes place automatically, on the basis of user-defined properties such as the layer of each entity. User interaction generally implies an arbitrary selection, e.g. a subset of the automatically-made selection.
2. Measurement of relevant properties for each entity. These properties are generally explicit attributes of the implementation mechanism used, e.g. area of a shape.
3. Simple processing and communication of the information, such as making total sums for each category and placing them in the agreed cells of a spreadsheet.

10.3.2 Dynamic aspects

Most static aspects are straightforward, also without the computer, but generally time-consuming and labour-intensive. Other aspects involve more complex human interaction with the built environment. Therefore, they may be less evident in the designer's perception of the representation. Such aspects include pedestrian circulation in buildings and the identification and measurement of routes between specific activities, as allocated in a design. In a well-defined spatial representation these tasks are performed at:

1. The topological level, with identification of the starting and end point of a route through user interaction or known properties of spaces. The route is identified mostly automatically, using adjacency properties to move from space to door to another space on the basis of circulation criteria, such as following the shortest route or using predominantly circulation spaces.
2. The geometric level, where the path of the route is calculated, usually on the basis of normative guidelines.

Identification of the route is followed by measurement and evaluation of not only the route length, as for fire escape routes (Koutamanis 1995), but also of intervening opportunities and time-related issues, especially for overlapping or intersecting parts of different routes (Koutamanis and Mitossi 1993).

10.3.3 Simulation and scientific visualisation

Spatial representations also provide ready input and a comprehensive container for the output of even more complex analysis, such as light and airflow simulation. As such simulations are normally performed at the level of individual spaces, the representation facilitates recognition and transformation of relevant entities, e.g. of a space into its interior wall surfaces and of a window into a light-emitting or air-supplying hole in a wall (Hartog et al. 1998). Following the principles of scientific visualization, the simulation results are presented both as analytical alphanumeric data and as visual patterns of light intensity or air movement in the particular space.
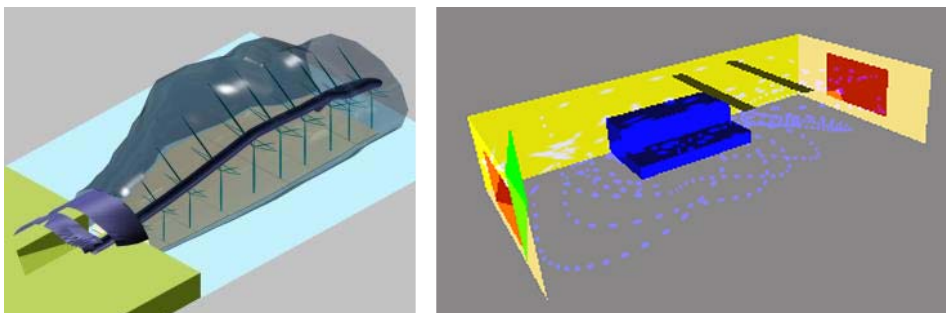

Figure 10.5: Airflow simulation by means of computational fluid dynamics.

10.3.4 Aesthetics

To the trained eye a drawing or photograph of a building provides ready evidence of building style and aesthetic quality. These relate to the acceptability of the design with respect to a particular formal system and the degree of acceptability. From a slightly different viewpoint, aesthetics arguably amounts to preference for one of the possible descriptions of an image. The preferred description meets the specifications of the particular formal system in terms of elements used in the design and relationships between elements that determine grouping into

identifiable compound entities such as a colonnade or a wing. Grouping relates the design to global coordinating devices that can be matches to the specifications of the formal system. Drawing from cognitive science and in particular from the recognition-by-components (Biederman 1987, 1995) and the structural information theory (Leeuwenberg 1967, 1971), we can devise systems that relate the spatial and/or building articulation of a building to preferences in human perception and to the specifications of an architectural formal system. Entities in the spatial representation are grouped together on the basis of preference for specific spatial relationships. The resulting configuration of groups makes explicit the canonical parts of the design and their overall arrangement in terms of the devices of the formal system, e.g. classical tripartition. This configuration constitutes an evaluation of 'figural goodness' and by extension of the aesthetic preference for the design (Koutamanis 1997).

10.4 References

Ackerman, J. S. (1977). *Palladio*, Penguin, Harmondsworth, Middlesex.

André, E. and Bosch, G. and Herzog, G. and Rist, T. (1987). Coping With the Intrinsic and Deictic Uses of Spatial Prepositions, in: Jorrand, P. and Sgurev, V. (eds.), *Artificial Intelligence II: Methodology, Systems, Applications*, North-Holland, Amsterdam.

Biederman, I. (1987). Recognition-By-Components: A Theory of Human Image Understanding, *Psychological Review* 94(**2**): pp. 115–147.

Biederman, I. (1995). Visual Object Recognition, in: Kosslyn, S.M. and Osherson, D.N. (eds.), *Visual Cognition - An Invitation to Cognitive Science, 2nd ed.*, Cambridge, Massachusetts.

Evans, R. (1995). *The Projective Cast - Architecture and Its Three Geometries*, MIT Press, Cambridge, Massachusetts.

Hartog, J. P. de and Koutamanis, A. and Luscuere, P. G. (1998). Simulation and Evaluation of Environmental Aspects Throughout the Design Process, in: Timmermans, H. (ed.) *4th Design and Decision Support Systems in Architecture and Urban Planning Conference*, Eindhoven.

Kalay, Y. E., and Carrara, G. (1996). A Performance-Based Paradigm of Design, in: J.S. Gero, (ed.), *Advances in Formal Design Methods for CAD*, Chapman & Hall, London.

Koutamanis, A. (1990). *Development of a Computerized Handbook of Architectural Plans*, Ph.D. thesis, Delft University of Technology.

Koutamanis, A. (1995). Multilevel Analysis of Fire Escape Routes in a Virtual Environment, in: Tan, M. and Teh, R. (eds.) *The Global Design Studio*, Centre for Advanced Studies in Architecture, National University of Singapore, Singapore.

Koutamanis, A. (1997). On the Evaluation of Figural Architectural Goodness: A Foundation for Computational Architectural Aesthetics, in: R. Junge, (ed.), *CAAD Futures 1997*, Kluwer, Dordrecht.

Koutamanis, A. and Mitossi, V. (1993). On the Representation of Dynamic Aspects of Architectural Design in Machine Environment, in: Beheshti, M.R. and Zreik, K. (eds.), *Advanced Technologies. Architecture, Planning, Civil Engineering*. Elsevier, Amsterdam.

Leeuwenberg, E. L. J. (1967). *Structural Information of Visual Patterns - An Efficient Coding System in Perception*, Doctoral dissertation, Catholic University of Nijmegen. Mouton, The Hague.

Leeuwenberg, E. L. J. (1971). A Perceptual Coding Language for Visual and Auditory Patterns. *American Journal of Psychology* **84**: pp. 307-350.

Leusen, M. van and Mitossi, V. (1998). A Practical Experiment in Representation and Analysis of Buildings, in: Timmermans, H. (ed.) *4th Design and Decision Support Systems in Architecture and Urban Planning Conference*, Eindhoven.

MacKellar, B. and Peckham, J. (1992). Representing Objects in SORAC, in: J. S. Gero, (ed.), *Artificial Intelligence in Design '92*. Kluwer, Dordrecht.

Marr, D. (1982). *Computer Vision*, W.H. Freeman, San Francisco.

Mitossi, V. and Koutamanis, A. (1998). Spatial Representations as the Basis of Formal and Functional Analysis, in: Timmermans, H. (ed.) *4th Design and Decision Support Systems in Architecture and Urban Planning Conference*, Eindhoven.

Nakayama, K. and He, Z. J. and Shimojo, S. (1995). Visual Surface Representation: A Critical Link Between Lower-Level and Higher-Level Vision, in: S. M. Kosslyn, and D. N. Osherson, (eds.), *Visual Cognition - An Invitation to Cognitive Science, 2nd ed.*, Cambridge, Massachusetts.

Peckham, J. and MacKellar, B. and Doherty, M. (1995). Data Model for Extensible Support of Explicit Relationships in Design Databases, in: *Journal of Very Large Data Bases* 4(**2**): pp. 157-191.

Samet, H. (1990). *The Design and Analysis of Spatial Data Structures*, Addison-Wesley, Massachusetts.

Steadman, J.P. (1976). Graph-Theoretic Representation of Architectural Arrangement, in: L.J. March, (ed.), *The Architecture of Form*, Cambridge University Press, Cambridge.

Steadman, J.P. (1983). *Architectural Morphology*, Pion, London.

Stiny, G. and Mitchell, W.J. (1978). The Palladian Grammar, in: *Environment and Planning B* **5**, pp. 5–18.

Summerson, J. (1980). *The Classical Language of Architecture*, Thames and Hudson, London.

Tzonis, A. and Lefaivre, L. (1986). *Classical Architecture: The Poetics of Order*, MIT Press, Cambridge, Massachusetts.

Wittkower, R. (1952). *Architectural Principles in the Age of Humanism*, Alec Tiranti, London.

DESIGN COMPUTATION

11. An AI Tool for Conceptual Design of Complex Products

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Abstract

This paper describes the set-up of AIDA, a computer tool that supports the conceptual design of complex objects and products. The AIDA system is based on a combination of three methods: Case Based Reasoning for suggesting initial proposals, Rule-Based Reasoning to assess these proposals on their functional merit, and Constraint-Based Geometric Modelling to model and visualise the proposals. These reasoning and modelling techniques are implemented in separate modules. In this paper we present the underlying ideas of the AIDA system and show how this framework can be used for conceptual design of aircraft.

11.1 Introduction

Aircraft design is a complex problem, comparable with the design of other complex objects and systems like buildings, industrial products, and ships. The list of requirements for an aircraft design may contain a large number of issues, from functional requirements such as the aircraft's size, capacity, and payload-range ratio, to technical requirements such as flight control, aerodynamics, stability of its structures, production, costs, environmental impact, etc. After analysing these requirements, the designer may come up with an initial conceptual solution. In the case of aircraft, this first concept will describe the configuration of the aircraft in global terms, i.e. its general arrangement and its size in terms of weight, thrust or power, wing span and area, etc. At this point it is difficult to assess the proposed solution. Existing numerical and analytical tools for aircraft design, such as Acsynt (Mason 1993), Aaa (Roskam 1986), Rds (Raymer 1992) and Adas (Bil 1988, 1989), require much more detail than is available in the conceptual design phase. However, it is very expensive and time-consuming to elaborate the initial design into a fully detailed product, only to learn that the proposed solution in the end does not satisfy the functional requirements.

Another drawback of the existing CAD tools is that they do not support the suggestion of initial configurations. Therefore the designer has to rely on his experience, and on examples of existing aircraft. Further, some simplified physics, statistical data and empirical rules may be available. The designer may have deduced some 'rules-of-thumb' from the physics and these experiences, which results in lists of advantages and disadvantages coupled to each configuration choice. These lists are dominated by qualitative arguments that make it difficult to draw conclusions.

Against these issues, which make the conceptual design of aircraft complicated, stands the convenient feature that most complex objects are composed of a set of basic components. In the case of aircraft: the fuselage, the wing, the tail-surfaces, the undercarriage, and the powerplant. Because conceptual design only deals with approximate sizes, this decomposition of the aircraft greatly enhances the overview of the design possibilities. For conventional aircraft the solution-space is then reduced to a limited number of configuration alternatives:

high-, mid- or low-wing; T-tail, cross-tail or conventional tail; turbofan, turboprop or piston engines; wing- or fuselage-mounted engines; etc. However, the number of possible configuration combinations is still too large to be fully elaborated.

In this paper, we propose a new design methodology for conceptual design, using several AI techniques, which, in combination, support the total design cycle of proposing and evaluating solutions. First we discuss conceptual design and how AI techniques can be used to implement the required qualitative kind of reasoning needed for suggesting and analysing design concepts. Then we describe the implementation of AIDA and show how it can be used to design aircraft.

11.2 Conceptual design

11.2.1 Design

Design is an activity that generates a 'materialised' solution for a 'functional' problem, i.e. it proposes a system or 'structure' that shows some 'behaviour' that satisfies the 'functional' demands. However, there is no direct reasoning possible from functions to behaviour and structure, i.e. a logical, straightforward deduction of the structure from the function is not possible. It is even feasible that more than one structure is capable of realising the demanded functions, or none at all. Hence, designing is a non-deterministic process.

Designing has more challenging features. Typically, it is often an 'ill-defined' process, meaning that the functional requirements may change during the process, for example when they appear to be too conflicting. Also time and resources may be limited, and the designer may have to decide in a situation of uncertainty. Another challenge is to define the optimality criteria based on the diversity of design specifications, in order to generate an optimal design or select the best feasible design.

Because straightforward reasoning is not feasible, a 'generate-and-test' strategy is often applied. This strategy leads to a number of iterations through the design cycle that is visualized in Figure 11.1.
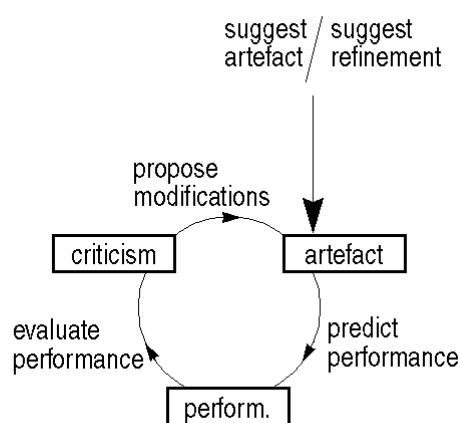

Figure 11.1: The basic tasks in the design cycle.

Using his experience, the designer first suggests a solution, then the performances are predicted (because a full assessment is seldom possible), then the performances are evaluated with respect to the requirements, then modifications are proposed to remedy the shortcomings, and the cycle repeats. When the solution is deemed to be good enough, the

designer suggests refinements. This means that the artefact will be described more completely by adding details, for example by focusing on one of the components.

An often-applied strategy to avoid exhaustive generate-and-test searches is the 'divide-and-conquer' method. The problem is decomposed into several sub-problems that are easier to solve and the different sub-solutions are then combined into one integrated solution. An example of such a decomposition strategy is the 'function-means' method. Requirements are recursively decomposed until a solution can be provided and the part-solutions are then successively combined. This decomposition strategy does not solve the design problem itself but transposes it to the 'integration' activity; the initial decomposition and analysis may provide some useful clues for the integration phase, however. The decomposition-integration cycle can be repeated for different levels of detail, or different functional decompositions.

The integration step can be avoided when an existing solution is taken as a starting point. The chosen solution, which partly satisfies the new functional requirements, is then refined via a 'reuse-and-adapt' or 'diagnosis-and-repair' cycle. The solution is analysed and modifications are proposed that relieve some of its weaknesses.

This approach is better suited to so-called 'routine design' problems than for 'creative' designs where new principles are applied in a new context. Most designs fall in between routine design and creative design: a new design is often a new composition of existing components. According to (Mittal 1989) this type of design can be classified as 'configuration design'. Typically large-scale design problems such as design of aircraft, buildings, ships and industrial appliances can be characterized as configuration design: certain aspects of a new design may be 'innovative' but in most cases there will be quite some similarity with earlier designs. Although the reuse of existing components greatly benefits the design process, the number of possible combinations is still far too large to be fully elaborated. Hence a good initial choice is very important.

In the next section we will review to what extent AI techniques can be used to cope with these issues.

11.2.2 AI and design

Artificial Intelligence (AI) is concerned with the application of knowledge. Within AI, three main directions of reasoning can be distinguished: reasoning by logic, reasoning by learning, and reasoning by analogy. Expert systems apply Rule-Based Reasoning (RBR) technique, a form of reasoning by logic. An expert system is useful when the domain knowledge can be formalised into simple rules, such as mathematical problems, and when common sense does not play an important role. Unfortunately, design cannot be formalized this way. Reasoning by learning can be implemented with Artificial Neural Networks (ANN). An ANN consists of a network of nodes (processing elements) connected via adjustable weights (connections). By training the network with a large set of input-output pairs, the system learns the functional relation between the input and the output space. This type of generalized learning cannot be applied to the design problem because the solution space is sparse and discontinuous. The third form of reasoning (reasoning by analogy) is best exemplified by Cased-Based Reasoning (CBR). Cases are stored in a case-base to create a reservoir of problem-solution combinations. When a new problem is presented, CBR searches for cases with similar problem descriptions. Although the retrieved case usually does not completely fit the new problem, the retrieved solution may be a good starting point for further adaptation and optimisation. The difference with the other AI methodologies is that CBR does not use generalized domain knowledge but knowledge which is locally valid: the implicit knowledge within a case which relates a problem with a solution only holds for that particular case. See Figure 11.2.
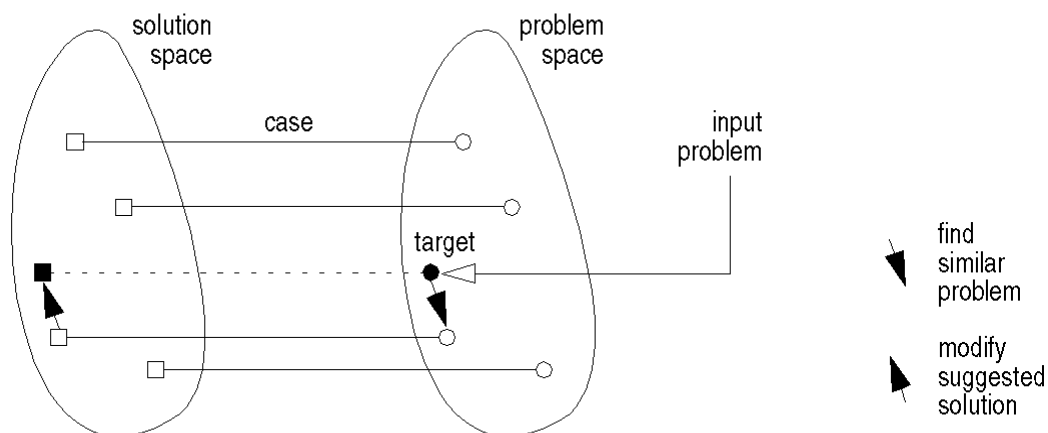
Figure 11.2: Principles of problem-solving with Case-Based Reasoning (from Leake 1996).

Considering the characteristics of conceptual design, reasoning by analogy seems to be a helpful method to assist the suggestion of a concept. Because CBR applies implicit knowledge, this paradigm offers interesting possibilities to overcome the lack of (quantitative) knowledge at this design phase. CBR in design, however, differs from other CBR applications where the number of cases is generally quite large but each individual case is relatively simple. In design the examples are few but often complex and may cover a large diversity of functions. Hence, to be able to use CBR properly, the information about the design cases will have to be encoded in a flexible way.

A useful representation scheme for design cases is the triad Function-Behaviour-Structure (Gero 1992). Structure represents the materialized version of the design: the geometry, the components and the assembly. Function represents the performances of the functional aspects of the model. Behaviour describes more explicitly how the structure is able to accomplish the functions; i.e. the mechanism by which the (functional) problem is solved. The behaviour component is very much dependent on the structure. Given two different design configurations, there may be a completely different set of behaviour data to evaluate each of them.

In addition to functional requirements, the list of specifications may also contain requirements for the behaviour and structure of the design. Some functionality may therefore be an indirect result of behavioural and structural choices given by the list of requirements, but not directly described in the list of requirements.

For a proper evaluation of the structure via the behaviour and the function components, explicit knowledge can be applied. Because of its logical character, the RBR technique seems suitable for the implementation of this knowledge. Compared with the conventional techniques implemented in existing computer support tools, rule-based techniques may improve flexible use of domain knowledge. By logical reasoning, the input and output of the calculation methods can easily be matched in order to determine a proper evaluation sequence. Also the transparency of the applied knowledge will be improved. Instead of performing complicated calculations within a module, RBR can be used to split up these calculations into basic functions and connect them on-line by logical reasoning.

Strongly associated with the evaluation functions are constraints and relations imposed on the (standard) components of the structure. These constraints keep the structure functionally

consistent, encode some form of parameterisation of the structure, and/or are part of the interface specification between components. These constraints are not directly used to evaluate the design but to model the design and put some intelligence into the configuration and adaptation process.

In the next section we will describe how these techniques can be applied for conceptual design. A system set-up is presented based on the use of case-based reasoning to propose design concepts, rule-based-techniques for the functional evaluation, and constrained-based geometric modelling for the geometrical evaluation of these concepts.

11.3 The AIDA system

The AIDA system (AI-supported Design of Aircraft) consists of three modules and a central interface; see Figure 11.3:

- Case-based reasoning (CBR) module. In this module case-based reasoning techniques are implemented to generate an acceptable initial concept that can be modified in the Functional module.
- Functional module. In this module rule-based reasoning techniques are implemented to perform sensitivity studies on the primary parameters of the concept. With these studies a feasible concept is designed.
- Geometrical module. This module automatically models and visualizes the concept. It uses feature-based and constraint-based modelling techniques.
- Central user interface (CUI). This module handles the communication between the three modules.

The following paragraphs describe the separate modules. For each module, existing tools have been used.
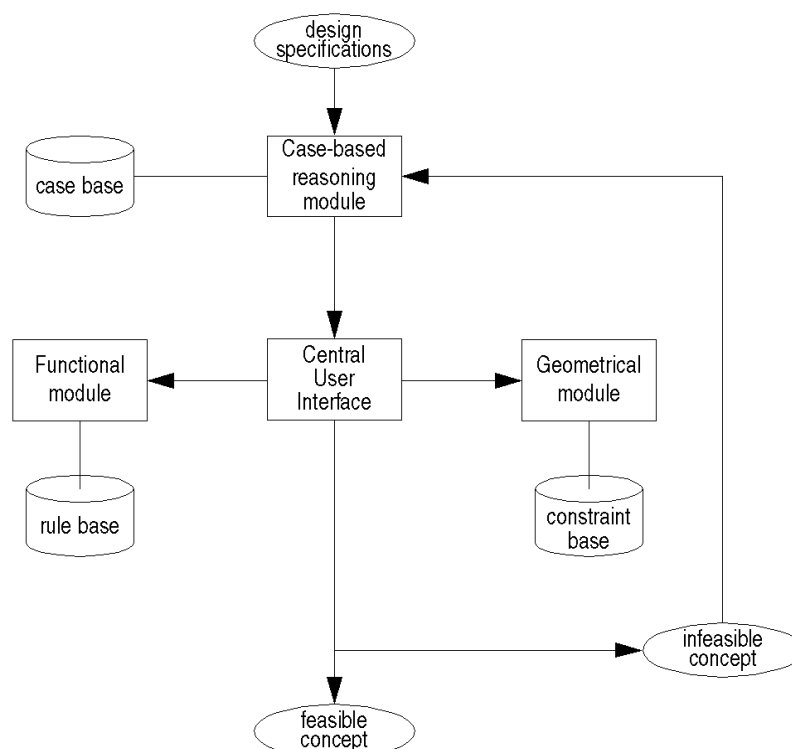

Figure 11.3: Modular set-up of the AIDA-tool.

11.3.1 Case-Based Reasoning module

As suggested by its name, the Case-based reasoning (CBR) module applies case-based reasoning techniques to generate an acceptable concept from the design specifications. These techniques enable the use of the design experience that is implicitly available in existing cases. Also, case-based reasoning is an approach to learning, since the result of previous design sessions can be added to the case-base, making it available for future design problems.

A complete case-based reasoning process can be considered as a cycle of four sequential steps; see (Aamodt 1994) and Figure 11.4:

- Retrieve: Find cases in the case-base which resembles the problem description;
- Reuse: Copy case-data or combine data of more cases;
- Revise: Evaluate the proposed solution; and
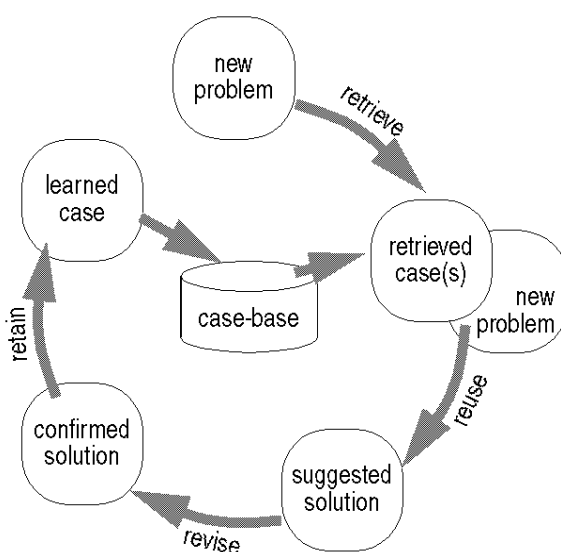- Retain: Put successful 'learned case' in the case-base.

Figure 11.4: The CBR cycle (adapted from Aamodt 1994).

The problem description defines the 'new case'. In the Retrieve step the case-base is searched for cases with data matching the 'new case'. The cases with most similar data are retrieved. In this step the matching process is most critical.

In the Reuse step, data is copied from a 'retrieved case'. Usually, the 'retrieved case' does not completely match the 'new case', i.e. the best matching case does not completely solve the problem. In that situation the data of more 'retrieved cases' can be combined. In other words, the best matching case is changed/adapted with data of other selected cases. This adaptation process requires domain knowledge and is very complex.

The result of the Reuse step, the 'solved case', is a suggested solution to the problem. It is evaluated and repaired when necessary in the Revise step. The evaluation process is often performed by numerical tools. This process also requires domain knowledge, as does the repair process. The result is a 'tested/ repaired case', or a confirmed solution to the problem.

The learning aspect is implemented by adding information about the confirmed solution to the case-base. The Retain step handles the transformation from the 'tested/repaired case' into the 'learned case'.

In AIDA, only the Retrieve, the Reuse and the Retain steps are implemented in the Case-based reasoning module. The evaluation in the Revise step is taken care of by the Functional

module, using rule-based reasoning techniques; see next paragraph. The CBR module has been developed in Eadocs (Netten 1997, 1998), a design system for composite sandwich panels. In this CBR module the Retrieve step, as well as the Reuse and the Retain steps have been implemented; the Revise step has been implemented in another module.

In aircraft design, the cases contain data about their function or performances, such as the range and speed, and data about their structure or physics, such as the weights and sizes. Also data which numerically expresses the quality of the aircraft is added, such as the wing-loading and maximum lift-coefficient; according to (Rosenman 1994) these can be considered as behavioural data.

The CBR module consists of two parts. The first part generates an indexing network. This network provides an index to the cases by the use of parameter domains. These parameter domains allow qualitative labelling of the continuous parameter values, such as 'small' and 'moderate' etc., to enable a kind of qualitative matching. The network is created off-line to improve the efficiency.

The second part uses the network to search for cases similar to the specified 'target set'. This is done on-line. For each part of the target set the matching results are shown, and the cases are ranked accordingly. The importance of each part of the target set is given by priority-values. Figure 11.5 shows a list of best-matching aircraft configurations.
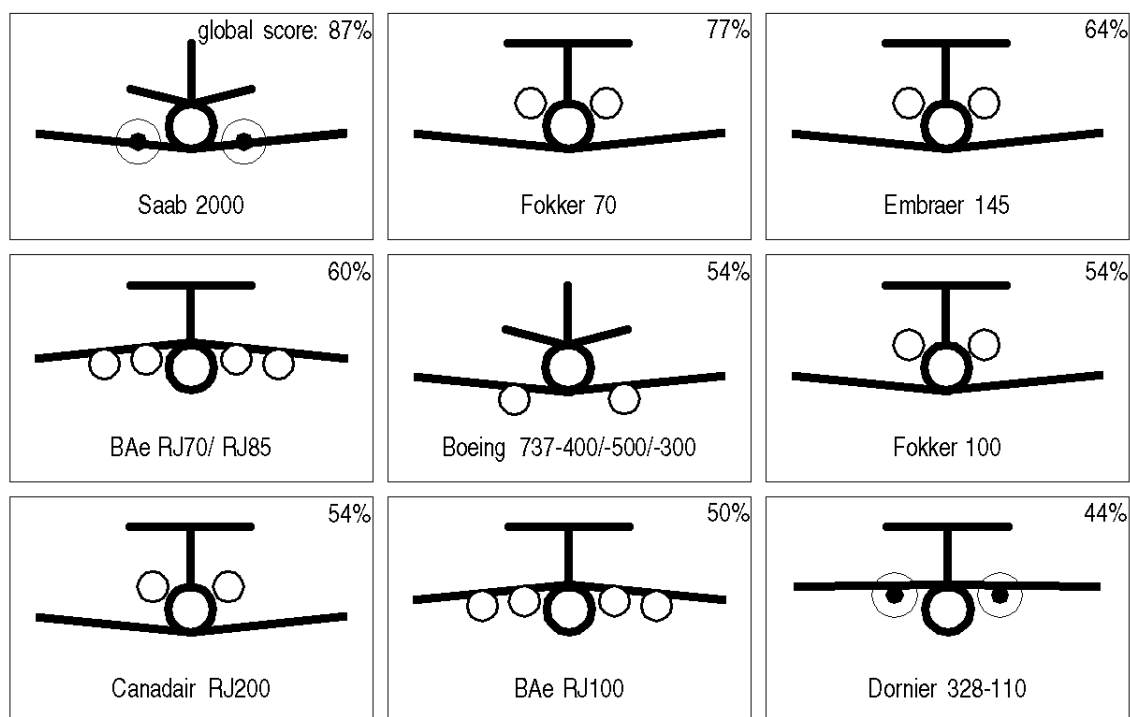

Figure 11.5: An example of best-matching aircraft configurations.

The strategy used for the CBR module is to first retrieve a 'best-matching' case completely, and then to reuse parts of other cases for the adaptations. The adaptation process, however, disrupts the link between the functional and the structural data. Therefore the adapted case is probably not valid anymore. The adapted case should be evaluated before other adaptations can be usefully applied.

It is difficult to adapt the case properly, due to the many interactions between the functional data and the structural data. Therefore a strategy is followed which should lead to as little adaptations as possible. A secondary target set is defined, consisting of the rest of the specifications that the 'best-matching' case does not satisfy, together with the most important structural and behavioural data of the 'best-matching' case. The result of the new matching process will give cases that resemble the structure of the 'best-matching' case, and which resemble the functional data as indicated by the unsatisfied specifications.

Domain knowledge is used to support the adaptation process. Expert rules have been collected which may help with focusing on the relevant data. For instance, when the 'best-matching' case does not reach the specified speed (function), the designer should focus on the thickness of the wing and its sweepback angle (structure). In Figure 11.6 this strategy is summarized.
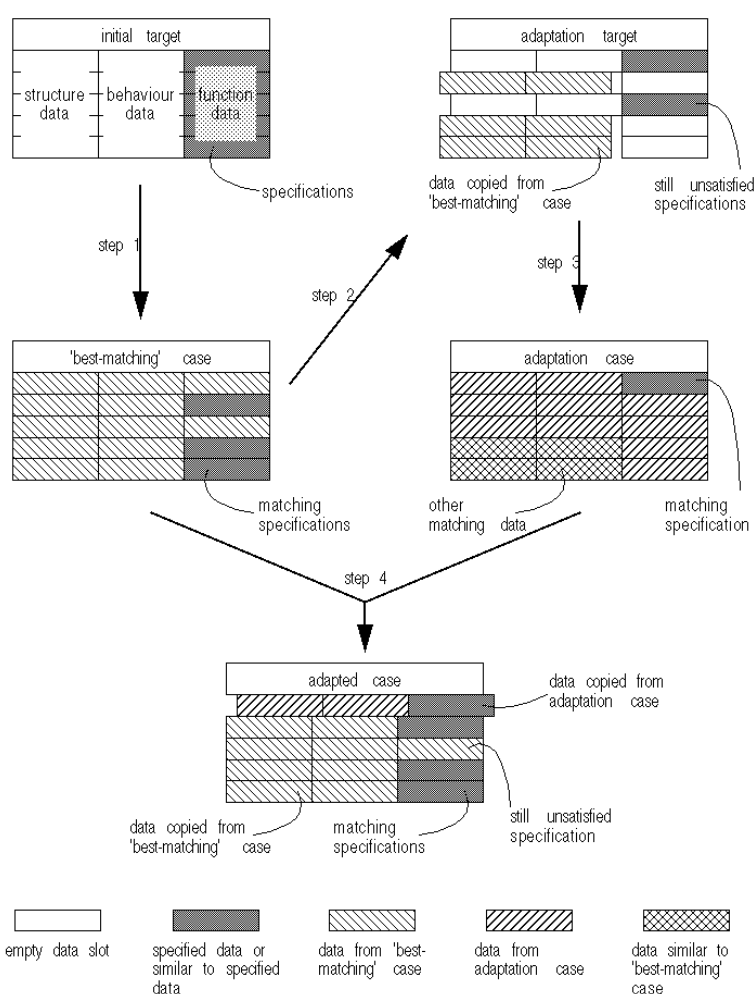

Figure 11.6: Case adaptation strategy.

The CBR module delivers a complete case, which may be inconsistent due to the adaptations. The complete structural data set is required by the Geometrical module in order to make a solid model of the concept. Some structural and some behavioural data is required by the Functional module when generating a relational network. They provide proper initial estimations that can be evaluated and modified.

11.3.2 Functional module

The Functional module supports the execution of parameter studies. These are used to evaluate and modify the adapted case as produced by the CBR module. The result is a feasible concept, according to the available knowledge. This knowledge is represented by numerical relations which express the heuristics such as collected in the books of Roskam (Roskam 1987) and Torenbeek (Torenbeek 1982).

In the Functional module rule-based reasoning techniques are applied to generate a network of numerical relations. The rules implement heuristic knowledge and simplified physics in an algebraic format. The network of these rules links functional parameters (from the specifications) to structural parameters (from the designed object). With this network sensitivity studies can be performed to estimate the structural parameter-values. This reasoning technique offers the flexibility to easily generate a different network for a different set of specifications.

The Functional module is implemented in Quaestor (van Hees 1997), an expert governed system for the assembly, execution and maintenance of revise parametric design models. This tool has been developed to support ship design in the early phases of design by improving access to and control over design-related knowledge.

Before Quaestor can be used, the rule-base has to be built. The rules represent numerical relations in an algebraic format. To each rule, conditions can be added to incorporate its limited validity. This is often the case with the heuristics and simplified physics. Within Quaestor the conditions are called 'constraints'. The third type of element within Quaestor is the parameter. The rule-base is built by one or more experts, and does not have to include the designer that uses the Functional module.

The designer starts a Quaestor session selecting the parameters to be calculated, for example the specification parameters. These are called the goal parameters. The inference engine of Quaestor searches the rule-base for relations that are associated with the goal parameter. That is, the parameter is one of the variables of the numerical relation. So, the backward chaining strategy is applied.

The designer selects one of the suggested relations. Usually the new relation introduces other, unknown parameters. The designer can make the unknown independent or dependent. The parameter becomes independent when it gets a value, for instance the value generated by the CBR module. The parameter becomes dependent when it is assigned as a new goal parameter for which other relations have to be found. The creation of the relational network is finished when no goal parameters are left. When the network is completed, the number of dependent parameters is equal to the number of relations. Quaestor uses Newton-Raphson and simplex methods to solve the set of relations, and calculate the goal parameters. Figure 11.7 shows a simple numerical link.

It is important to notice that Quaestor also searches for relations with the goal parameter on the right-hand side of the algebraic notation. This makes Quaestor very flexible. Instead of an algebraic relation, an external application can also be part of the network. This possibility makes the module even more powerful. However, the input and output parameters of these applications have to be known in advance.
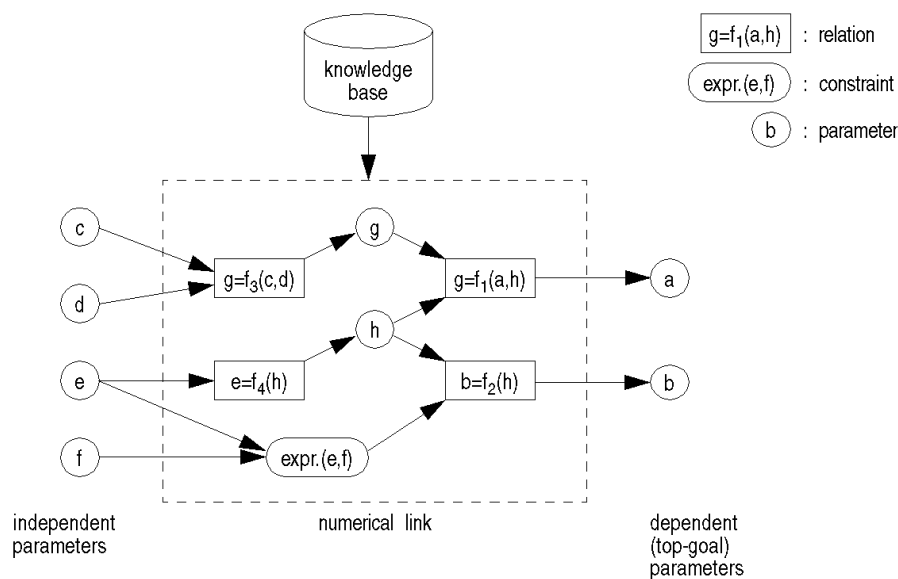
Figure 11.7: A Quaestor template, linking independent with dependent parameters.

To perform parameter studies, independent parameters can be given an array of values. The resulting arrays of the goal parameters can be saved in an ASCII-file, to be viewed graphically by the Central user interface.

11.3.3 Geometrical module

The Geometrical module models and visualizes the suggested aircraft concept automatically. This gives the designer a visual feedback of the concept. The module can also deduce some typical geometrical information, such as volumes and areas. The solid model can be used as input for other computer programs.

The module is implemented in Pro/Engineer (PTC 1999), a commercial feature based solid modeller. In this modeller the solids are constructed with engineering features, such as holes, protrusions, rounds etc. Features can be combined into parts, which can be combined into assemblies. The features are defined and located by parameters and by constraints between parameters and features. With these relations Pro/Engineer is able to preserve the consistency of the model when parameter values are changed.

Pro/Engineer can handle the variation of continuous parameters very well. However, to change the definition of features, parts and assemblies requires knowledge of the package, which is not the intention of the Geometrical modeller. Therefore the aircraft concept model is constructed with pre-defined parts, such as the fuselage, the wing, the engines, the horizontal and the vertical tail-surfaces. The geometrical constraints between these parts keep them properly located.

It is possible to visualize different types of these pre-defined parts, for example turbofan and turboprop engines. Both types are pre-defined, and the parameter which defines the type of engine will automatically suppress the other types. In this way the variation of the discrete parameters is managed.

This strategy of using standard aircraft parts is practicable because it is known which configuration elements are in the case-base. Figure 11.8 shows the hierarchical structure of the aircraft model.
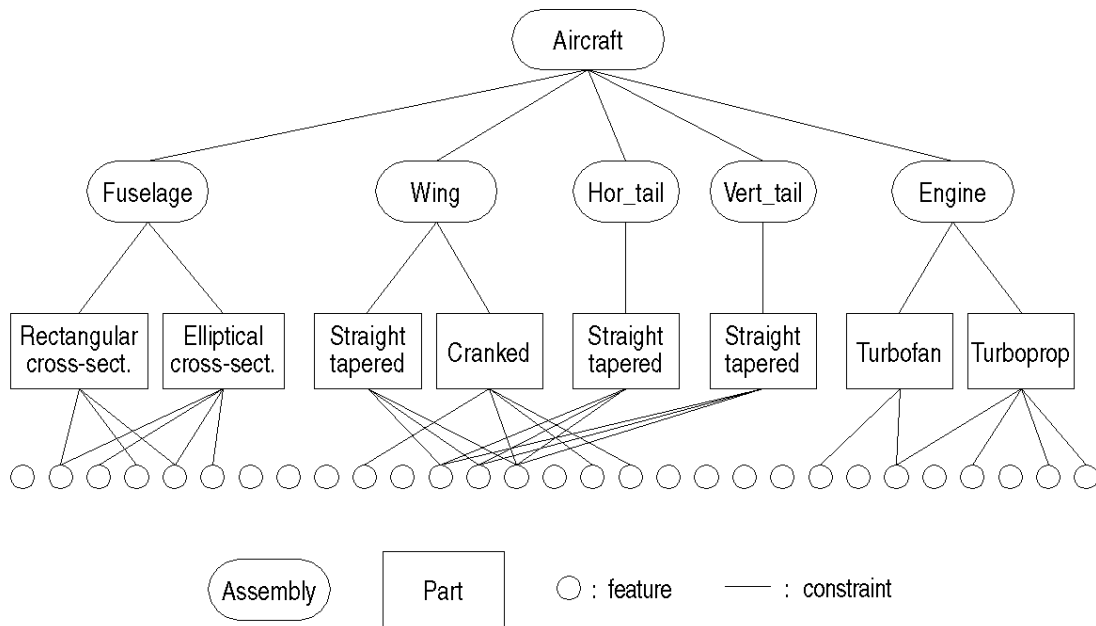
Figure 11.8: The hierarchical structure of the aircraft.

The Geometrical module is able to show a three-dimensional view as well as three side-views of the model. Figure 11.9 gives an example of a three-dimensional view. The model can also be saved in several graphical formats, for use in other computer programs.
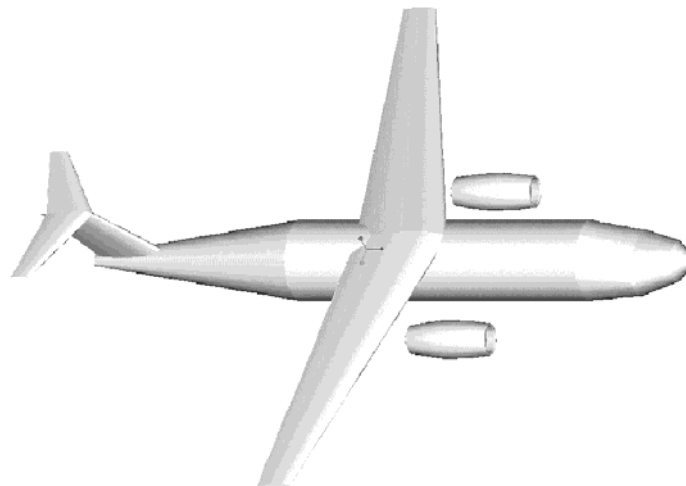

Figure 11.9: A shaded, 3-dimensional view of a concept design.

11.3.4 Central user interface

The Central user interface (CUI) handles the interaction between the other three modules and the designer. It reads the data generated by the CBR module, of the adapted case, filters it and directs the required data to the Geometrical module. The CUI is also able to present the results of the sensitivity studies, performed by the Functional module, in a graphical format. See Figure 11.10 (next page).
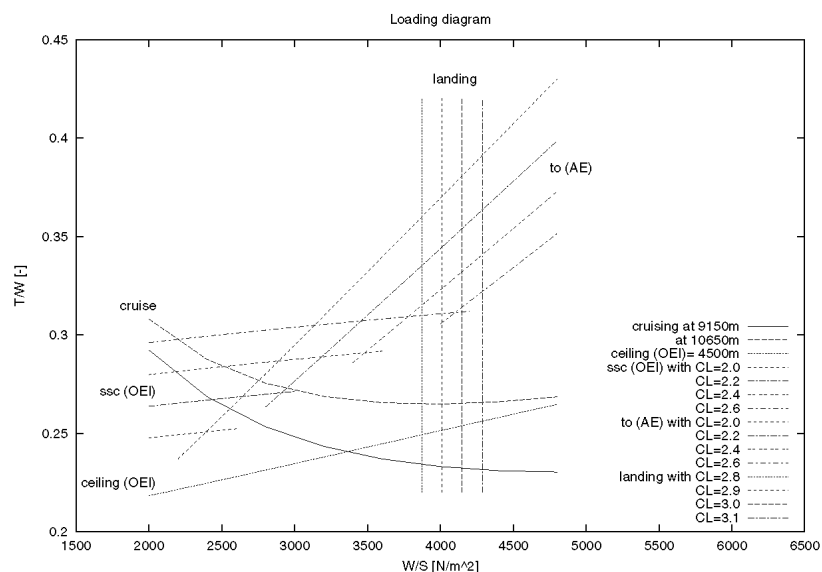
Figure 11.10: Sensitivity studies of sime. Behaviour parameters in aircraft conceptual design.

11.4 Conclusion

We have analysed the conceptual design process, and suggested a design cycle that uses CBR-techniques to propose and adapt initial concepts, RBR-techniques to analyse and evaluate the concept, and geometric modelling techniques that model the concept automatically. These three techniques are implemented in three independent modules, with a central user interface to connect the modules.

The system has been evaluated for the conceptual design of aircraft. This application allows the decomposition of the design product into basic components. The current approach therefore relies heavily on the decomposition of the design product into basic components. For a more general approach without the basic components the case representation will need to be more comprehensive.

Another aspect of further research will be the implementation of the separate modules into one integrated framework.

11.5 References

Aamodt, A. and Plaza, E. (1994). Case-Based Reasoning: Foundational Issues, Methodological Variations, and System Approaches, in: *AICOM*, Vol. 7, Nr. **1**, March.

Bil, C. (1989). ADAS: A Design System for Aircraft Configuration Development, *AIAA 89-2131*.

Bil, C. (1988). *Development and Application of a Computer Based System for Conceptual Aircraft Design*, PhD thesis, Delft University of Technology, The Netherlands.

Gero, J.S. and Tham, K.W. and Lee, H.S. (1992). Behaviour: A Link Between Function and Structure in Design, in: Brown, D.C. and Waldron, M. and Yoshikawa, H. (eds), *Intelligent Computer Aided Design*, Elsevier Science Publishers B.V., The Netherlands, pp. 193-221.

Hees, M van (1997). *Quaestor: Expert Governed Parametric Model Assembling*, PhD thesis, Delft University of Technology, The Netherlands.

Leake, D.B. (1996). *Case-Based Reasoning: Experiences, Lessons, and Future Directions*, AAAI Press.

Mason, W.H. and Arledge, T.K. (1993). Acsynt Aerodynamic Estimation - An Examination and Validation for Use in Conceptual Design, *AIAA 93-0973*.

Mittal, S. and Frayman (1989). Towards a Generic Model of Configuration Tasks, *Proc. 11th IJCAI*, Morgan Kaufman, pp. 1395 - 1401.

Netten B.D. and Vingerhoeds R.A. and Koppelaar, H. (1995). Expert Assisted Design of Aircraft, in: Oxman R.M. and Bax M.F.Th and Achten H.H. (eds), *Design Research in The Netherlands*, Eindhoven University of Technology, pp. 63-67.

Netten, B.D. (1997). *Knowledge Based Conceptual Design; An Application to Fibre Reinforced Composite Sandwich Panels*, PhD thesis, Delft University of Technology.

Netten, B.D. (1998). A Hybrid Reasoning System for Conceptual Design, in: *AAAI-98 Workshop Case-Based Reasoning Integrations*, Madison, Wisconsin.

Oxman, R.M. and Bax, M.F.Th. and Achten, H.H. (1995). *Design Research in the Netherlands – A Symposium Convened by Design Methods Group and Information Technology for Architecture*, January 1995. Bouwstenen 37. Faculteit Bouwkunde, Eindhoven University of Technology.

PTC. (1999). *Pro/Engineer Manuals, Release 2000i*, Parametric Technology Corporation, USA.

Raymer, D.P. (1992). RDS: A PC-Based Aircraft Design, Sizing and Performance System, *AIAA 92-4226*.

Rentema D.W.E. and Vingerhoeds R.A. and Netten B.D. and Jansen F.W. (1996). The Development of a Support Tool for the First Phases of Aircraft Design, in: *ICTAI96 Workshop on Artificial Intelligence for Aeronautics and Space*, Toulouse, France.

Rentema D.W.E. and Jansen F.W. and Netten B.D. and Vingerhoeds R.A. (1997). An AI-Based Support Tool for the Conceptual Design of Aircraft, in: *Computer Aided Conceptual Design (CACD'97)*, Cumbria.

Rentema D.W.E. and Jansen F.W. and Torenbeek, E. (1998). The Application of AI and Geometric Modelling Techniques in Conceptual Aircraft Design, in: *7th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization*, St.Louis, Missouri.

Rosenman, M.A and Gero, J.S. (1994). The What, the How, and the Why in Design, in: *Applied Artificial Intelligence*, Vol. **8**.

Roskam, J. (1987-1999). *Airplane Design; Parts I-VIII*, Roskam Aviation and Engineering Corporation, Ottawa, Kansas.

Roskam, J. and Anemaat, W.A. (1996). General Aviation Aircraft Design Methodology in a PC Environment, *AIAA 96-5520*.

Torenbeek, E. (1982). *Synthesis of Subsonic Airplane Design*, Kluwer Academic Publishers, Dordrecht.

12. The Delft ID Studio Lab

Research Through and For Design

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12.1 Introduction

The face of product design is changing. Whereas for the main part of the past century, the relation between physical form and technical function has dominated design theory and practice, the last decades show a shift to use and user. The focus of attention is shifting from a technology-driven, product-centred view to a view that is better described as user-centred, use-centred, and interaction-centred.

With this change in focus comes a need for different methods of designing, and for a new expressive design language that can cope with the highly interactive potential of new product categories that are emerging from interlinked miniaturised electronics invisibly integrated into products. All this requires much work, much interdisciplinary work.

In an effort to promote the fusion of ideas between research teams, four groups in Industrial Design Engineering at TU Delft formed the ID StudioLab in 1999. In one way the StudioLab is a physical space where researchers from participating groups work in a way that resembles a design-studio more than a conventional academic department composed of many little rooms. But it also is a statement of the intent to forge and develop links between related, but hitherto largely separate research streams. That statement is built upon three beliefs shared by all members of the Studio.

First, although the original four groups were already interdisciplinary, it is our conviction that breakthroughs and innovative research in the present field of product design requires a level of co-operation that goes beyond all traditional boundaries. To meet this requirement, product and interface designers, psychologists, physicists, specialists in the field of ergonomics and human-computer interaction, work together in integrated design and research teams.

Second, and in line with the changed focus in the field, product design and, as a result, design research must have an eye for the full experience of the user. This experience not only covers the often-studied perceptual-motor and cognitive skills of the user, but also emotional reactions. Furthermore, it is acknowledged that this full experience draws heavily upon the social, cultural, and technological context in which the interaction with the product takes place.

Finally, all research efforts should be designer-driven. That is, projects are either (among others) carried out by designers or directed towards designers. In the former case, exploring new forms of interaction through actual designing constitutes the basis of the research. In the latter case, the research must lead to new techniques or methods that support the designer in addressing the full product experience of the user.

In this paper we present a common stream of thought underlying work in the groups, and illustrate this with a number of projects. In line with the conference millennial theme, the

presentation will highlight directions and sample projects, but also sketch the recent history of the groups.

12.2 Work of participating groups

In this section we describe some recent projects by members of the ID StudioLab. We present these projects in the form of a sampler rather than as a complete overview. This "historical sketch" indicates the shift from cognitive and perceptual-motor skills to the full experiential context, including emotional skills. For example, Djajadiningrat's work on the Cubby VR system is strongly driven on the level of perceptual-motor skills: what spatial impression do people need to perform a detailed manipulative task. The more recent work of Hummels focuses on emotional skills: what forms of interaction do people need to feel a bond with a product.

12.2.1 Cubby, detailed form manipulations in VR (Djajadiningrat, 1998)

Many of today's 3D systems tease the user by showing highly lifelike virtual objects locked away behind a screen where he cannot reach them, and frustrate him by forcing him to use input devices which ignore the skills he has developed in everyday life. Cubby, a desktop VR system shown in Figure 12.1 left, addresses these problems through unification of the display and manipulation spaces and the use of a tweezers-like instrument. With this instrument, see Figure 12.1 middle, the user can operate on virtual objects where they appear (Djajadiningrat 1998).

Unlike many VR systems, Cubby is well suited to precision manipulation tasks. Possible areas of application include surgical simulation and computer aided modelling. Three orthogonally placed back-projection screens form the workspace. There is one projector per screen. Two are placed on the top surface, one stands below the workspace. The user's head-position, tracked with a device mounted over the workspace, is recorded to adjust the perspective of the images on the screens.

Cubby's tweezer-like instrument consists of a physical barrel and a virtual tip. The tip is rendered as an extension of the barrel. Since the tip is virtual, it can be moved behind a virtual object without occlusion conflicts occurring. The instrument features a single button that makes it behave and feel like a pair of tweezers. Because Cubby's workspace is compact, the positional error of the instrument can be kept small.

12.2.2 Two-handed 3D interaction in conceptual modelling (Gribnau, 1999)

The quick generation, comparison and evaluation of concepts is more difficult with the computer than with traditional materials such as cardboard, foam, clay, etc. This is largely due to the set-up of most computers systems (mouse, keyboard and screen) and the associated interfaces. To improve computer support of the early phases of design, the use of spatial interaction (whereby the hands can move freely in 3D) and two-handed operation was explored. Since most computer systems do not support either 3D or two-handed interaction, alternative interaction devices and new interface techniques were developed to test whether spatial interaction with two hands could help to make computer systems more suitable for geometric modelling.

With the Frog interaction devices and the ID8Model application developed in the project, two rounds of experiments were conducted; see Figure 12.1, right. The results indicated that both 3D interaction and two-handed operation were easy to learn. Working with two hands proved to be faster than working single-handedly and gives the designer more control over the modelling task. In addition, with bi-manual operation, the workload is divided between the

hands. The combination of 3D and two-handed interaction can lead to interfaces with a more direct intuitive way of interaction that fit closer to the capabilities and skills of the designer than the interfaces of current computer systems.
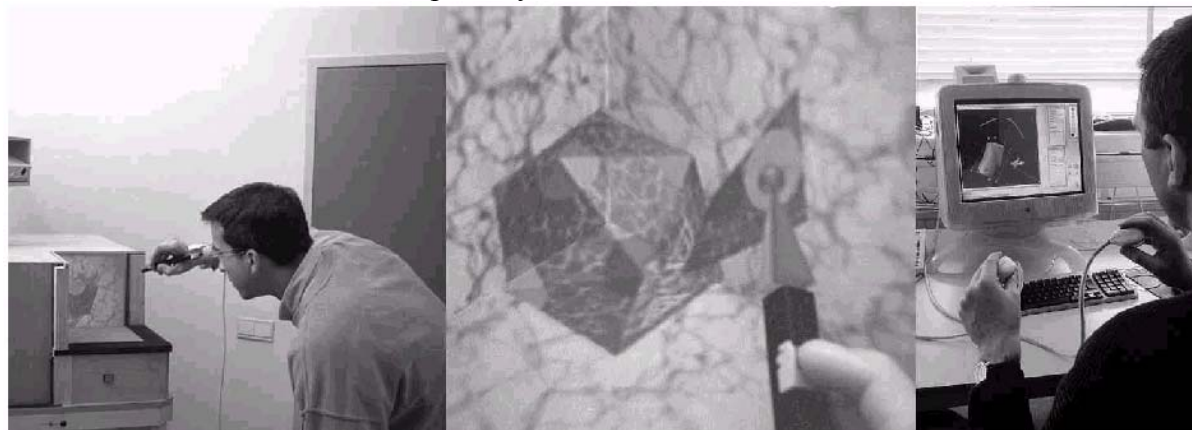

Figure 12.1: Cubby setup, Cubby's instrument; ID8Model operated with Frogs.

12.2.3 Multimodal interaction (Keyson, 1996)

Keyson's research before joining the laboratory addressed the role of synergetic and concurrent uses of multimodal feedback. In synergetic multimodal representations, sensory modalities are combined to form an integrated interpretation. Several such interaction styles were developed at Philips Research.

Integrated tactile, auditory, and visual information was used to create multimodal user interface objects for an electronic TV program guide (Bongers, Eggen, and Keyson 1998). The guide presents generic message chips in the foreground of a TV program. The chips can represent voice, video or E-mail. Moving a trackball with force feedback over the objects, to view content, creates the feeling of flipping a chip, with accompanying visual and auditory effects. Figure 12.2, left, shows a tactual-auditory landscape. The user can move between objects while receiving multimodal navigational cues. For example, selection categories are felt, heard and seen as "holes". The distance between the tactual virtual holes can be accurately judged (Keyson 2000). As the user approaches a TV program category the sound from the target selection can be heard while the sound associated with the category being left fades into the background. Visually, the target category comes into focus and a cyclone-like cursor moves into the felt "hole" force fields (Keyson 1997). TV programs are portrayed as a globe. The globe can be rotated using a 3D trackball with force feedback (Keyson 1996), so that users can easily manipulate and roll the ball-like globe object. Each program option is felt when it is rolled into view. Programs can be selected by pressing on the trackball. At this point the program warps into a second smaller ball and can be rolled over or into other objects such as a 'record' basket. User testing showed that users tended to prefer multimodal designs compared over designs where only visual feedback was provided. Studies on concurrent use of multimodal interaction focused on how the user could perform two tasks concurrently using two or more modalities of communication. For example, users were able to search visually for text while guided tactually along a particular course in a virtual space.

To support the above mentioned research a multimodal prototyping tool was developed called TacTool (Keyson and van Stuivenberg 1997). TacTool enables force field objects to be drawn and manipulated as graphic representations. Force fields objects, i.e., touchcons, earcons and icons can be stored in a library and grouped together as reusable multimodal objects.

12.2.4 Gestural design (Hummels, 2000)

Products are more than a withdrawn machine with buttons and icons. They can serve as a context for experience, rather than a mere function-provider. A product should be open and engaging, it tempts and supports users to have an experience. This means that the focus of product design shifts from the *result after interaction* towards the involvement, pleasure, beauty, and so forth, *during interaction*. The interaction has become the central theme of design, especially the aesthetics of interaction.

Hummels explores in her dissertation "Gestural design tools: prototypes, experiments and scenarios" whether and how new computer tools can support designers to create contexts for experience and focus on the aesthetics of interaction. Her thesis is composed of three parts. The first part proposes a new view on design. It discusses on a product, a social and a design discipline level, that designers and users can benefit from new digital tools, such as gestural sketching. The second part of the dissertation scrutinizes existing design tools and proposes scenarios and working prototypes for possible gestural computer tools for design. The last part explores the possibilities of implementing a gestural design tool that adapts to the individual user, see Figure 12.2 middle and right (Hummels and Overbeeke 1999).
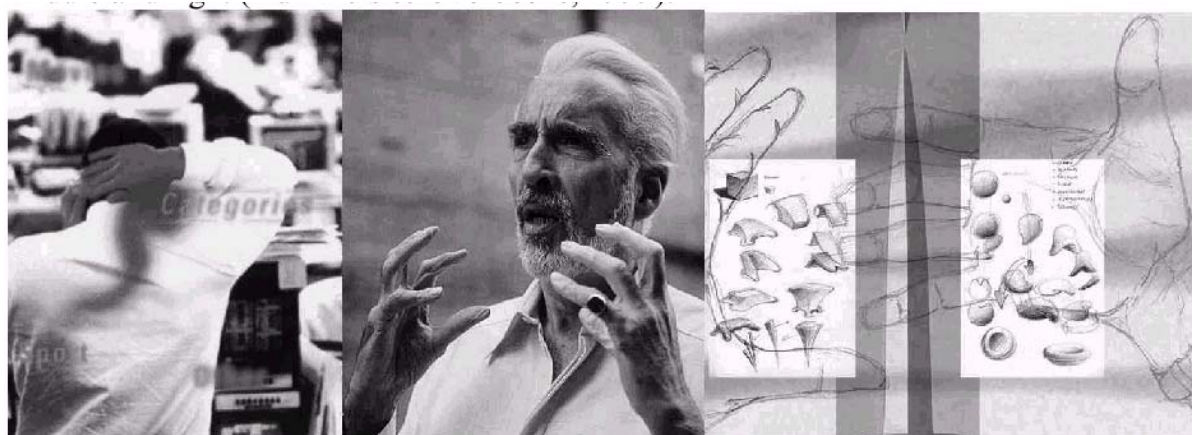

Figure 12.2: A multimodal landscape; designer gesturing and gestural sketching scenario.

12.3 New directions

The above projects illustrate our interest in the cognitive and perceptual-motor skills of designers and users. However, these aspects only partially address a person. We believe that the starting point for design and design research has to be respect for people as whole. For the sake of analysis, a person's skills in interacting with products, may be considered on three levels, the 'wholly trinity of interaction': cognitive skills, perceptual-motor skills and emotional skills: doing and feeling. Moreover, the social role of the product becomes central to our approach: social interaction is in the first place *between people*, possibly aided by products. In short, we shift our focus from the isolated product and its form toward the experience of designers and users.

When designing for an experience, a designer should not only create the product's function, make this function accessible and the product's appearance beautiful, but also make the interaction with the product beautiful. The designer creates a context for experience, rather than a product.

What are the implications of a context for experience for research? First and foremost, design research has to become research through design. Contexts for experience presuppose

diversity, subtlety and richness of design solutions in order to support individual users. To conduct experiments on human-product interaction, one needs to use fairly detailed designs that allow for this diversity, subtlety and richness during interaction. One needs to design wealthy solutions and test them in their context: with users in their environment.

As designing has become essentially contextual, scientific work and results should also be contextual, i.e., lead to conditional regularities instead of general laws. The main challenge for designer-researchers lies in integrating of the different aspects that compose a context for experience. How can functional analyses be integrated with atmospheric collages of the feelings and experiences of a user? How can the characteristics of an individual and a situation be captured and formulated? How can the designer-researcher preserve richness and subtleties of interaction, without drowning in the complexity of the context?

Because experiential and contextual design is a fairly new area in industrial design and still on the frontiers of knowledge, designer-researchers need to find new methods and research techniques to find such conditional laws. In the remaining part of this paper, we will show several of our research projects that try to gain insight in human-product interaction on an experiential level.

12.3.1 Evaluating product emotions (Desmet)

Nowadays, it is often difficult to distinguish products on the basis of their technological functioning or quality. Consequently, emotional responses to consumer products are often a decisive factor in purchase decisions. A product that has an emotional surplus value over other models can incite the customer to pick this particular model out of the row. So far, however, little is known about how people emotionally respond to products and what aspects of a design trigger an emotional reaction. The project aims to clarify the relationship between products and the emotional responses or feelings they elicit. The goal is to develop a model that explains how products elicit emotions (Desmet 1999) and a new set of tools that support designers in evaluating and manipulating the emotional impact of a design.

The model of product emotions is based on appraisal theories from psychology. A method, called PrEmo, was developed that measures product emotions (Desmet, Hekkert, and Jacobs, in press). PrEmo, see Figure 12.3 left, is a non-verbal self-report measure that uses eighteen animations of a puppet as metaphors for the user's emotions that go with a certain product.

12.3.2 Emotional intelligence for products (Wensveen)

Wensveen's contribution to the growing research field of emotion in design starts from an industrial designer's point of view. His research focuses on how 'intelligent' products can adapt to the emotional experience of the individual user. He starts from the following questions:

1) What are the relevant emotional aspects that form a context for experience?

2) How can a product recognise and express these aspects?

3) How should the product adapt its behaviour to the user on the basis of this information?

The first question was answered by using 'probes' to explore user's experiences (see Figure 12.3, right). This technique was developed by Gaver et al. (Gaver et al. 1999; Wensveen 1999) at the Royal College of Art, London. A lot of research on the second question focuses on *detecting* physiological indicators, e.g., blood pressure, skin conductivity and heart rate. However, we do not use this kind of information, as it doesn't allow the user to *express* his emotion to the product. Keeping this in mind, industrial designers can offer an alternative approach to detect and recognise emotions. In this approach a product is designed in such a way that it elicits behaviour which is rich in emotional content. Through his perceptual skills

the user perceives the possibility of acting in an emotionally expressive way (the product's affordance) and uses motor skills to express how he feels. Experiments will be conducted to test how the designed product can register this emotional expression and adapt to it.
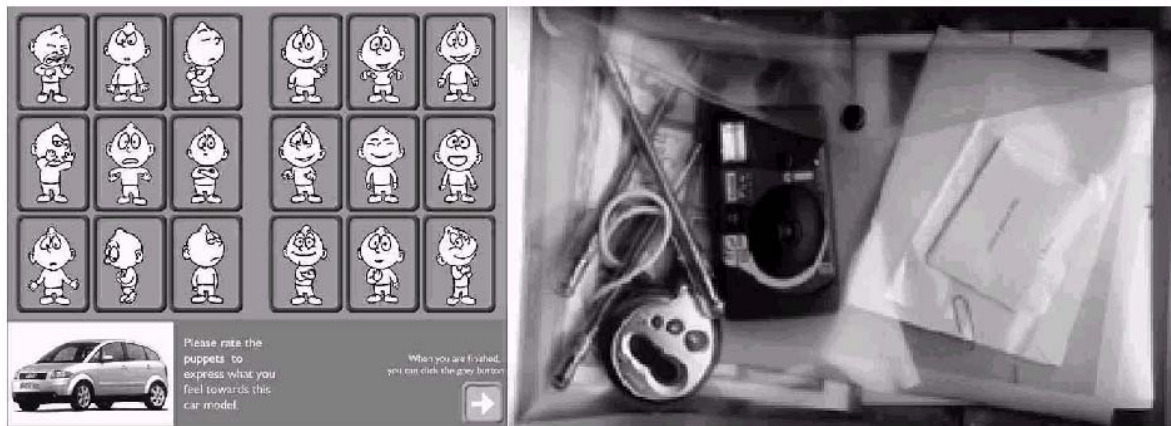

Figure 12.3: PrEmo interface; experience probe.

12.3.3 Innovating with precedent designs (Pasman)

Existing or precedent designs form an important source of information in the design process. When faced with a design problem, many designers draw reference to existing solutions as inputs for their idea generation. Thus collecting precedents in the form of product samples, product catalogues, photographs, slides etc. as well as organising them into moodboards, collages or folders is a major activity during the conceptual phase. Pasman's research is aimed at understanding and supporting this activity. From a design-methodological perspective the objective is to gain a better understanding of the role and meaning of precedent designs. What role do they play in the creation of new designs and how can this role be influenced? From a technological perspective the focus is on the development of a computer tool, which assists the designer in developing, organising and consulting a large collection of precedent designs. How then should such a tool be structured and in what ways would the designer interact with it? These issues are being addressed using a variety of research methods. A theoretical framework has been developed, which classifies products on their typical features regarding function, form and use (Muller and Pasman 1996). Based on this framework a method of organising precedents has been proposed. The effects of this method on the results of a design task have been studied in a design experiment, in which designers were provided with examples of existing telephones while designing a new one (Pasman and Hennessey 1999; see Figure 12.4, left). The different ways in which designers organise products and the influence of a specific context such as a design brief on this structuring behaviour, are studied through a number of classification experiments.

Finally a number of design proposals for the user interface of the design tool have been generated, prototyped and tested. So far these studies support our notion that existing designs can be a powerful source of design knowledge if they are organised and represented in ways which reflect the 'thinking and acting' processes of designers.

12.3.4 Tools for inspiration (Keller)

An important aspect of the new design methods is the ability to experience, communicate and discuss not just the form, but also the interactivity of the product. Keller's project looks at different ways to support the communication, visualisation and experience of a product's

interactivity using new (computer-aided) tools. These tools support the sketchy and expressive strengths of the traditional tools, combined with the dynamics and interactivity of the new interactive products. One of the studies explores interactive, dynamic video collages projected in the environment of the designer's workplace, see Figure 12.4, right.

The video collages open up a wide range of explorations. Current studies look at the different ways of displaying the video collages to allow the designer to experience these collages in the corner of the eye, similar to the way the designers hang the pictures, collages and sketching on the walls of their workspace (Keller, Stappers, and Adriaanse 2000). Another aspect of these collages is the direct and indirect ways in which the designer can interact with these video collages. But most importantly, these new dynamic video collages allow for an expressive way to experience, communicate and discuss the interaction experience by using moving images, ambient sounds and immersive projections.
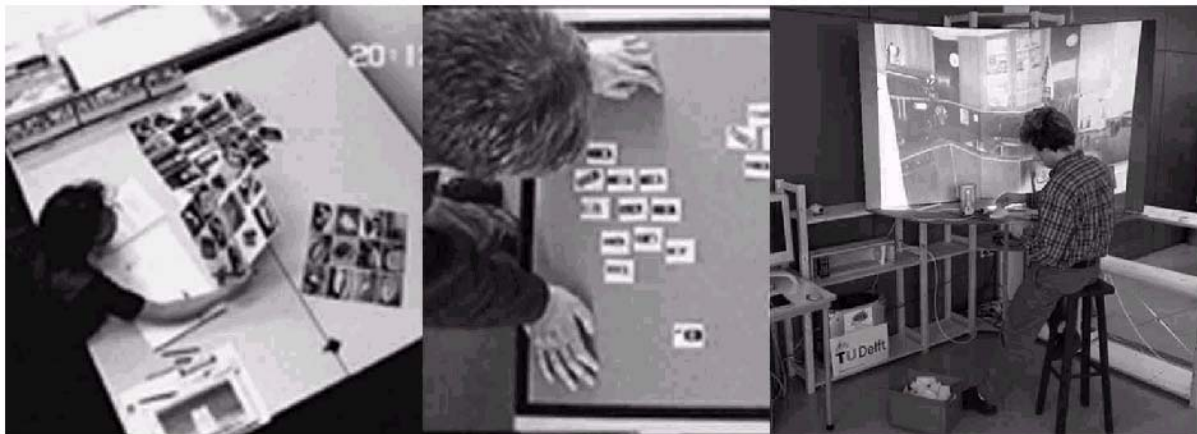

Figure 12.4: Design experiment, product classification; environmental video-collage.

12.3.5 Researching touch (Sonneveld)

Touch is an important sense for people to explore and experience the world. Although we intuitively understand the importance of touch in our daily lives, there is little research available on the emotional role of touch in human-product-interaction. Visual aspects had most of our attention. The lack of attention for the tactile aspects is often (negatively) reflected in the design of current products.

However, awareness of the power of the tactile aspects in products will give a product designer the opportunity to enrich the interaction of the user with the product. One of the difficulties one is confronted with while researching tactile aspects of products and their influence on the experience of the user, is the fact that we don't have an established set of research methods appropriate for this topic. Research on touch was mainly focused on psychophysical tactile sensations. But questions as "Why do we want to touch objects? How can we create 'irresistibles'? (see Figure 12.5, left) cannot be answered from the psychophysical point of view.

In this PhD project, different ways to research the influence of tactile aspects on the user's experience of products are explored. The main research questions are:

1) How does touching objects influence the experience of these objects?

2) How can we communicate about these experiences?

3) How can a designer incorporate this knowledge about touch in his work?

The aim is to develop tools for designers, that will focus their attention on the tactile aspects of products, and that will give them the possibility to work on these aspects in an explicit way.

12.3.6 Embedded help (Thomassen de Sosa)

With the increased functionality and intelligence in products, user control is in danger of becoming less explicit. The goal of this research is to create help tools which can bridge the gap between implicit functionality, common to intelligent products, and the user's sense of control. For example, Figure 12.5 shows the classic telephone where the physical affordance of the interface is high compared to newer communication devices containing embedded functionality. The current research is aimed at developing a systematic understanding of the types and levels of errors untrained users make while interacting with complex products, resulting in context-aware help tools which can reduce human errors and cognitive load.

Figure 12.5: 'Irresistibles'; expressiveness in telephone shapes.

12.3.7 Interaction beyond the GUI "The Thermostat Project"(Dekoven)

Despite advances in software and hardware technology, the basic principles of windows, icons, and the mouse still dominate human-computer interaction (HCI) styles. Even advances such as speech recognition are primarily used today with computers to drive the GUI or run a very rigid dialog sequence. User goals often have to be mapped to the way the system functionality is presented and choices at the task level are not evident. Typically, the user has to look in system help documentation to find more in-depth information about what is possible or how a certain task can be accomplished.

In Dekoven's Ph.D. research an investigation through product design is being conducted into the acceptability of user-product dialogue coupled with a GUI. Embedded task models of likely user actions support the system's dialogue with the user. To support this study an Intelligent Thermostat interface has been designed (Keyson, de Hoogh, Freudentahl and Vermeeren 2000), as shown in Figure 12.6, left. The thermostat is devised to encourage users to trust, explore, communicate, learn, and achieve a goal, rather than interact at the feature level for the sake of interaction. To support communication with the thermostat, the user is shown a dialog box of "things to say" via speech recognition or by touching one of the sentences on the screen. The "things to say" will be determined by actions performed in the GUI using the Collagen collaboration manager (Rich and Sidner 1998), which refers to task recipe libraries. Several complimentary strengths are expected in the GUI and task based "Things to Say" dialog. Usability testing is currently being conducted.

12.3.8 Vision in product design (Hekkert)

The Vision in Product design (ViP) project is a design methodology project and was initiated due to unease with dominant design methods (Hekkert 1997). Whereas most traditional methods regard designing as a rational-analytic problem solving activity, the ViP approach places emphasis on the personality of the designer including intuition, sensitivity, and creativity. In the design method, these 'abilities' are addressed to build a personally coloured context in which an expected or desired human-product interaction must fit. A qualitative notion of this relationship between a product and its user (the vision of interaction) is the key of the approach and directs further concept and product development. The basic assumption of the ViP-approach has been empirically tested and shown to result in original design solutions (Snoek and Hekkert 1999). Until now, the approach has been applied in a great number of student design projects. The approach has also attracted the attention of industries and design offices that acknowledge its potential for contributing to the development of original designs that clearly express a vision and the signature of their designers.

The ViP method is applied in a project aiming to increase the life cycle of automobiles by strengthening the bond between user and the car (Figure 12.6, right). This resulted in two conclusions. First, the car should be clean and open to interpretation and change by the user. It should become more meaningful during use, like a carrier for the mix and match lifestyle. This way it will be able to survive and be adapted to many lifestyles by which it becomes more sustainable. Second, at higher driving speeds interaction becomes less human and focuses more and more on signals from the environment and the car. Given a basic car the user can fill his or her own personal preferences. The user-car bond gets closer when the car is personalised during use or exploration. Doing so makes a lightweight car meaningful in technological terms and in user emotional terms as well.
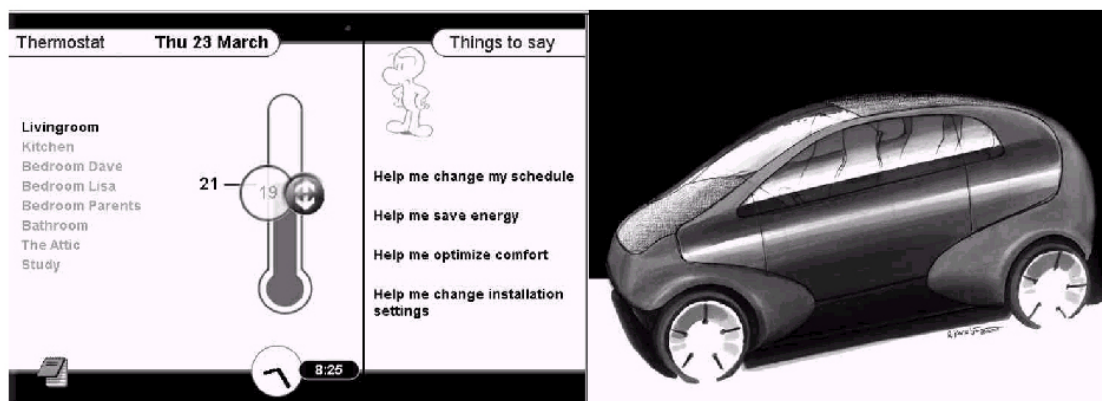

Figure 12.6: Thermostat interface; mix-and-match concept car.

12.4 Conclusions

Despite the apparent diversity in the overview of research projects presented, the projects share the critical features that were summarized in the introduction. All projects are design(er)-centred in that they either explore the boundaries of design through research or by developing support tools and methods for designers. Most importantly, they all go beyond the traditional function-oriented notion of design in addressing (aspects of) the full experience of the user in his or her interaction with products, and with an eye for the context of this experience.

12.5 References

Desmet, P.M.A. (1999). To Love and Not to Love: Why do Products Elicit Mixed Emotions? In: C.J. Overbeeke and P. Hekkert (Eds), *Proceedings of the First International Conference on Design and Emotion*, pp. 67-73, Delft.

Desmet, P.M.A. and Hekkert, P. and Jacobs, J.J. (in press). When a Car Makes You Smile - Development and Application of an Instrument to Measure Product Emotions, in: S. J. Hoch and R. J. Meyer (eds), Advances of Consumer Research, vol. **XXVII**.

Djajadiningrat, J.P. (1998). *Cubby: What You See is Where You Act - Interlacing the Display and Manipulating Spaces*, PhD thesis, Delft University of Technology.

Gaver, W. and Dunne, T. and Pacenti, E. (1999). *Cultural Probes, Interactions, ACM*, Danvers, pp. 21-29.

Gielen, M.A. and Hekkert, P. and van Ooy, C.M. (1998). Problem Restructuring as a Key to a New Solution Space: A Sample Project in the Field of Toy Design for Disabled Children, *The Design Journal*, **1**, pp. 12-23.

Gribnau, M.W. (1999). *Two-Handed Interaction in Computer Supported 3D Conceptual Modeling*, Ph.D. Thesis, Delft University of Technology.

Hekkert, P. (1997). Productive Designing: A Path to Creative Design Solutions, in: L. Svengren (ed.), *Proceedings of the Second European Academy of Design Conference*, Internet publication: http://www.svid.se/ead.htm.

Hummels, C.C.M. (2000). *Gestural Design Tools: Prototypes, Experiments and Scenarios*, Ph.D. Thesis, Delft University of Technology.

Hummels, C.C.M, and Overbeeke, C.J. (1999). The Expressive Power of Gestures: Capturing Scent in a Spatial Shape, in: Braffort, A. and Gherbi, R. and Gibet, S. and Richardson, J. and Teil, D. (eds), *Gesture-Based Communication in Human-Computer Interaction - Proceedings of the International Gesture Workshop*, Springer Verlag, Berlin, pp. 23-36.

Keller, A.I. and Stappers, P.J. and Adriaanse, J. (2000). Presence for Design: Creating an Atmosphere With Videocollages, Paper presented at *Presence2000 Conference*, Delft, March 2000.

Keyson, D.V. (1996). *Touch in User Interface Navigation*, PhD Dissertation, Eindhoven University of Technology.

Keyson, D.V. (1997). Dynamic Cursor Gain and Tactual Feedback in the Capture of Cursor Movements, *Ergonomics*, 40, **12**, pp. 1287-1298.

Keyson, D.V. and van Stuivenberg, L. (1997). TacTool v2.0: An Object-Based Multimodal Interface Design Platform, in: Smith, M.J. and Salvendy, G. and Koubek, R.J. (eds.) *Advances in Human Factors/Ergonomics. Design of Computing Systems: Social and Ergonomic Considerations - Proceedings of HCI International '97, Volume 21B*, Elsevier, Amsterdam, pp. 311-314.

Keyson, D.V. and de Hoogh, M.P.A.J. and Freudenthal, A. and Vermeeren, A.P.O.S. (2000). The Intelligent Thermostat: A Mixed-Initiative User Interface, *CHI 2000 Extended Abstracts, Conference on Human Factors in Computing Systems*, pp. 59-60, ACM Press.

Keyson, D.V. (in press), Estimation of Virtually Perceived Length, to appear in *PRESENCE 9.4*.

Muller, W. and Pasman, G. (1996). Typology and the Organization of Design Knowledge, in: *Design Studies* Vol 17 No **2**, pp. 111-130.

Pasman, G. and Hennessey, J. (1999). Random versus Typological Organization of Precedents in a Design Task, *Proceedings of the 4th Design Thinking Research Symposium*, MIT, Boston.

Rich, C. and Sidner, C.L. (1998). COLLAGEN: A Collaboration Manager for Software Interface Agents. In: *User Modelling and User-Adapted Interaction* **8**:3-4, pp. 315-350.

Snoek, H. and Hekkert, P. (1999). Directing Designers Towards Innovative Solutions, in: B. Jerrard and M. Trueman and R. Newport (eds.) *Managing New Product Innovation*, pp. 167-180, Taylor & Francis, London.

Wensveen, S.A.G. (1999). Probing Experiences, in: *Proceedings of the First International Conference on Design and Emotion*, Delft University of Technology, pp. 23-29.

13. Design and Building Informatics Research

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Keywords
Design and building informatics, product modelling, concept modellers.

13.1 Introduction

This paper gives an overview of current education, research and development activities of the design and building informatics group at Civil Engineering section of the Faculty of Civil Engineering and Geosciences, Delft University of Technology. The group also benefits from other informatics and IT research and development activities within the section such as application of artificial neural networks and decision support systems.

The Building Informatics group aims at contributing to the generation and dissemination of knowledge in the field of computational intelligence for design, building and construction systems. The group wants to bridge and integrate the disciplines building and civil engineering with informatics by means of research on complex design, building and construction systems. The theme of education and research of the group concerns the modelling of complex design and construction projects, that is the description of the end-result and intermediate stages of resulting facilities, the construction processes with the resources and controls and the supporting information and knowledge. Perhaps rightly we keep the subtitle of the theme as Building Design and Construction IT.
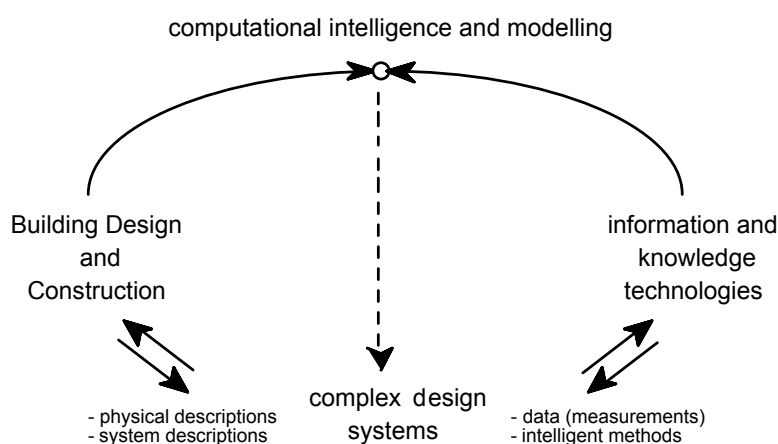

Figure 13.1: The scope of research of the Building Informatics group.

13.2 Nature of research

The group aims at performing:
- Fundamental research on design, building and construction modelling methods.
- Fundamental and applied research on method integration in modelling of complex design, building and construction systems.

The group encourages curiosity driven research with academic freedom within project aims.

13.2.1 Research aims

The aim is to contribute in three ways to building and civil engineering science:
- Contribute to new modelling methods.
- Contribute to integrated method modelling.
- Contribute to knowledge of physical phenomena by application of integrated method modelling.

The research is at such a level that it meets the international standards including:
- EU standards for large research projects.
- STW Technology Foundation.

The fundamental research orientation should meet the interest of science and academic community as well as professional parties in such a way that results are promising for further practical applications.

13.2.2 Object of research

The research of Building Informatics Group consists of modelling methods for complex building and civil engineering systems. The main research theme of the group is Building and Construction IT that concerns the modelling of complex construction projects, i.e. descriptions of the end-result and intermediate stages of resulting facilities, the construction processes with the resources and controls and the supporting information and knowledge.
Building and Construction is a sector of industry that has extreme difficulty in improving or even maintaining its competitiveness. Information, Communication and Knowledge Technology (ICKT) support is very relevant here. Improvements are sought for inter and intra project communication, reduction of cost of failure, multi-discipline design, engineering and construction, process quality and speed, robotics, integration issues and re-use of existing information and knowledge. The main questions under research are:
- Meaningful sharing and communication of electronic project data, information and knowledge. Communication standards like STEP, IFC, and XML. Concurrent and co-operative design, engineering and construction. Internet applications.
- Neutral modelling of artefacts and construction processes in different life cycle stages. Geometry and topology modelling. Simulation. Virtual Reality.
- Integration of multiple discipline views, information and knowledge. Object Trees.
- Knowledge modelling, sharing and exchanging. Multiple knowledge paradigm support. Re-use of knowledge and earlier designs and plans.

13.2.3 Methodology

In Building & Construction IT, integration also plays a major role. Here the emphasis is on integration of different partner roles, models and methods like product modelling, communication technology and knowledge engineering in order to cope with complex

systems. The research in this field is strongly driven by present and long term needs of the Building and Construction industry.

In both research themes some other methods are also used such as expert system technology, database technology, genetic algorithms, genetic programming and intelligent agent technology.

13.2.4 Co-operation

In accordance with the bridging role of the research the group co-operates with other research groups in civil engineering and informatics. The orientation on method integration approaches is appreciated by both civil engineering groups and informatics groups. The co-operative initiatives from the informatics discipline within civil engineering lead to results that would not have been achieved otherwise.

The concentration of both hydro-informatics and Building & Construction IT in one group on the faculty has the advantage that researchers in the same methodological field stimulate and encourage each other and there is a better occasion for cross-disciplinary idea exchange. External co-operations have a national as well as an international nature.

13.2.5 Products

Ph.D. theses, papers in scientific journals, papers in proceedings of conferences and reports about contract research results. The contract research products other than computer programs have been also been published in a scientific environment since the emphasis is on new modelling methods. The group organises and chairs among others the 8th EuropIA International Conferences on Advances in Design Sciences and Technology (April 2001).

13.2.6 Funding

There has been a gradual shift in funding sources during the last five years. After a start with mainly contract research, the faculty recognised our results and provided some project funding. Later, because some 'past performance' had been achieved, national and European funds became available. By the end of the period a proposal for fundamental research, based on a ideas and results of the group, was written among others for the following:

- European Commission (EC: ATLAS, CONCUR, E-Construct).
- STW Technology Foundation.
- Delft Cluster.
- Directorate General for Public Works and Water Management.
- TNO Building and Construction Research.

13.2.7 The role of the research programme in the educational programme

The impact of the research on masters' education has three aspects:

- Knowledge that is generated in the research is introduced in courses at higher level. This is especially the case of a fifth year course of the curriculum where advanced modelling and information systems are integrated into the curriculum.
- Tools that have become available as spin-off during the research are used in the fifth year's course of advanced applied informatics exercise of the section Civil Engineering informatics. Also, most products of the course are being initiated and used as educational tools by various courses at the faculty of civil engineering. Some of these products are used by various research projects such as a recent computer program developed as a tool for designing mooring systems for offshore platforms.

- During the final curriculum year students may choose their engineers thesis project within the research program of the group. This provides graduate students with the latest knowledge on design, building and construction ICT developments, which is useful for the research activities of the group as well as being valuable experience for students graduating with specialization in Building Informatics.

As impact on international masters education in the research co-operations have led to common courses of five European partners on modelling in the field of river design. The following universities participated in this experiment: universities of Cottbus (Germany), Grenoble (France) and Budapest (Hungary), IHE (Delft), TUD (Delft). In this courses students from different countries are co-operating in the same exercises. The international teams communication via Internet, email and ftp. They run models that are located at one of research groups. This experiment is part of a research project on web-based virtual campus initiated by the group to design and develop among others distant learning and design tools using the latest available technologies (Beheshti).
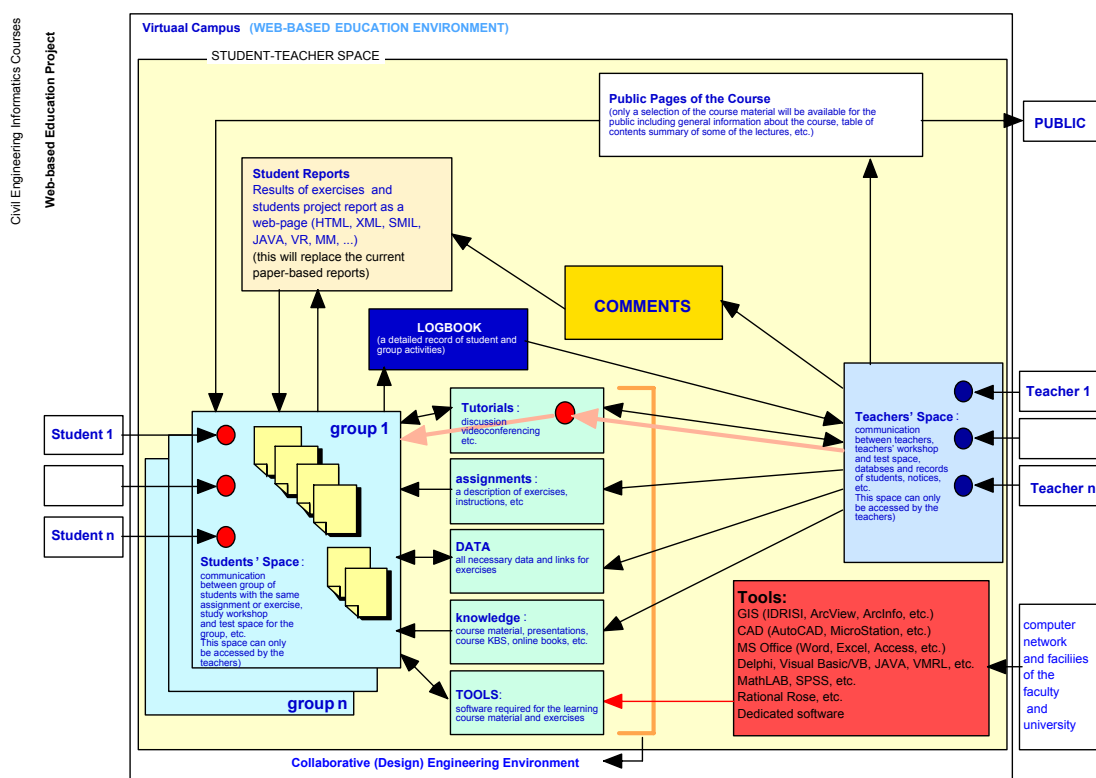

Figure 13.2: Web-based virtual campus.

An impact on PhD education in various groups is realised by our research seminars (ca. 10 times per year). Presentation and discussion between PhD students of different groups with a common interest in computational intelligence lead to exchange of knowledge between students.

The group contributes to PAO, an organisation for post-graduate education. In the lectures the state-of-the-art of research is presented, embedded in an overview of the fundamental and practical aspects of the methods that are covered.

13.3 Overview of academic results

The present research programme started five years ago. Collaboration with other research groups have been set up and intensified. Recognition has been gained in winning relevant European projects. Principal results obtained during the last five years are described below in order of the research aims.

The theme Building and Construction IT focuses on the modelling in complex building and construction projects. The current situation is that the knowledge of Communication Technologies for Building and Construction has deepened and that two PhD studies on Inception Support for large-scale Building & Construction projects could be started.

Research on costs aspects and the required multidiscipline knowledge structure dealt with conflicting knowledge from different sources. For that problem methods have been developed and a prototype tool was made that can handle multi-layer inception processes like (a) the inception of a power plant somewhere in a foreign country, (b) the inception of the power plant layout, (c) the inception of the turbine building.

Modelling methods for value aspects, both end-user values and general Building & Construction values have lead to a first prototype system for the inception of new or renovated Hospitals. Shortly a new PhD research project will start on the application and possibilities of XML technology for the building industry as part of e-Construct project (Tolman).
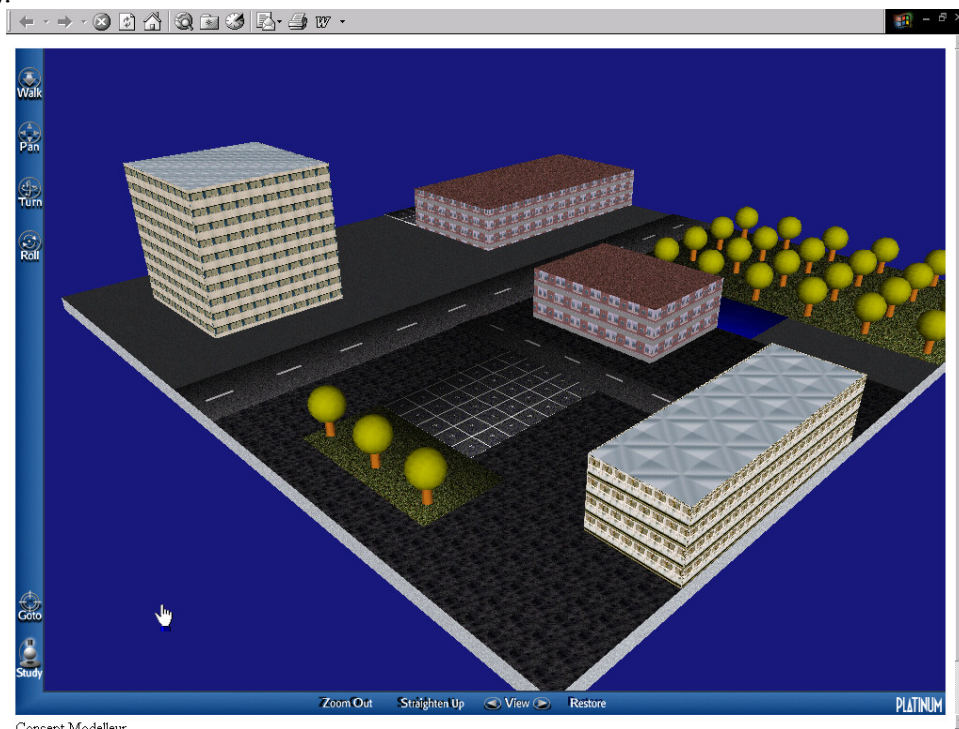

Figure 13.3: The conceptual design modeller for hospital design (Schevers).

A new theory called Neutral Object Trees has been developed for meaningful electronic communication in design, planning and realisation of complex Building and Construction projects. It is currently being applied in the High Speed Railroad (HSL) project in the Netherlands. This work influences the communication of hundreds of workers (managers, designers, planners, contractors) all being involved in the project. A new shape algorithm was developed that enables the semantical description of complex crossings and such including the underground and all the road furniture (Nederveen).
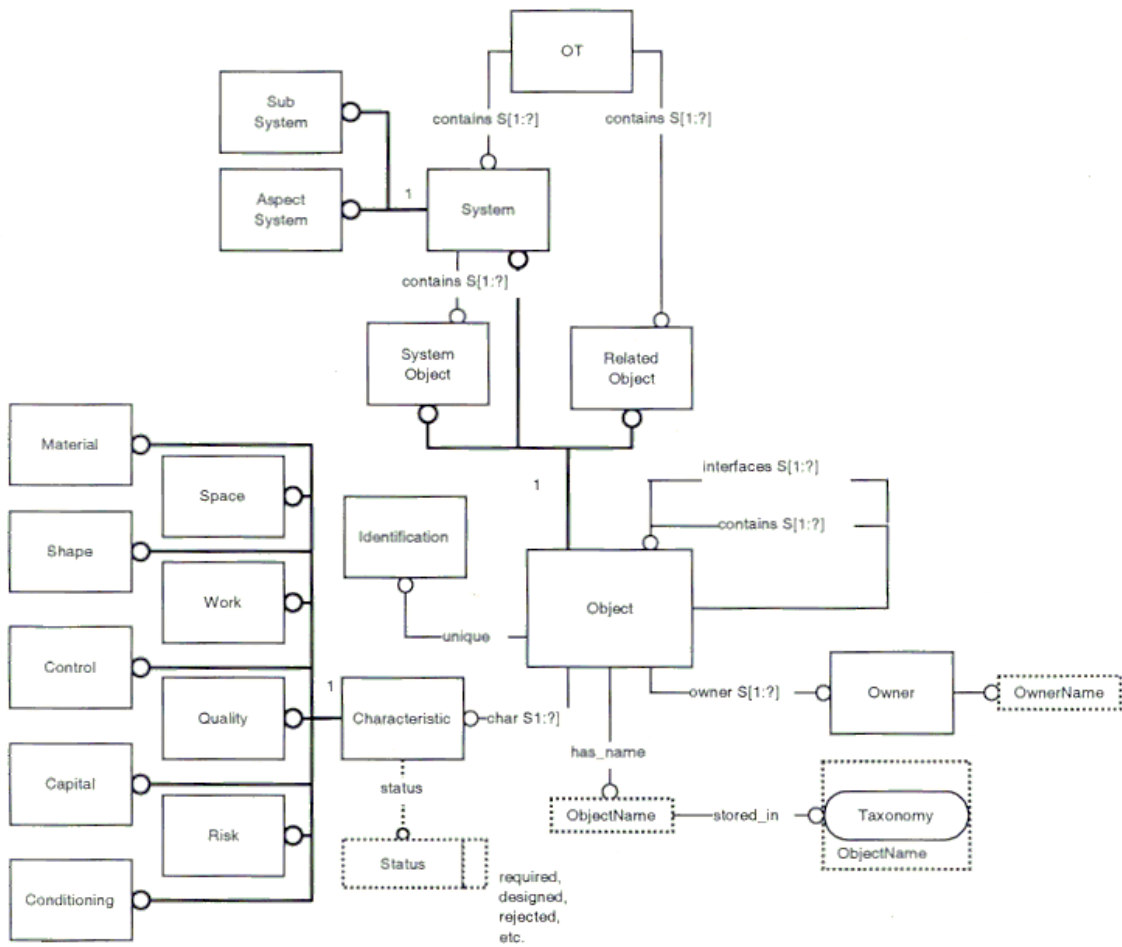
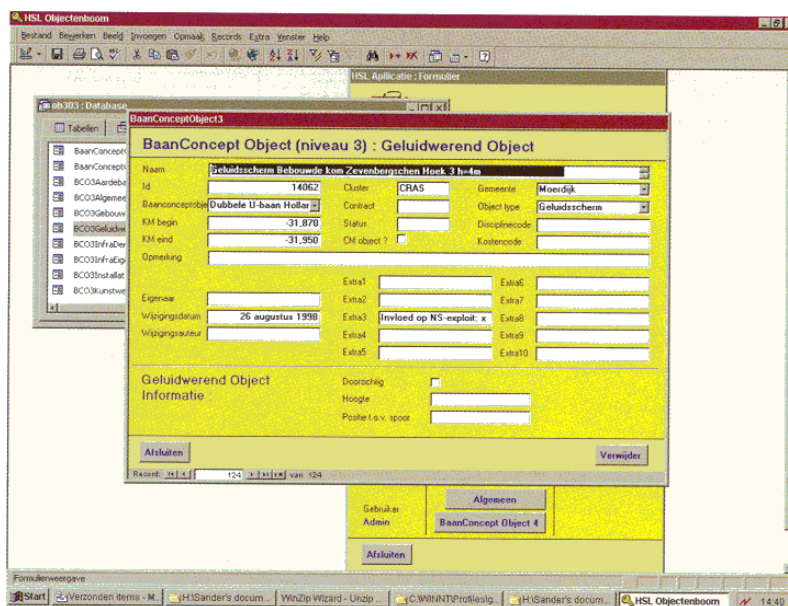*Figure 13.4: The basic principle of the Neutral Object Trees.*

Figure 13.5: Application of the Neutral Object Trees for HSL project.

A theory on Computer Integrated Structural Analysis was developed that describes how structural engineers can participate in co-operative design/engineering processes of complex structures. The basis is a two-dimensional cross section of a building in the CAD-system Allplan of Nemetschek Programmsystem GmbH. Allplan is not a drawing system; it is a product-model based CAD-system that is able to automatically derive such a cross section from the three-dimensional product model (image by courtesy of Nemetschek Program system GmbH). Geometric modelling systems offer the same support as drawing systems on a somewhat higher level. Geometric modelling systems also only support the specification of the (final) solution.

Figure 13.6 gives a typical example of a three-dimensional model. To a certain degree geometric modelling systems support the generation of solutions, especially for details in routine design. Often such systems use a three-dimensional model (or a simple product model) internally but can only produce two-dimensional views and cross sections or bending schedules for communication purposes. CADS8110, the system used in the case described here, is a good example of this. It is a suite of tools to analyse reinforced-concrete (Re) frames, and to design and detail reinforcement. Its modules 'understand' structural engineering concepts like load, concrete grade, bending moment, shear force and bar diameter. This understanding enables the modules to analyse frames, and design and detail reinforcement. However, the modules don't use an internal product model. All this structural engineering knowledge is hard-coded into the modules (Bakkeren).
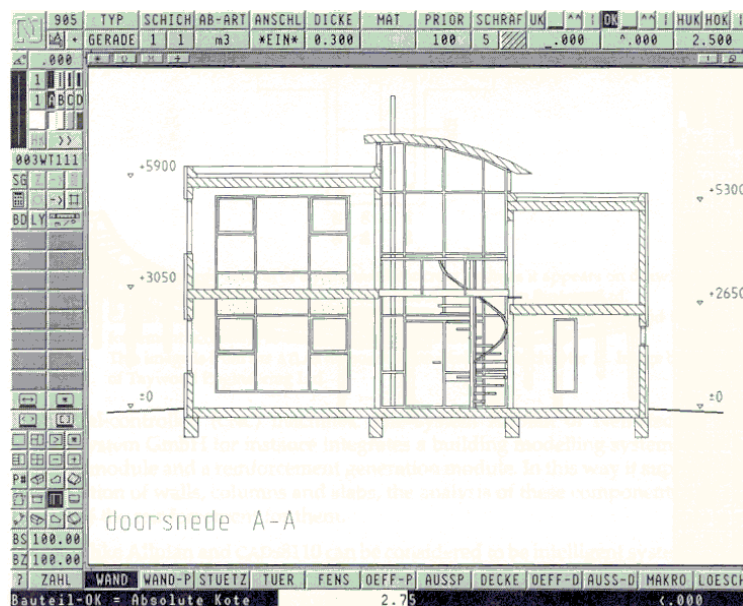

Figure 13.6: The Computer Integrated Structural Analysis Modeller.

Referring to the second research aim, an important accomplishment is noted: in the Building & Construction IT theme the group won a 25 man-year European project for Concurrent Engineering in Building and Construction, called CONCUR. The proposal was written by Tolman (chair of building informatics), who also formed the consortium and is the technical project leader. The aim of CONCUR is to provide two-way electronic communication between Clients and Main Contractors (and every party in between) with the aim (1) to reduce the costs of tendering with at least 50% and (2) to increase the hit-rate with at least 30%.
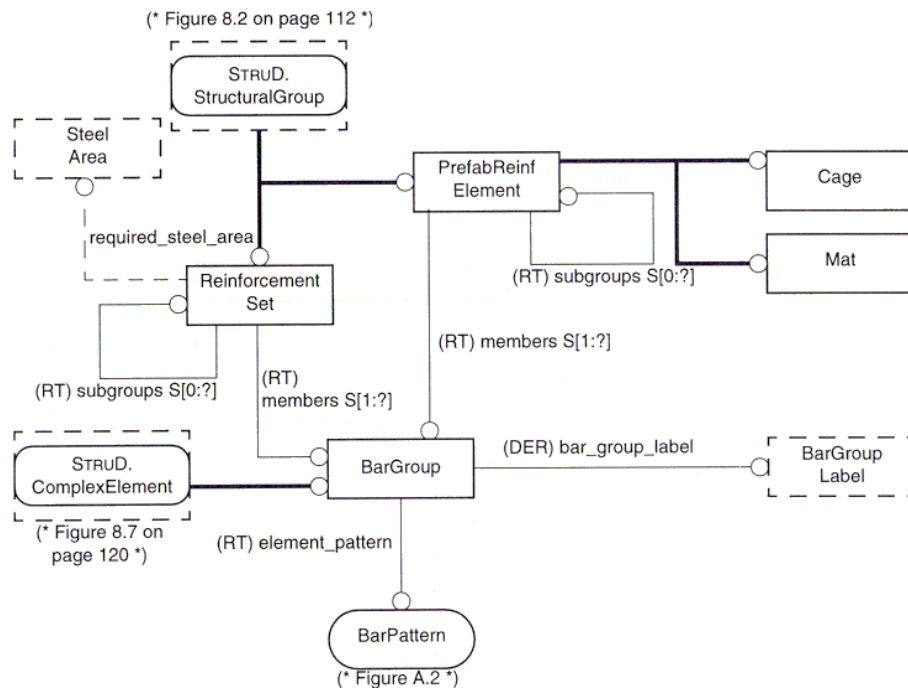
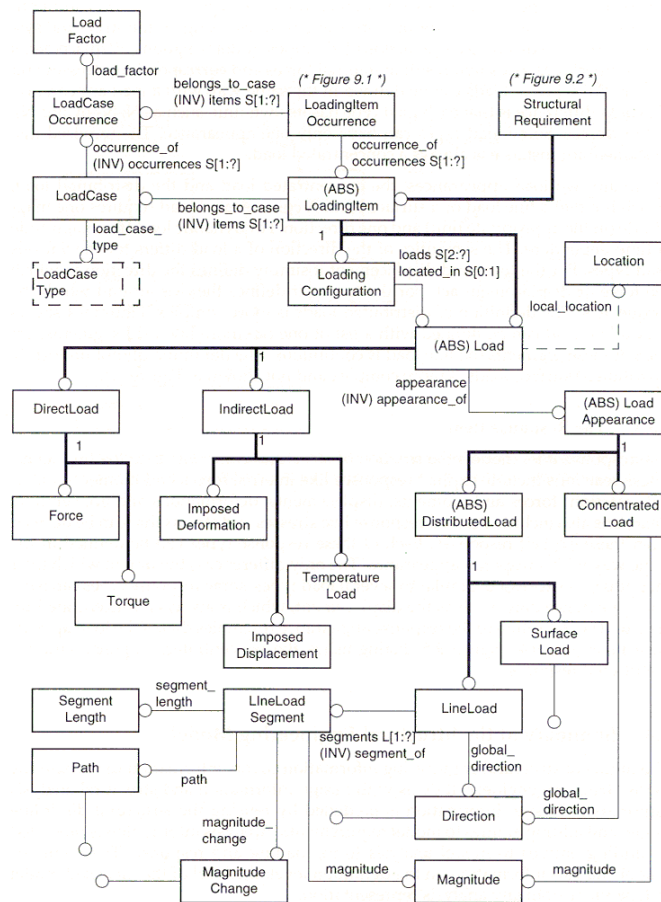*Figure 13.7: Reinforcement set, prefabricated reinforcement element and bar group.*

Figure 13.8: Express-G entity level diagram. A model of loading information.

As a recent accomplishment Tolman succeeded to win a major EU-contract for the European "eConstruct" project (IST 10303). This 25 man-year project was again initiated by the group. The focus is on the development of a new Communication Technology based on XML for the next generation Internet (van Rees). Referring to the third research aim it is noted that most of the research produces prototype software which is frequently used by partners in practise.

Also research and development is being carried out for the development of a Space Frame Modeller using product-modelling technology (PDT). The modeller will be a tool for designing large-scale space frame structures. The modeller will among others be a tool for designing, calculating, as well as architectural design and facility planning of such building systems.

Work is also done on formulating a research proposal for developing a functional design modeller based on product data technology. This tool will benefit from an earlier tool VLEK3 developed earlier as a prototype using clustering techniques and algorithms. The new proposal aims at investigating the possibility of using genetic algorithms instead (Beheshti).
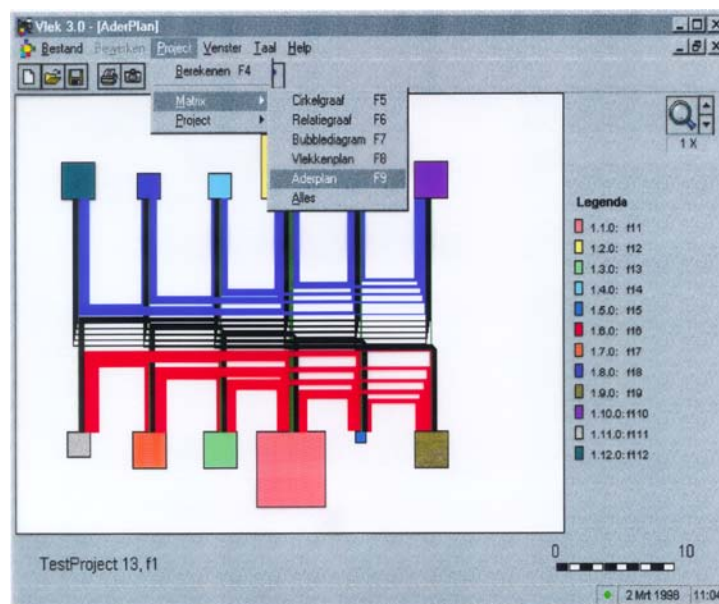

Figure 13.9: The functional design modeller (VLEK3 prototype).

13.4 Programme development

In the forthcoming period the mission statement, themes and methods will remain the same. However some accents will be shifted and some points of attention have to be mentioned.

13.4.1 Scientific aspects:

In Building & Construction IT the focus of research has shifted recently from the Design/Engineering stage upwards to (1) the Inception and Very Early Design stage and downwards (2) to the Planning and Execution stage, though still sufficiently supporting Design/Engineering to study feed-back and feed-forward information and knowledge flows over the life cycle.

13.4.2 Organisational aspects:

The present policy to have each year for 4-6 months a research fellow from a foreign university in the group will be continued since experiences are very fruitful. It is noted that

here will be also a shift in interests as we have slightly shifted some scientific aspects of the main research theme. In this regards during the next year a visiting professor from the university of Caen will participate in our research and education programmes aiming at the exchange of information and setting up EU-level research projects following the steps of groups earlier success such as ATLAS, CONCUR and e-Construct projects (Tolman).

13.4.3 Publications:

Besides publication on conferences, which is very fruitful for PhD students from a self-fulfilment point of view (and attractively fast, which is mandatory in our field), more attention will be paid to publishing in the following international journals; (with these journals there are already good relationships since the group members act as reviewers for the journals or are in the editorial boards such as the International Journal of Construction Information Technology, as the International Journal of Design Sciences, the Design Research Internet Magazine, etc.).

13.4.4 Potential impact of the research

The potential impact of the research is large as the group always places its research in the context of an industrial project, preferably a European project involving end-user companies (contractors, specification institutes, design offices), ICKT vendor companies and fellow research groups in Europe. This mechanism ensures that the research serves the intended needs and is commercially viable. It is also noted that Building & Construction is a large market. If only a small increase in efficiency and effectiveness can be provided large gains for society result.

13.4.5 Realised impact of the research

- Based on research on geometry modelling in the Building Industry, the Dutch Rijkswaterstaat developed design tools for viaducts and tunnels that allowed more geometry freedom. The drilling robot, resulting from construction robot research, has been used to drill many thousands of (unhealthy) holes in underground concrete tunnels.

- Research on Communication Technology resulted in the first international STEP standard for our industry (STEP Building-Construction Core Model, part 106). Related work resulted in the IAI-IFC standard that is now being used in many large-scale building projects all over the world.

- The Neutral Object Tree approach is currently used in the Dutch HSL project.

13.5 Conclusions

In Building and Construction IT, integration plays a major role. Here the emphasis is on integration of different partner roles in building industry, models and methods like product modelling, communication technology and knowledge engineering in order to cope with complex systems. The research in this field is strongly driven by present and long term needs of the building and construction industry. In this research theme some other methods are also used such as expert system technology, database technology, generic algorithms, generic programming and intelligent agent technology.

The group initiated and participates in three European projects: ATLAS, CONCUR and E-Construct. In these projects the group co-operates with different research groups as well as members of building industry. The outcome of research influences education programme offered by the group. The group provides three Building and Construction IT courses at the Faculty of Civil Engineering, respectively on product modelling in Buildings, knowledge

engineering for building and construction as well as application of advanced technologies in building design and construction.

The current situation of this theme is that knowledge for building and construction has deepened and that two PhD research projects deal with studies on Inception Support for large-scale building and construction projects. Research on cost aspects and the required multi-discipline knowledge structure dealt with conflicting knowledge from different sources. Modelling methods for value aspects, both end-user values and general building and construction values, have lead to a first prototype system for the inception of new or renovated hospitals.

The potential impact of the research carried out is large as the group always places its research in the context of an industrial project, preferably a European project involving end-user companies (such as contractors, specification institutes and design offices), ICKT vendor companies and fellow research groups in Europe. This mechanism ensures that the research serves the intended needs and is commercially viable. It is also noted that building and construction is a large market. If only a small increase in efficiency and effectiveness can be provided, it can result in large gains for the building industry.

13.5.1 Appendix 1: Activities

The following are some of the activities of members of the Building Informatics group:

F.P. Tolman, Building & Construction IT

- Editor of the electronic journal ICT in Construction.
- Initiator, editor and technical project leader of EU-project ATLAS.
- Initiator, editor and technical project leader of EU-project CONCUR.
- Initiator, editor and technical project leader of EU-project eConstruct.
- Member Scientific Board STABU.
- Scientific Advisor TNO Building Construction Research.

R. Beheshti, Building & Construction IT

- Co-ordinator of Design Informatics Theme of Research School Building and Construction.
- Editor-in-Chief of the International Journal of Design Sciences and Technology.
- Member editorial Board of the journal DriM (Design Research Internet Magazine).
- Member Technical Advisory Board of the International Journal of Construction Information Technology.
- Member Design Research Foundation (chairman of the board).
- Member EuropIA Association (European Association for Advanced Technologies in Design: Artificial Intelligence, Image Processing and Robotics).
- Member EuroGraphics (European Computer Graphics Society).
- Member MCDA (International Association for Multi-criteria Decision Analysis).
- Member Design Research Society (International Society for Advanced Studies in Design).

13.5.2 Appendix 2: Engineering products:

- Two Construction Robots, one for Drilling holes in concrete tunnel sections and one for brick laying.

- A design system for large-scale linear infrastructure works based on the Shape Deformation Tree.

- A pilot version of a measurement control system.

- A pilot of a dynamic model implemented in Java/Java3D for on-site application integration.

- A pilot of a Knowledge Base System that supports multiple views and non-monotonic design.

- A prototype of an information management system for large-scale projects based on Neutral Object Trees.

- A Concept Modeller for Hospitals.

13.5.3 Appendix 3: Dissertations

Following the nature of the discipline, the group has taken initiatives to co-operate with colleagues in research and research guidance. As a result of that policy many publications have more than one author and often PhD students have two promotors.

- Koetsveld, M.J. van (1995). *Product Data Interchange States*, Delft.

- Ying Liu (1996). *A Pattern Directed Approach Towards an Object Adaptive Decision Support Environment for Water Resources Management*, Delft.

- Bakkeren, W.J.C. (1997). *Computer-Integrated Structural Engineering*, Delft.

- Krom, R. (1997). *Robots in the Building Industry*, Delft.

- Minns, A.W. (1998). *Artificial Neural Networks as Subsymbolic Process Descriptors*, Delft.

- Willems, P. (1998). *Conceptual Modelling of Structure and Shape of Complex Civil Engineering Projects*, Delft.

- Nederveen, S. (1999). *The Neutral Object Trees*, Delft.

14. Computational Design Research

The VR-DIS Research Programme

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14.1 Introduction

In 1995, when the previous Design Research in the Netherlands Symposium was organised, the Department of Building and Architecture consisted of four groups working in design research and design computation: Vormleer, the Design Methods Group (GOM), the Bouwinformatica (Building Informatics) Group, and the research institute Calibre.

In the period 1997-1998 this situation changed: GOM and BI merged to form the current Design Systems Group, and Calibre became a commercial business under the TUE holding. A new research direction was formulated for Design Systems, based on the existing expertise particularly in design support, CAAD, VR, and design methods. The new research programme was titled VR-DIS. In this paper we will outline VR-DIS, discuss a number of design research approaches that underlie the philosophy of VR-DIS, and present results and ongoing work in the research programme.

14.2 VR-DIS

Computational design support is still in its infancy. Among various problems that can be seen, we note, in particular, the following:

- Most computer applications are task specific and data-exchange between them is difficult.
- The human-computer interface can be greatly improved to become a fluid medium of expression in the design process, which it is not today.
- Design representations and design knowledge in the various disciplines are understandable in those disciplines themselves but difficult to exchange.

The Bouwinformatica Group and the Calibre Institute had gathered considerable expertise in computational design support, most notably in the areas of visualisation and Virtual Reality technology. From this basis, the following future situation was hypothesised as a context for research:

- Computational applications that aid in the design of inherently spatial objects (e.g. buildings in Architecture, products in Industrial Design, HVAC systems in Engineering, etc.) will move toward a spatial metaphor.
- Design knowledge and information of the design stored in the computer will have spatial representations.
- The motoric and cognitive capacities of designers in everyday life and professional life can be mapped more easily on spatial metaphors than others.

In short, we believe that VR can become the key representation not only for electronic design media (VR-based CAD), but also for replacing the current two-dimensional desktop metaphor. For the development of such a comprehensive use of design knowledge in a VR environment, the VR-DIS programme was defined in 1998.

VR-DIS is an acronym that has two meanings: Virtual Reality – Design Information System, and Virtual Reality – Distributed Interactive Simulation. The first acronym refers to the visualisation of design knowledge and outcomes of design actions in the building design. The second acronym refers to multiple users on different locations engaging a model in Virtual Reality.

If we want to achieve spatial design representations both of the building design and the designer's knowledge, then we need to have access to this knowledge. For this purpose, the VR-DIS research programme is formulated department-wide. The goal is to investigate and incorporate the knowledge of groups such as Building Physics, Construction Management, Architectural Design, Urban Design, etc. into the VR environment.

The core activity lies with the Design Systems group, because in this group the key expertise on VR, formalisation of design knowledge, design research, and software development is present. People from Design Systems are involved with VR-DIS projects that are located within the various groups of the Department of Building and Architecture. Since the Design Systems group is involved in the VR-DIS programme to a great extent, the groups' own research programme has also been named VR-DIS. Also, there is continuous research collaboration between Design Systems and the Calibre business. To make the picture complete (although perhaps less clear), the work of the Design Systems group is situated within the DDSS programme: Design Decision Support Systems, in which Design Systems co-operates with the Urban Planning group. In the framework of DDSS, a bi-annual international conference called "Design Decision Support Systems in Architecture and Urban Planning" is organised.

14.3 Research in VR-DIS

The end goal of achieving a VR-based design aid system is planned in a three-stage development. Each following step requires partial completion of the previous one:

1) System I: Interactive design system for one designer. This concerns study of design support for the total life-cycle of a building or the built environment. Aspects are: user interface, immersive design tools, knowledge representation, consulting design knowledge, checking against standards and rules, and simulating product behaviour (see Figure 14.1; left).

2) System II: Networked distributed multi-disciplinary design system. Study of the requirements for multiple users working on the same design in VR. Aspects are: user representation, different user views, consistency of design data, management of design and process, collaborative design, and (a)synchronous communication (Figure 14.1; middle).

3) System III: Networked interactive evaluation system, which also takes into account future user reactions. This concerns the study of user behaviour in a design. Aspects are: measurement of user behaviour in building and urban design, evaluation of behaviour and information handling, agent theory, and conjoint measurements (Figure 14.1; right).
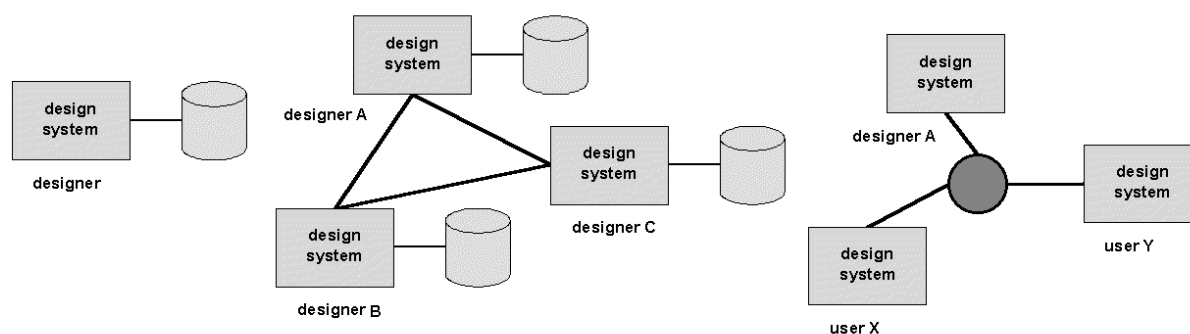
Figure 14.1: Three systems in VR-DIS.

At the moment, a number of prototypes have been developed that deal with issues for system I: the Feature Manager, the Constraint Solver, ILSA, WEDA, and DDDoolz. Projects dealing with systems II and III have more or less recently started.

In the next sections, we will present some broader issues that are connected to the VR-DIS research.

14.3.1 Ph.D.'s in VR-DIS

In the context of VR-DIS, numerous Ph.D. research projects have been formulated, each concerned with a specific aspect of the research discipline in which it is located (e.g. building physics or construction management) and the connection with VR-DIS. Although the ultimate aim is to yield results integrated in a VR-based system, the main goal of the Ph.D.'s is to establish the theoretical work that will make it possible to further use the results in the VR-DIS programme. In section 14.4 the Ph.D. projects are summarised.

Data model: Feature Based Modelling

For computational design support to be realised, it is necessary to have an information model that can capture the richness of design information. In Design Systems, this information model is based on Feature-Based Modelling (FBM). The foundations for this have been established in the doctorate thesis of Jos van Leeuwen (1999). First a modelling tool was developed to support this method of data modelling. This so-called "Feature Tool" was implemented on a relational database. In a second development, the relational database was replaced by a Feature Manager that is based on an Object Oriented database and which greatly resembles the Feature Model structure defined by van Leeuwen.

FBM has the advantage that it can capture information in various degrees of abstraction. The work of van Leeuwen was aimed at giving it additional flexibility and extensibility so that the dynamic nature of design with its continuously changing datamodels can be described. In our research on the user requirements for a design support system, we have extended FBM to analyse design processes.

Research method: case study

With the FBM approach we have the main framework to formalise design knowledge and the building design. To get to a dynamic support of design through feature models however, it is also necessary to understand how these models change, and which tools are required to make these changes possible.

For this purpose, we have made a case study of a concrete design from an architect's office and described the design process in terms of changing feature models. This was achieved by taking all the drawings made during the design, describing each drawing as a design state in a

feature model, and analysing the changes from design state to design state in terms of changes in the feature model. The analysis per drawing was based on the research work on generic representations (Achten 1997). Through this work we have established a classification of design actions that, to date, amount to eight classes of changes in the design process (Achten and van Leeuwen 1998; Achten and van Leeuwen 1999).

The classification is very useful when tools will be developed that support the designer. Usually, the propagation of changes in a design, while maintaining a consistent model is very hard, and, perhaps, even impossible. Understanding what exactly goes on during design actions can aid in this respect and also give more insight in design reasoning processes.

Feature view and model view

In our discussions on the envisioned VR-based design aid system (system I) we distinguish between two basic views of the design: the model view and the feature view. The model view shows the three-dimensional geometric design with additional representations for cost, structural stress, energy loss, etc. The model view is a representation with a high degree of verisimilitude. The feature view however, enables the designer to see and manipulate the underlying datastructure (feature model) of the design. The feature view option has the advantage that it can address more semantic properties of the design that are hard to represent in geometry. The information stored in the feature model is present in different degrees of abstraction. The designer may choose to manipulate those rather than the geometric representation (for example when changing the heat transfer quotient of a wall, changing the colour of a whole group of objects, or when some information about objects needs to be found).

Knowledge from education

The Design Systems group is quite involved in teaching in the Department of Building and Architecture. Historically, this has been basic CAAD training as well as design methodology and theory. In 1998, with the formulation of the VR-DIS programme, a more fundamental link between teaching and research was initiated. Parallel to the research effort, a Design Studio was initiated in which prototypes could be tested and used in ongoing design projects. The Design Studio features six Intergraph computers that can support desk-top Virtual Reality. From its inception, the Design Studio has proven to be of great value in understanding, in particular, the challenges of VR in design and the current difficulties in using it. Also, it is a very usable test platform for developed prototypes.

A second educational stream that is connected to research is two projects on distance learning and CAAD: the AVOCAAD project, completed in 1999, and its follow-up, AVOCAAD Multi. Both projects are initiated and co-ordinated in Brussels, with the Hogeschool voor Wetenschap en Kunst (WenK) and feature research partners in Europe. A third teaching/research project has been started by WenK and the Technical University Delft called {ACCOLADE}, which is a European start-up workshop for collaborative design. The work here has significance to the developments in system II mentioned above.

14.4 Results and ongoing work

By its very nature, the VR-DIS research programme relies on multidisciplinary research. People from Design Systems participate in many ongoing projects that are located in different groups and departments. For this purpose, the following list also mentions the locations of research. Successful collaboration has been achieved, in particular, with Building Physics and Computer Graphics.

14.4.1 Finished research projects

- 1996. Ph.D.: Bauke de Vries. "Communication in the Building Industry – A Strategy for Implementing Electronic Information Exchange." Building Information Technology.

- 1997. Ph.D. Henri Achten. "Generic Representations – An Approach for Modelling Procedural and Declarative Knowledge of Building Types in Architectural Design." Design Methods Group.

- 1999. Software: Ren Manager 1 and Ren Manager 2. Design Systems.

- 1998. Software: Joran Jessurun. WUPWalker routine. Design Systems.

- 1998. Software: Joran Jessurun. Feature Manager. Design Systems.

- 1999. Ph.D.: Richard Kelleners. "Constraints in Object Oriented Graphics." Computer Graphics.

- 1999. Ph.D.: Jos van Leeuwen. "Modelling Architectural Design Information by Features – An Approach to Dynamic Product Modelling for Application in Architectural Design." Building Information Technology / Design Systems.

- 1999. Ph.D.: Ellie de Groot. "Integrated Lighting System Assistant." VR-DIS / Building Physics.

- 1999. Software: DDDoolz. Design Systems.

14.4.2 Ongoing research projects

- Ph.D.: Marc Coomans. "Visualisation and Manipulation of Dynamic Data Structures in Virtual Reality." VR-DIS / Design Systems.

- Ph.D.: Shauna Mallory-Hill. "Workplace Environment Design Assistant." VR-DIS / Building Physics.

- Ph.D.: Maciej Orzechowski. "Measurements of User's Reactions and Behaviour in VR for any Building Environment." VR-DIS / Urban planning.

- Ph.D.: Amy Tan. "The Reliability and Validity of Interactive Virtual Reality Computer Experiments." VR-DIS / Urban Planning.

- Ph.D.: Nicole Segers. "Interactive Architectural Design Tools in Virtual Environments." VR-DIS Design Systems.

- Project: Brite Euram: "Refurbishment." Design Systems / Vastgoedbeheer

- Project: Building Management Simulation Centre. Design Systems / Calibre.

- Project: E3DAD (Easy 3D Architectural Design). Design Systems / Instituut voor Perceptie Onderzoek / Computer Graphics.

- Software: Joran Jessurun. REF Manager. Design Systems.

14.4.3 Summary of key projects and results

Many research projects yield applications for testing the work in practice. These can be conceptual mock-ups that mimic intended functionality, but they can also work as normal running software. Table 14.1 shows a list of products and the scientific methods that form the theoretical and scientific basis of the work. Products between "{ }" are in development. Names between "( )" indicate additional participating groups in the research.

TABLE 14.1. Products and methods in VR-DIS

Products	Methods
Feature manager	Feature based modelling. Flexible and extendible data information model for design.
{CBR system}	Generic representations. Analysis method for capturing design decisions established in representations. Retrieval of cases based on design drawings.
{Exspect simulation}	Message exchange model. Simulation of the information exchange process between the participants in a building project.
Feature view	Feature visualisation and manipulation in Virtual Reality.
DDDoolz	Face orientation method. Use the face of a voxel as a plane of reference for generating new voxels.
VIP (IPO)	Design support for collaborative design in the VIP augmented reality system.
Constraint solver/tester (W&I)	Geometric constraints. Constraint definition between 3D objects. Propagation and maintenance in a designerly fashion.
Blocks (W&I)	Implicit geometric relations. Relations defined in the design without explicitly stating them. Recognition and maintenance. Interpretation of various meanings during design actions.
ACAD -> 3DS -> WUPWalker	VR Cycle. Fast cyclic method of incorporating Virtual Reality in the design process to investigate influence of VR.
WEDA & ILSA	CBR, KBS. Case definition in the fields of lighting design and comfort in workplace and reasoning in new design situations.

14.4.4 DDDoolz

The first prototype of a truly 3D sketch tool in VR was developed initially by Bauke de Vries during a sabbatical leave at the ETH Zürich. DDDoolz was meant to demonstrate an approach in which sketching was as easy as point, click, and drag, without addressing any extra command structure through menu's or keys.

DDDoolz is a voxel system, meaning that the smallest element is a cube. The basic idea of DDDoolz is that any creation act starts from an existing voxel. New voxels can be created by clicking on the side of an existing voxel, and taking that side as the implicitly defined plane of reference, drag new voxels with a pointing device. Voxels can be rotated to achieve different orientations, moved and deleted.

The user interface has proven to be very simple and effective (see Figure 14.2). The system has been given to first-year students of architecture with an assignment to create a small exhibition pavilion. After a short while, student were able to work and design with DDDoolz. Since it is implemented in VR, the user can immediately walk through the design while still designing.
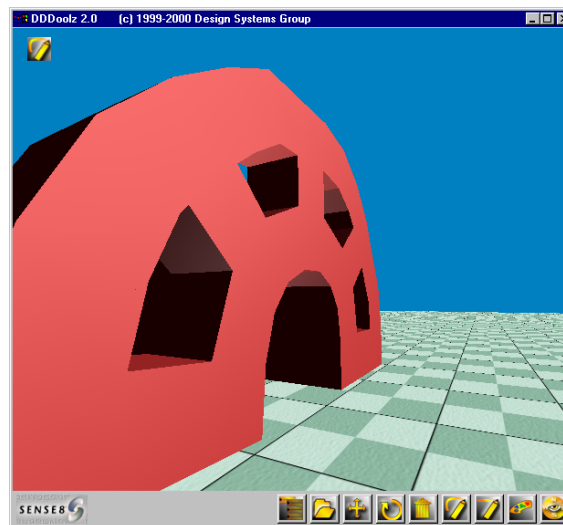

Figure 14.2: DDDoolz (version 2).

The software has also been used in an architect's office for evaluation purpose. The positive reaction and feedback on additional functionality has prompted the effort to find financing for the further development of the tool. Later additions to DDDoolz have added some aspects of gesture-based shape recognition and have restyled the user interface. In all cases, DDDoolz proved the validity of the concept of the minimal user interface and a simple and direct approach to design.

14.5 Conclusion

The Design Systems group has an active interest in design research focused on computational design support. The research and development work on design aid systems in the VR-DIS programme needs to have a foundation in an understanding of design. For these reasons, the Design Systems group has organised a number of activities in the field. These include: Design Research in the Netherlands (1995, 2000), Design Education in the Netherlands (1997), Design Futures (1999), Ontwerpend Leren – Leren Ontwerpen (2000), and together with Shauna Mallory-Hill a Case-Based Design workshop (1998) with Professor Mary Lou Maher as guest speaker. The group will organise and host the CAAD Futures 2001 conference in Eindhoven (Vries, van Leeuwen and Achten 2001). In a broader context, John Carp has organised the Supervisor (1998) symposium, and the Themawijken symposium (to be held may 2001), and has been involved as advisor in a historical overview of the SAR (Bosma et al 2000).

The work on Feature Based Modelling has provided a methodology for capturing design processes in a formalism that is understandable to a computer system. The formalism also provides a very detailed way to study design processes. Mechanisms can be defined that play a role in design processes. As a result, there will be a formalised description that can run on a computer, which provides one viable explanation of a design process. The question whether such a description holds for the actual cognitive processes of a designer must be left open here.

14.6 References

Achten, H.H. (1997). *Generic Representations – An Approach for Modelling Procedural and Declarative Knowledge of Building Types in Architectural Design*, Ph.D. thesis. Bouwstenen 46. Faculteit Bouwkunde. Eindhoven University of Technology, Eindhoven.

Achten, H.H. and Mallory-Hill, S.M. and Vries, B. de (1998). *Workshop Case Based Reasoning and Design – featuring prof. Mary Lou Maher*, Design Systems Report 1998/2, Faculty of Architecture, Building, and Planning, Eindhoven University of Technology.

Achten, H.H. and Roelen, W.A.H. and Boekholt, J.T. and Turksma, A. and Jessurun, J. (1999). Virtual Reality in the Design Studio: The Eindhoven perspective, in: Brown, A. and Knight, M. and Berridge, P. (eds.) *Architectural Computing - Turing to 2000. Proceedings of the 17th eCAADe Conference.* 15th-17th September, Liverpool.

Achten, H.H. and Turksma, A. (1999). Virtual Reality in Early Design: The Design Studio Experiences. Nys, K. and Provoost, T. and Verbeke, J. and Verleye, J. (eds.) 1999, *AVOCAAD Second International Conference*, pp. 327-335.

Achten, H.H. and Leeuwen, J.P. van (1999). Feature-Based High Level Design Tools – A Classification, in: Augenbroe, G. and Eastman, C. (eds.) *Computers in Building. Proceedings of the 8th International Conference on Computer Aided Architectural Design Futures held in Atlanta, Georgia, USA on june 7-8, 1999*, Kluwer Academic Publishers, Dordrecht, pp. 275-290.

Achten, H.H. (2000). Design Case Retrieval by Generic Representations, in: *Proceedings of AID 2000 – Sixth International Conference On Artificial Intelligence In Design*, Worcester, pp. 373-392.

Achten, H.H. and de Vries, B. and Jessurun, J. (2000). DDDoolz – A Virtual Reality Sketch Tool for Early Design, in: *Proceedings of CAADRIA – The Fifth International Conference on Computer-Aided Architectural Design Research in Asia*, Singapore, pp. 451-460.

Boekholt, J.T. (2000). *Ontwerpend Leren – Leren Ontwerpen – Een Boekje Voor Iedereen Die Iets Wil Leren over Ontwerpen of die Ontwerpprojecten Moet Begeleiden*. Bouwstenen 57. Faculteit Bouwkunde. Technische Universiteit Eindhoven.

Bosma, K. and Hoogstraten, D. van and Vos, M. (2000). Housing for the Millions: John Habraken and the SAR (1960-2000), NAi Publishers, Rotterdam.

Coomans, M.K.D. and Achten, H.H. (1998). Mixed Task Domain Representation in VR-DIS, in: *Proceedings of the 3rd Asia-Pacific Conference on Human Computer Interaction, APCHI'98*, Shonan village Center, Japan, July 15-17, 1998.

Coomans, M.K.D. and Timmermans, H.J.P. (1998). A VR-User Interface for Design by Features, in: Timmermans, H. (ed). *Proceedings of the 4th International Conference on Design and Decision Support Systems in Architecture and Urban Planning*, Maastricht.

Coomans, M.K.D. (1999). A Virtual Reality User Interface for a Design Information system. *CCAI : The Journal for the Integrated Study of Artificial Intelligence, Cognitive Science and Applied Epistemology*, Rijks Universiteit Gent, Belgium.

Dijkstra, J. and H.J.P. Timmermans (1997). The Application Of Conjoint Measurement As A Dynamic Decision Making Tool in a Virtual Reality Environment, in: Junge, Richard (ed.) 1997, *CAAD futures 1997. Proceedings of the 7th International Conference on Computer Aided Architectural Design Futures held in Munich, Germany, 4-6 August 1997*. Kluwer Academic Publishers, Dordrecht, pp. 757-770.

Dijkstra, J. and H.J.P. Timmermans (1998). Conjoint Measurement and Virtual Reality: A Review, in: Timmermans, H.J.P. (ed.) *DDSS 98 - Proceedings of the 4th International Conference on Design and Decision Support Systems in Architecture and Urban Planning Conference*, Maastricht.

Groot, E.H. de (1999). *Integrated Lighting System Assistant*. Bouwstenen 56. Ph.D.thesis. Faculteit Bouwkunde. Technische Universiteit Eindhoven.

Kelleners, R.H.M.C. (1999). *Constraints in Object-Oriented Graphics*. Ph.D. thesis. Technische Universiteit Eindhoven.

Leeuwen, J.P. van and H. Wagter (1998). A Features Framework for Architectural Information, Dynamic Models for Design, in: Gero, J.S. and Sudweeks, F. (eds). *Proceedings of Artificial Intelligence in Design '98, Lisbon, Portugal, 20-23 July 1998*. Kluwer Academic Publishers, Dordrecht.

Leeuwen, J.P. van (1999). *Modelling Architectural Design Information by Features*. Bouwstenen 54. Ph.D. thesis. Faculteit Bouwkunde. Technische Universiteit Eindhoven.

Oxman, R.M. and Bax, M.F.Th. and Achten, H.H. (1995). *Design Research in the Netherlands – A Symposium Convened by Design Methods Group and Information Technology for Architecture*, January 1995. Bouwstenen 37. Faculteit Bouwkunde, Eindhoven University of Technology.

Verbeke, J. and Achten, H. and Provoost, T. and Verleye, J. and Nys, K. and Pittioni, G. and Asanowicz, A. and Jakimowicz, A. and af Klercker, J. and van Zutphen, R. and Turksma, A. (2000). AVOCAAD – A Framework and Website for Teaching CAAD, in: Donath, D. (ed.) *Promise and Reality: Proceedings of the 18th Conference on Education in Computer Aided Architectural Design in Europe*, Weimar, pp. 101-104.

Vries, B. de (1996). *Communication in the Building Industry – A Strategy for Implementing Electronic Information Exchange*. Bouwstenen 38. Ph.D. thesis. Faculteit Bouwkunde. Technische Universiteit Eindhoven.

Vries, B. de and Jessurun, A.J. and Kelleners, R.H.M.C. (2000). Using 3D Geometric Constraints in Architectural Design Support Systems. In: *Proceedings of the 8-th International Conference in Central Europe on Computer Graphics, Visualization and Interactive Digital Media 2000*, University of West Bohemia, Czech Republic, February 7 - 10, 2000.

Vries, B. de and Leeuwen, J.P. van and Achten, H.H. (Eds.) (2001). *Computer Aided Architectural Design Futures 2001: Proceedings of the Ninth International Conference held at the Eindhoven University of Technology, Eindhoven, The Netherlands, on July 8-11, 2001*, Kluwer Academic Publishers, Dordrecht.

Wijk, J.J. van and Vries, B. de and Overveld, C.W.A.M. (1999). Towards an Understanding 3D VR Architectural Design System. *TWI workshop on Virtual Environments*. Enschede.

Smeets, J. and Jessurun, J. and Zutphen, R. van (2000). An Application of the REN Manager in the Field of Housing Management, in: Timmermans, H. (ed.) *Proceedings of the 5th International Conference on Design and Decision Support Systems in Architecture*, Eindhoven, pp. 341-352.