

# Design research in the Netherlands 2005 : proceedings of the symposium held on 19-20 May 2005, Eindhoven University of Technology

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Henri Achten, Kees Dorst, Pieter Jan Stappers, Bauke de Vries  
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# A Decade of Design Research in the Netherlands

Henri Achten, Kees Dorst, Pieter Jan Stappers, Bauke de Vries

## 1. The changing focus of design research

Design Research in the Netherlands 2005 is the third instalment of a symposium that intends to provide a forum for researchers across the academic and designing disciplines. The five-year interval (1995, 2000, and 2005) allows participants to take a step back from daily considerations and to reflect on their basic methodological assumptions, research programmes, and outcomes. It also provides us with the opportunity to witness the dynamics in organisations that are usually less apparent in annual or bi-annual meetings. Over the three proceedings of the symposium, we can see groups merge, split up, change names, being created, or disappear. The same applies to research programmes. Apart from the general academic dynamics (baffling as these sometimes may appear), do these changes reflect some more fundamental movements within the field of design research?

In the proceedings of 1995, Robert Oxman noted two major orientations of design research: the design cognition orientation which leaned very much on protocol analysis, and the computational models orientation which leaned very much on information processing theory (Oxman 1995). Either orientation was grounded in a variety of theories to guide inquiry. At the risk of oversimplifying, one can defend that many considered at the time an overarching theory or vision ‘what design is’ feasible. Today, this does not seem to be the case anymore, so a shift in understanding must have occurred in the meantime. Perhaps one of many possible answers lies in the formative role that Rational Problem Solving and computation played in design research.

The impact of Rational Problem Solving (RPS) and computation on design research is hard to overestimate. It is fair to say that much of the rigorous, methodological, and scientific content of design research has come into being just because of the concepts and framework introduced by RPS and computation. They proved a liberation from the mainly introspective and “beaux-arts”-traditional body of knowledge on design as present up to that period. Design methodology was introduced to solve immediately present large technical challenges for which there was no time to evolve approaches and typology in the traditional way (a point well-put in Jones 1980:27-34).

On the other hand, by being so successful, RPS and computation “jumped to solutions,” so to speak, rather than introducing time for self-reflection. This seems to be a recurring challenge with innovations, to strike a good balance between keeping the existing and trying the new. Only through confrontation with practice is it possible to learn the value of a new approach, while on the other hand one has to keep in mind the whole context of the problem area. One can note that the applied work of RPS was often performed under (wilful) ignorance of other, sometimes more traditional, ways of working. To be fair, the vast amount of work on RPS yielded a wealth of techniques to tackle all kinds of problems (see Michalewicz and Fogel (2000) for a fine collection), but somehow it seemed that design problems always redefined themselves to stay just out of reach.

The most important victim of RPS's inability to tackle design problems adequately was design methodology. The limited scope of RPS led to the failure of design methodology, which has ever since been viewed with suspicion from the designing community (in particular architecture) – again, this is a simplified account; other considerations that played a role in the demise of design methodology are very well documented in Cross (1984:*Introduction*). Since then, there is a sharp understanding what design *is not* (problem solving), but it is still not clear what design *is*. To answer this, the discipline of design research broadened its view again.

For a long time the only serious contender as alternative to RPS was the work by Donald Schön on Reflective Practice (Schön 1983). This led to an often polarised debate between rational problem solving versus reflective practice-adherents. A lot of work has been done in particular by Dorst (1997; 2005: this book) to put both paradigms in perspective, and the work by Valkenburg (2000) and Reymen (2001) proved important for further structuring of Schön's concepts. The result is a more balanced appreciation when each paradigm is better suited to describe design activity, but it does not yield a unified view on design as such. One of the major contributions of Schön's work is the realisation that design does not proceed from a general breakdown of the problem in sub-problems (as advocated in RPS), but that the question 'what to deal with now,' is a repetitive framing action by the designer as he or she is working on the problem. Obviously, some framing steps can take place along the lines of RPS, but not necessarily so.

The renewed interest in the designer, the designer's situation, and the way the design is understood has led to a proliferation of research orientations that does justice to the varied and kaleidoscopic nature of design, but we are yet far removed from a general overview.

## 2. Where we stand now

Design research aims to clarify what design is, how designing proceeds, how it can be supported or improved, and to come up with a rigorous scientific body of knowledge to record this understanding. This academic rigour is often at odds with daily practice of designers. The field of design research has a responsibility to clearly communicate its findings to design practice; and vice versa, the professional community of designers has a responsibility to add in a systematic way to the body of knowledge of design. A mutual effort to understand each others position and modes of argument is necessary for this to succeed. The requirements of scientific rigour often leads to a discarding of reflection produced in the designers practice. This is an omission: there is a wealth of theoretical and anecdotal material published by designers on their work. To be true, a sizeable portion of this output is irrelevant, vaguely put, misleading, or outright mistaken, and it is not easy to sieve through it all. Again, here lies a responsibility in the professional community. A comfortable and sensible integration of professional fluidity and scientific rigour has not been established in either design research nor design practice. This is a point of continuing concern.

### Design research

The papers of this book in the first part – termed *Design Research* – address the tension between rigorous description of design and bringing the designer back in the picture. This is a theme in the papers by Kees Dorst (pp. 1-12), Petra Badke-Schaub et al. (pp. 23-31), and Jack Breen (pp. 33-48) although each argues from a different viewpoint. Dorst offers a preliminary categorisation of levels of expertise as a framework to study the associated forms of design reasoning at each level. Badke-Schaub proposes a three-track research programme which brings together the

empirical, theoretical, and applied levels of design research. Breen discusses the matter from the practical perspective of the designer faced with the question how to integrate research in his or her design work. Complementing these three papers are the philosophical work by Pieter Vermaas et al. (pp. 13-22) and the survey of design studies by de Jong (pp. 49-54). Vermaas et al. do not claim that their notion of ‘use plan’ has prescriptive value, but that it functions very well as a retrospective device for understanding what is going on in design. In this sense, their work also respects the distance between theory and practice, and thus leaves room for more subjective working methods. De Jong surveys the many ways of studying design at the Faculty of Architecture in Delft and comes up with a great variety of approaches. The concept of ‘context’ provides the organising principle for grasping the various approaches presented in the survey.

### Design processes

From the contributions presented in the second part of this book – termed *Design Processes* – we can infer that design methods are making a come-back. All of the papers presented here are from the domain of building and construction industry. This is not surprising, as this industry is facing many challenges in the light of complex multi-organisational design problems under pressure of sustainability. Time-tested team organisations and structuring of the design problem are no longer feasible. Mistakes lead to high costs, losses, and eventually poorly performing buildings. In this context, a more fundamental reflection on improved design processes pays off and matters to the end result.

A fundamental reflection on improved design processes requires a more comprehensive view than ‘just’ design methods, as can be seen from the managerial overview offered by Reymen et al. (pp. 55-61). Their focus is on a balanced study of aspects of design management *and* demand and supply. Concerning the aspect of design management, three authors in particular stress collaboration as a means to tackle the complexity of the design task: Frans van Gassel (pp. 63-70), Rudi Stouffs et al. (pp. 85-94), and Wim Zeiler et al. (pp. 95-107) although the latter prefer the term *integral design methodology*. Collaboration as such is not a method, but it pays particular attention to an equal share of all participants in the design process, and aims to improve the outcome of the design process by making specialised knowledge earlier available to all participants. As a specific illustration of this strategy, Vreenegoor et al. (pp. 109-119) demonstrate how the specialised knowledge of comfort and physical aspects of interior climate can be brought to non-specialists. Al Hassan et al. (pp. 71-84) get closest of all papers towards a methodology for *strategic concept generation*. Their work relies on a comprehensive account of values, senses, and levels of scale to generate structures that may further drive the design process.

### Design tools

Continuing a trend already noticed in the previous DRN proceedings, there is a substantial amount of work that aims to support design by offering *Design Tools* – the final part of this book. This work is invariably linked up with computation, since this provides the only responsive medium through which design information, actions of the designer, and subsequent consequences can be processed. It has proven a successful combination since the application of computation presupposes a formalisation of design(er) knowledge – although in all fairness one has to note that having a formalism alone is insufficient for producing sensible results. Koutamanis (pp. 169-177) puts forward a genealogy of CAAD which carefully traces the development from the early 1960’s to today. He provides a reasoned account how the chair in Delft has evolved in the past five years, in close reflection to changes in the field in general.

Computer Aided Design balances between *technology-exploration*, *computation theory*, and an *understanding of the designer*. The emphasis on one or more of these aspects characterises the kind of work produced in this area. De Bruin and Scha (pp. 121-129) and Stouffs (pp. 131-137) show work which has an emphasis on computation theory, in particular on formal languages. The work presented by La Rocca and van Tooren (pp. 139-153), van Nederveen (pp. 155-167), and Steijns and Koutamanis (pp. 179-191) are oriented from the technology exploration aspect. La Rocca and Van Tooren present a comprehensive system to generate design concepts for aircraft design. Van Nederveen provides a showcase of applied research projects combined with a grounding in more fundamental aspects of information technology. Steijns and Koutamanis present applied research in the area of school building design and management. To conclude, Pasman et al. (pp. 193-204) and de Vries et al. (pp. 205-214) primarily are designer oriented – both groups do this by focussing on the more cognitive and experiential aspects of design, and develop tools that are meant to enhance the creativity or awareness of design(ers).

### Research and methodology

The proliferation of research orientations has come with the loss of an overarching vision or framework in which researchers can piece together the evidence to come up with a picture of ‘what design is.’ In terms of research methodology, we can also see an increase of research techniques without yet a good way of integrating findings from such work. What a future theoretical and methodological framework might look like, is difficult to assess. One question in all cases is whether design research has to look for knowledge or concepts from other research areas to find the missing pieces of the puzzle. If so, then a likely candidate may be *decision-making under uncertainty*, which has seen a lot of research from psychology on how people argue and reason (see for example Baron 2000). Another candidate domain may be *agency* and *multi-agent systems* to provide the formal tools to understand and model group processes and communication (Weiss 2001); and in recent years we have seen work informed by the social sciences, which in particular shed light on the interpersonal dynamics of design (e.g. Lloyd and Busby 2001; 2003).

## 3. Design research and industrial design

The past decades have shown an increasing role of research in the processes of industrial design, an increasing visibility of design research for practitioners, especially in the human-product interaction fields that have come to fruition in the areas of Computer-Human Interaction, and an increased awareness of the role that designers can play in research programmes.

The first of these developments is witnessed by the growth of BSc and MSc programmes at all technical universities in the Netherlands. In the past five years, both TU’s at Eindhoven and Twente have started Bachelor’s and Master’s programmes in Industrial Design, with focuses on intelligent and mechanical products respectively, and Delft’s Faculty of Industrial Design Engineering has diversified its existing Master programmes into three master programmes with emphases on business strategy, user-product interaction, and general product design, respectively. At all these institutes, the master programmes are linked to existing, or newly formed, research groups on the respective topics, which holds the promise that a richer design research culture in the field of industrial design will develop in the coming years.

The second development is an increased visibility of design research and methods reflection in the field of Computer-Human Interaction. As has happened with many other fields, the computer science managed to create a visible forum for other domains. Especially now that

computers have become the ubiquitous tools of the professional thinking person (over the past ten years we witnessed the transition from occasional use to almost exclusive use of computers as tools) and their form is at the same time disappearing into products, we see increasing overlaps of these research communities. Much of the work in this area doesn't really fit in either the RPS approach or the classical beaux-arts approaches, but is a third, pragmatic, approach, focused around development of tools and methods (Fallman 2003). Exemplary in this area is the tools development work of Mark Gross (keynote speaker in DRN 2000), work at ID-StudioLab (Pasman et al., this book), showing a particular mix of designing, design research and research in the growing list of contributing disciplines, among which psychology and ethnography have become very visible in recent years.

The third development, linked to the other two, is the increased attention in general for the activity of designing as an important part of research itself. Designers are more and more finding their way as key players in research programmes in industries and universities. This reflects and supports the societal need for multidisciplinary research projects centred around phenomena (and ways to make them pay) rather than strict development of theories. Moreover, the solution-oriented mindset of designers lends itself especially for strengthening the generative part of research projects (whereas traditional research education focuses often on evaluative skills). Taken together, we are witnessing a very interesting period in the visibility of design as an academic discipline, a diversification and – hopefully – integration of different types of design research, and an emancipation of designing as an important ingredient in research.

#### 4. Design research and education

Design research is required for establishing a body of knowledge on design that serves professionals as well as the education of students to become designers. In this sense, design education is the main 'market' for the knowledge that design research generates. Consequently, one would expect a close interaction between design research and design education – but alas, that does not seem to be the case. There is a surprising but persistent gap between the knowledge generated in design research and the practice of design education. We will argue here that this is caused by the assumptions that design researchers build into the construction of their theories of design. Some of these assumptions may be inevitable, but we will try to argue that others should be candidate for careful reconsideration over the coming years.

Of course it is in the very nature of constructing any design model or theory, that in doing so we abstract from design practice. In abstracting, we effectively are 'putting things between brackets,' leaving them out because there are other points we want to concentrate on. For instance, much of design research has traditionally been focussed on the dynamics of design *processes*, and has not dealt with the other factors in design (the designer(s), the nature of the specific design problem at hand, and the circumstances in which the design project takes place). Those other factors have really been put between brackets. This is fair enough, but design theories that do focus exclusively on the design process in such a way often claim that, because of this, they are applicable to *any* designer, for *any* design problem, and under *any* circumstances. Just the fact that the design theorist abstracted away from these factors is used as the basis for this claim.

This is a very harmful logical fallacy, that results in a terrible overstatement of the width and applicability of such design process models and methods. And it is in design education that the consequences of this overstatement are most keenly felt. Because in design education, all these factors that the researcher put between brackets in his effort to arrive at an elegant model

or theory of design processes, come back to haunt you. That is why we cannot teach ‘design’ by just teaching our students design process models and methods: the students need to work on a very broad range of design assignments, not so much to train them in the process of design, but to train them in dealing with the factors that the process models and methods do *not* deal with: their own identity as a designer, a real understanding of how to approach specific (unique) design problems, and the adaptation of their way of working to the circumstances that can have such a overriding impact on the practice of design (clients, resources, time constraints, etc). The design assignments require staff to tutor the students on the aspects that design methodology does not deal with.

This can be a real source of frustration for design tutors: the overstated claims of design theory are eagerly taken up in design schools, because they represent an own ‘science’ that thinking about design should be based on. As a consequence, whole design curricula are organised around the teaching of the design process, not around the teaching of ‘design.’

There are two things that urgently need to be done if we want to repair this situation: (1) all design models and methods should clearly state their ‘area of applicability’ and not just claim to describe, explain or prescribe the whole world of design, and (2) the range of factors that is taken into account in the making of design models should broaden considerably.

The good news in this edition 2005 of Design Research in the Netherlands is that the design researchers that present their work here are clearly working towards these goals. Many of the papers in this book already profess to deal with a specific, more modest range of design problems or design situations. And most importantly: the complete set of papers takes an impressive array of factors in the design situation into account. Apparently, these design researchers are finally moving beyond their exclusive focus on the design process. This will enrich design research enormously, and make the models and methods that design researchers develop much more realistic in the years to come.

This richness and realism in design models and methods will then make them much easier to apply in design education. Through this development, the rift between design research and design education will finally disappear.

## 5. Design research and information technology

Information Technology (IT) is providing tools not only for doing design research, but also for supporting the design process itself. Design research has a much longer tradition than IT. In fact part of the design research presented at this symposium is not related to IT at all, but many researchers are challenged by new computer technologies. The last decade we are faced with new technologies at such speed that there is no time to thoroughly research their potentials. In this book we present an almost complete overview of researchers from the academic institutes from the Netherlands that make this effort. Since the appreciation of the designer for the developed new technology plays such a crucial role, IT related research usually includes the development and/or application of prototypes. Such research is very time consuming but absolutely necessary to make steps forward in this process. The adoption by design software industry is yet another very complicated and often slow process. We are almost used to working with inadequate, error prone, not task-specific design tools. In design research we can notice and experience that better design tools are possible – and much appreciated! Designers in collaboration with IT engineers are needed to develop these tools. It is very promising to observe that these collaborations are established at many research institutes.

Next to the role of IT as a driving research factor, it also provides methods as a common ground for different disciplines. At the DRN symposium we welcome researchers from design and engineering disciplines. Traditionally designers are less skilled in using formal methods than engineers. Therefore there is a serious risk of lack of involvement of designers in the research of new IT applications in design. Absence of designers in the development of new design tools undoubtedly will lead to bad design tools. Again collaboration between the disciplines will prevent these mistakes. In the DRN proceedings you will find many good examples of fruitful collaborations.

## 6. Conclusion

Just before the Call for Papers for the DRN 2005 symposium, Design Systems conducted an Internet-based survey of institutions and researchers who state they are involved in some way with design research. The survey was based on a list of the 16 universities of the Netherlands, and the information offered on their websites (see [www.designresearch.nl/DRN\\_links.htm](http://www.designresearch.nl/DRN_links.htm)). It appears that at 10 universities in some 34 Faculties (or similar organisation level unit) in 88 groups one can find some kind of interest in design(ing). In many cases, and this seems to be a structural feature, this interest is found on the personal level or in a running research project. Design research as an autonomous domain is seldom reflected in the existence of a dedicated design research group. It seems fair to conclude that design as such is acknowledged as an important factor, but that either design as an activity is taken for granted or not reflected upon. Hopefully, initiatives such as the Design Research in the Netherlands symposium and the website Design Research in the Netherlands ([www.designresearch.nl](http://www.designresearch.nl)) can give a positive stimulus to a more profound exchange of thoughts in the domain of design research.





## **Part One: Design Research**

### **1      Studying Design Problems**

Kees Dorst

### **13     A Philosophical Analysis of Designing**

Pieter Vermaas, Wybo Houkes, Jeroen de Ridder

### **23     Human-Centered Design Methodology**

Petra Badke-Schaub, Peter Lloyd, Remko van der Lugt, Norbert Roozenburg

### **33     Design, Designerly Enquiry and Design Research**

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### **49     Ways to Study and Research Urban, Architectural and Technical Design**

Taeke de Jong



# Studying Design Problems

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## 1. Introduction

This paper reports on a research project that has been running at the Eindhoven University of Technology. First at the department of Philosophy (within the Faculty of Management and Innovation Sciences) and later at the Designed Intelligence research group at the Faculty of Industrial Design. The paper will set out, briefly, by discussing the original starting points of the project (section 2), and it will go on to describe the core steps in the intellectual journey that the project has turned into.

The subject of study was the structure of design problems, and the philosophical notion of ‘underdetermination’ has taken as a possible fruitful concept to make some inroads into this huge and uncharted territory. The project was, naturally, started with the studying of relevant literature and the making of an inventory of our knowledge on design problems (as ill-structured problems, as underdetermined problems) and of the way in which the design methodology has dealt with design problems, in the broader context, of the modeling of design processes (section 3). This has not turned out to be a very fruitful approach to the issue of design problems. Therefore, an interest was developed in some other theories on how designers deal with their problems, specifically focusing on describing design problems as situated problems (section 4).

The inherent subjectivity of design situations has lead to a study in how we could capture and describe the way a designer builds up a view of the situation, and responds to this situation. A fairly coarse, but interesting approach to characterizing and describing the way designers build-up a view on a design situation was found in the work of Dreyfus, where he models the levels of expertise in which a designer operates (section 5). In the last section we will summarize our conclusions on the study of design problems, reflecting on the role that philosophical investigations can play in Design Methodology, and sketch proposals for further research into design problems and design expertise (section 6).

## 2. Starting point: studying ‘Design and Underdetermination’

The idea for starting this research project was born out of the need to provide a link to design methodology for the NWO program ‘The Dual Nature of Technical Artefacts’. This NWO program is jointly run by Delft University of Technology and Eindhoven University of Technology. The overall aim of this research program is to develop a coherent conceptualization of technical artefacts:

*In our thinking, speaking and doing we employ two basic conceptualizations of the world... On the one hand, we see the world as consisting of physical objects interacting through causal connections. On the other hand, we see it as consisting of agents who intentionally represent the world and act in it.... Correspondingly, technical*

*artefacts have a Dual Nature: they cannot exhaustively be described within the physical conceptualization, since this has no place for their functional features, nor can they be described exhaustively within the intentional conceptualization, since their functionality must be realized in a physical structure that is adequate to it...*' (Kroes and Meijers, 1999)

The core of this philosophical research program is an analysis of the link between physical structure and the functions of artefacts. One of the ways to inform this analysis is to study the process in which designers and engineers connect function and structure in the design process. A special area of interest within this domain is the way in which designers and engineers deal with the inherent *underdetermination* of design problems. The concept of underdetermination also plays an important role in the philosophy and methodology of science – underdetermination was selected as an area where the methodology of design and the methodology of science might cross each other's path in an interesting way.

But what do we mean with 'underdetermination' in the context of design? Design activities can be seen as the reasoning from a set of requirements and intentions to a new bit of reality, consisting of a (physical) structure and an intended use. This process of reasoning is abductive: there is no closed pattern of reasoning to connect the requirements and intentions with a form and mode of use (Simon 1973; Rittel 1972; Cross 1999). Design problems are thus fundamentally underdetermined in the sense that the set of requirements and intentions can never be stated in such a way that the creation of its solution can be a deductive process. This underdetermination actually takes two forms: as stated, a functional description can never be complete, and secondly, 'Function' and 'Form' belong to fundamentally different conceptual worlds. But despite these fundamental problems, designers nonetheless, somehow, overcome this underdetermination of design problems in their design processes. This is a gradual process, involving many steps, which are performed in patterns ('design strategies').

This research project investigates how designers overcome the underdetermination of design problems. It takes place within the realm of Design Methodology, and is, thus complementary to the core NWO program, which is philosophical in nature. For the researcher, a design methodologist of the empirical bend, one of the main interests in embarking on this ambitious project was to explore how philosophers deal with design related issues, and investigate how the two fields of Philosophy and Design Methodology can be connected to one another, or maybe complement each other in a way that is inspiring and fruitful to both fields.

### 3. The structure of design problems

The first hurdle we have to take, in the study of underdetermination, in design is that the notion of underdetermination itself is a negative one: it describes the absence of connections, the lack of a structure in a design problem. How can we find a good way to describe something that is not there? Do we need to describe the structure or unstructuredness? The study, initially, concentrates on exploring the *structure* of design problems, as design problems have always been something of a blind-spot in Design Methodology: the focus in Design Methodology has almost exclusively been on the support of the *process* of designing. But any method for aiding design activities necessarily contains statements or assumptions from all three 'dimensions of design activities': the dynamics of a design process, the designer and the design problem (Dorst 1997). Within Design Methodology, the nature of design problems has been described as 'ill-structured,' or even 'wicked' (Rittel et al. 1984), but little more has been said. Some process-focused design methods however, seem to incorporate strong assumptions about what design problems are (e.g. concerning the independence of sub-problems, the objectivity of problems, the possibility to

create an overview of a design problem, etc). We know that this blind spot for design problems is hampering the development of design methodology. Design problems may be weak in structure, but it is really important to find out what structure they have as a starting point for the construction of taxonomic design problems. Such taxonomy will help Design Methodology to attain a much-needed new level of precision in its descriptions and prescription (i.e. if we have a well-established taxonomy of design problems, we could also start defining which design method or design technique would be appropriate to use by solving a particular type of design problem...). If we can find a way to trace the structure of design problems, we can then match that to the way designers tackle those problems, then this will lead to a much closer description and a much better understanding of the way designers work, and *why* they take the actions we see.

Our initial investigation into design problems focuses on two questions:

1. What can we find in Design Methodology about the structure of design problems? This will focus on the existing descriptions in Design Methodology of design problems as ‘ill-structured problems,’ as ‘underdetermined problems’ and on the way design problems are treated within the two paradigms of Design Methodology. This will lead to the second research question:
2. How can we further develop (i.e. combine) these approaches into a comprehensive study of structure design problems? As mentioned, we will take the (philosophical) notion of underdetermination as a starting point for these investigations.

### Underdetermination

In Design Methodology literature, we find very little about underdetermination as such (the term is not in common usage), but studying the statements about design problems in research papers and textbooks, we can conclude that one of the problems designers face in tackling their design problems is this, because design problems are not completely determined, but also not completely free (Dorst, 2001). Most design problems in fact seem to have a threefold nature:

- They are partly *determined* by ‘hard’ (unalterable) needs, requirements and intentions. A designer will have to reserve time in the early part of his design process to unearth these ‘hard facts’ by information gathering and analysis, and live with these specifications. This information can be seen as a necessary input at the start of the design process, and this type of interaction can very well be described and modeled within the rational problem-solving paradigm.
- But a major part of the design problem is *underdetermined*. The interpretation of the design problem and the creation and selection of possible suitable solutions can only be decided during the design process on the basis of proposals made by the designer. These proposals thus entail both the possible interpretations of the design problem and possible solutions to those problems.
- Part of the design problem can be considered *undetermined*, in the sense that the designer is to a large extent free to design according to his own taste, style and abilities (it is, of course, not the case that the designer would never have to defend these aspects of the design to others, but in these areas the designer is dominant, in the sense, that he also provides the criteria on which this aspect or part of the design is to be judged).

### Ill-structured problems

A second way of describing design problems, that is much more explicitly discussed in Design Methodological literature, and can even be said to loom large over our thinking about design, is the idea that design problems are ‘ill-structured.’ In his seminal paper ‘The structure of ill-structured problems’ (1973), Herbert Simon also starts out his description of ill-structuredness by looking for positive structure. He defines well structuredness by six criteria:

- There is a definite criterion for testing any proposed solution, and a merchandisable process in applying the criterion.
- There is, at least, one problem space in which can be represented the problem state, the goal state, and all other states that may be reached, or considered, in the course of attempting a solution to the problem.
- Attainable state changes can be represented in a problem space, as transitions from given states to the states directly attainable from them.
- Any knowledge that the problem-solver can acquire about the problem can be represented in one or more problem spaces.
- If the actual problem involves acting upon the external world, then the definition of state changes and of the effects upon the state of applying any operator reflect with complete accuracy in one or more problem spaces the laws that govern the external world.
- All of these conditions hold in the strong sense that the basic processes postulated require only practicable amounts of computation, and the information postulated is effectively available to the processes-i.e. available with only practicable amounts of search.

Lawson (1990), Roozenburg (1991) and others have held that design problems don’t adhere to the first two basic criteria for well-structuredness, and therefore cannot adhere to the others either.

### Design problems and the paradigms of Design Methodology

We will now explore the way ill-structured problems have nevertheless been described by Simon in the context of his view of designing as a rational problem solving process.

The main paradigm of design methodology, in which design is seen as a *rational problem solving* process, was introduced by Simon in the early 1970s. In this paradigm, design is viewed as a rational search process: the design problem defines the ‘problem space’ that has to be surveyed in search of a design solution. Problem solving theory is concerned with the ways in which people or artificial systems arrive at solutions to problems they encounter. This theory can be captured by four propositions:

- A few gross characteristics of the human Information Processing System are invariant over task and problem solver.
- These characteristics are sufficient to determine that a task environment is represented as a problem space, and that problem solving takes place in a problem space.
- The structure of the task environment determines the possible structures of the problem space.
- The structure of the problem space determines the possible programs that can be used for problem solving. (From: Simon 1969; 1992).

If this theory is valid for design, design problem solving will also take place within a problem space that is structured by the structure of the task environment, which in it’s turn determines the ‘programs’ (strategies or methods) that can be used for designing. In a later paper Simon

addressed some of the difficulties that might arise in applying the rational problem solving approach to design by defining design problems as ‘ill-structured problems.’ Ill-structured problems are to be tackled in an ‘immediate problem space.’ This is part of the total problem space, which is deemed too large, ill-structured and ill-defined to be described. The immediate problem space is addressed and put together by an (unspecified) ‘noticing and evoking mechanism.’ The basic ‘design’ problem-solving process would however be basically the same as in other kinds of problem solving. With the exception that the goal of a design process is to arrive at a solution that is ‘good enough,’

*‘we satisfy by looking for alternatives in such a way that we can generally find an acceptable one after only moderate search.’*

A radically different paradigm was proposed fifteen years later, by Donald Schön (1983), who describes design as an activity involving *reflective practice*. This constructionist theory is a reaction to the problem solving approach, specifically made to address some of the shortcomings Schön perceived in mainstream design methodology. Schön’s starting point is his feeling that the paradigm of technical rationality hampers the training of practitioners in the professions. He believes that the design-component of the professions is underestimated, and that the nature of human design activities is misunderstood. He shows that in the training programmes of professional schools, that recognize design as a core activity, design knowledge is defined in terms of generalities about design processes and declarative knowledge is needed to solve design problems. No attention is paid to the structure of design problems and the crucial problem of linking process and problem to a concrete design situation. This ‘action-oriented,’ often implicit knowledge, cannot be described within the paradigm of technical rationality. But Schön insists that this kind of knowledge is vital for action-oriented professions like design. He does recognize, however, that this implicit ‘knowing-in-action’ is difficult to describe and convey to students. What can be thought about, and taught is the explicit reflection that guides the development of one’s knowing-in-action habits. This he calls *reflection-in-action*.

One of the basic assumptions of the theory of technical rationality is that there is a definable design problem to start with. Schön remarks that:

*‘... Although Simon proposes to fill the gap between natural sciences and design practice with a science of design, his science can only be applied to well-formed problems already extracted from situations of practice...’*  
(from: Schön 1983)

Schön, on the other hand, does not make any such assumptions about the design problem. The description of design, as a reflective conversation, concentrates on the structuring role of the designer, setting the task and outlining possible solutions all in one ‘framing’ action. The strength of this framing action determines the amount of structure in the task. In reflective practice, design tasks may be analysed and subdivided into a number of different ways, and there is no *a priori* way to determine which approach will be the more fruitful. Therefore, design task and solution are always and inherently developed together. Schön thus seems to ignore the possible structure that design tasks and solutions might have, although he gives a table of ‘Normative Design Domains’ in ‘The Reflective Practitioner’. These ‘Normative Design Domains’ could provide a categorization for the description of design tasks, but unfortunately these domains are not connected to the core theories of reflective practice, and they are never mentioned again. Schön’s failure to link the theories of reflective practice to a model of design tasks means that descriptions of design activities within this paradigm can not benefit from any structure that might be present in the design task. Design problems are then ill-structured, because the designer treats them as such.



#### 4. Design problems as situated problems

Both these paradigms can be used to describe a design process. In some cases, the rational problems solving paradigm is more appropriate, in other cases the reflective practice paradigm will do more justice to what the designer is doing (Dorst 1997). This is not a very satisfactory conclusion: design gets something of a dual (schizophrenic) nature, and the relationship between the two fundamentally different ways of looking at design is not really clear. Any taxonomy of design problems that is based upon these paradigms will reflect this uneasy schism. Moreover, any *a priori* taxonomy of design problems will focus on describing different structures of reasonably determined problems. This is inevitable, because any taxonomy is based on the patterns in the network of connections between sub problems. This will not get us very far. To really capture design, we also need a taxonomy of underdetermined problems. But neither the rational problem solving approach nor the reflective practice approach gives us a foothold for that. To answer this question we will have to delve a bit deeper into the nature of underdetermination, and develop an approach in describing design that takes the situated nature of design problems into account.

In their paper, Dorst and Cross (2001) - have tried to find a way out of this dilemma by using an empirical study to take another step back. There is an assumption that underlies both paradigms, and that is that design is basically a reasoning process going from problem to solution. Within the *rational problem-solving* paradigm, the problem is objectively knowable. In the *reflective practice* paradigm the problem, in the guise of a *frame*, is a creation of the designer himself, who creatively interprets the ambiguity of the outside world. These images of design can be refined on the basis of empirical studies. If we take a closer look at design it seems to be a much more gradual process, like an evolution. It seems that creative design is not a matter of first fixing the problem (through objective analysis or the imposition of a frame) and then searching for a satisfactory solution concept. Creative design seems more to be a matter of developing and refining together both the formulation of a problem and ideas for a solution, with constant iteration of analysis, synthesis and evaluation processes between the two notional design 'spaces' - problem space and solution space. In creative design, the designer is seeking to generate a matching problem-solution pair, through a 'co-evolution' of the problem and the solution. The designer is busy adjusting both the design problem and the design solution. Our observations confirm that creative design involves a period of exploration in which problem and solution spaces are evolving and are unstable until (temporarily) fixed by an emergent bridge, which identifies a problem-solution pairing. This process can be described in detail, from the *rational problem solving* paradigm as well as the *reflective practice* paradigm. If we do this, the two ways of describing design will actually be very much alike. The only issue that really divides the two paradigms of design then are the two different epistemologies that they represent, positivism and constructionism (phenomenology).

This description of design as the co-evolution of problem and solution again points us toward the idea that in describing design, we cannot pre-suppose that there is something like a fixed 'design problem.' But if that is the case, can we still describe design if we let go of the idea that it is a process running from 'a problem' to 'a solution'? Again, we have to take a step back and look at the origins of our thinking about design, and revisit the implicit assumptions that might be bothering us...

The Rational Problem Solving paradigm and the Reflective Practice paradigm have both been developed in the 60's and 70's, largely inspired by developments in AI and the cognitive sciences. The epic endeavor to build intelligent computer systems focused on the ability of such a

system to solve ill-structured problems within an open context, somewhat comparable to designing. The systems were based on a Rational Problem Solving approach, representing the ‘relevant aspects’ of the world and setting up formal procedures that manipulate these representations to solve a problem. This approach has failed (Dreyfus 1992). Alternative approaches are now developed that are inspired upon the situatedness of problem solving activity (Varela 1991; Winograd 1986; Suchman 1987). We will, now, explore whether the consideration of design as a situated problem solving will help us get closer to a description of what structure design problems have. A fundamental choice that is associated with situated problem solving is that we are first and foremost interested in what design problems are to the designer, seen through the eyes of the designer, in the design situation. This means that we concentrate on the ‘local’ design problem that a designer faces, and bracket the ‘overall’ design problem as something of an abstraction (for now). So we will also have to confront the vagueness (i.e. lack of overview) and subjectivity that is involved in local design actions and decisions. Seen from this perspective, ‘the design problem’ as such does not really exist as an objective entity in the world. There is an amalgamate of different problems that centers around the basic challenge that is described in a design brief. This amalgamate of problems is partly there to be discovered by the designer in the design process, and part of it has to be *made* by the designer.

The process of ‘approaching a design problem’ or ‘dealing with a problematic situation’ becomes the vital clue to understanding what design problems are. The latter formulation is important: for much of the design project the problem solving steps can be quite logical, routine and implicit, without a real choice for the designer. Dreyfus holds that real problematic situations are the results of a ‘breakdown’ in this normal, fluent problem solving behavior (the problem becomes ‘at hand,’ in Heidegger’s terms (see Varela 1991). These ‘breakdowns’ then are the moments of real choice. It thus becomes very important to distinguish and describe the nature of these breakdowns, the critical situations in design (Frankenberger 1996). These breakdowns are the points that Schön describes as ‘surprises,’ the turning points in the designer’s reflective conversation with the situation. In the solution of these breakdowns ‘objective’ or ‘subjective’ interpretation can play a role. This is where the existing (but possibly implicit or unknown) structure of the design problem and the structuring actions of the designer meet. A well-structured problem ‘leads’ the designer (through deduction, or abduction with a clearly dominant result) to an ill-structured problem requires something like a framing action. These fundamental issues show that the study of the structure of design problems is not a straightforward affair at all. And that we just cannot develop a meaningful ‘objective’ taxonomy of design problems if we can be convinced by Dreyfus and others that it doesn’t exist, that there is never a (complete) representation of the design problem in the head of the designer. The only thing now left for us to study is the ‘local’ network of links that a designer considers while tackling a design problem in the design situation. The subjective nature of this local network of problems means that we need to have a model of how designers approach a problematic situation. In the next section we will discuss a model of design expertise that could be the basis for this.

## 5. Levels of expertise

To explore the levels of expertise we now turn to a lecture by Hubert Dreyfus (2002; 2003), in which he pointed out that the nature of the problem that is considered in a problem-solving situation depends on the level of expertise of the problem solver.

Dreyfus distinguishes seven distinct levels of expertise, corresponding with seven ways of perceiving, interpreting, structuring and solving problems:

- A *novice* will consider the objective features of a situation, as they are given by the experts, and will follow strict rules to deal with the problem.
- For an *advanced beginner* the situational aspects are important, there is sensitivity to exceptions to the 'hard' rules of the novice. Maxims are used for guidance through the problem situation.
- A *competent* problem solver works in a radically different way. He selects the elements in a situation that are relevant, and chooses a plan to achieve the goals. This selection and choice can only be made on the basis of a much higher involvement in the design situation than displayed by a novice or an advanced beginner. Problem solving at this level involves the seeking of opportunities, and of building up expectations. There is an emotional attachment, a feeling of responsibility accompanied by a sense of hope, risk, threat, etc. At this level of involvement the problem solving process takes on a trial-and-error character, and there is a clear need for learning and reflection, that was absent in the novice and the beginner.
- A problem solver that then moves on to be *proficient* immediately sees the most important issues and appropriate plan, and then reasons out what to do.
- The real *expert* responds to specific situation intuitively, and performs the appropriate action, straightaway. There is no problem solving and reasoning that can be distinguished at this level of working. This is actually a very comfortable level to be functioning on, and a lot of professionals do not progress beyond this point.
- With the next level, the *master*, a new uneasiness creeps in. The master sees the standard ways of working that experienced professionals use not as natural but as contingent. A master displays a deeper involvement into the professional field as a whole, dwelling on success and failures. This attitude requires an acute sense of context, and openness to subtle cues. In his/her own work the master will perform more nuanced appropriate actions than the expert.
- The world discloser or '*visionary*' consciously strives to extend the domain in which he/she works. The world discloser develops new ways things could be, defines the issues, opens new worlds and creates new domains. To do this a world discloser operates more on the margins of a domain, paying attention to other domains as well, and to anomalies and marginal practices that hold promises for a new vision of the domain.

Most of these levels are recognizable to anyone involved in teaching design. The definitions of the levels are still sketchy, and not all the steps may be described unequivocally (this is very much work in progress). The most important step to focus on in this paper is the one from advanced beginner to competent designer that can be recognized in design education too (Dorst 2003). This is where involvement and reflection come in to change the problem solving process. This is also where there is a radical shift in the perception and interpretation of the problematic situation: we move from a detached view of an 'objective' reality to the involvement and active interpretation of a situation. These fundamentally different ways of looking at problematic situations can actually co-exist in a design project: nobody is an expert on all aspects of design, on some problems we might be novices, at others we might be competent, or experts. Designers display rule-following behavior, as well as the interpretation and reflection that characterize higher levels of expertise at work.

The nature of the design problem as seen by the designer thus depends on the level of expertise of the designer in solving the problem. This makes the level of expertise potentially a central notion in the description of design practice: the choice of paradigm for describing and supporting design processes depends on the level of expertise that the designer has. The rule-following behavior of the novice and the advanced beginner needs to be described within the framework of the Rational Problem Solving paradigm. The behavior of the competent designer and higher can be described using both paradigms; with the Reflective Practice paradigm becoming more relevant the closer we are to expert behavior.

## 6. Conclusions

### Studying design problems

In this paper we have explored ways to describe the structure of design problems. In doing this we have moved away from making *a priori* taxonomy of design problems, because that inevitably focuses on describing the structures of reasonably determined problems. For design, this will not get us very far: design problems are largely underdetermined or possibly undetermined. To really capture what happens in design practice, we need to consider the problems as situated problems, as they are seen through the eyes of the designer. Thus the original research question has shifted from the development of taxonomy of design problems, to a description of critical design situations. This involves the study of the breakdowns that can occur in the flow of design problem solving, and the designer's response to these breakdowns. To describe this response we can turn to the paradigms of design methodology and to the co-evolution model of design processes.

But these are just descriptions of what happens in a design situation. To really *understand* why a designer tackles a problematic situation in a certain way we have to turn to a model of design expertise. This is where all the elements we need for a close description of design problem solving behavior that have been explored in this paper connect. The levels of expertise potentially have the power to coherently describe the ways in which designers perceive, interpret, structure and solve design problems. The primitive model of design expertise that was presented in this paper needs to be developed further, and validated by empirical research.

### Towards a research programme on design expertise

The classic remark, at the end of almost every scientific paper, is that 'more research is needed.' That is putting it very mildly, in this case: we have hardly begun. This model of design expertise opens up a whole field of design studies, concentrating on describing and defining the properties of the designers and their development in design training and practice. There are several directions for the further development of this design expertise model. We can distinguish three main questions/directions for research:

- We should explore the different kinds of reflection and problem solving that take place on every level of expertise. For instance, the kind of problem that is perceived by the designer at the first level of expertise (how can I use my methods?) is quite different from that on the second level (when should I use this particular method/rule of thumb?). The reflection that takes place on the novice-level deals with the rules themselves, the reflection for the advanced beginner centers on the applicability of a rule in a specific design situation.

- This can then help us define and study the transitions that link the different levels of expertise. What does a designer need to learn to get from one level to the next? How can he/she do that? What problems stand in the way of learning the next set of skills? It has been observed before (Dorst 2003) that the acquisition of design skills is not a gradual process, but that it goes in leaps and bounds. But what are the conditions for such which leaps to occur?
- A third stream of research should be focused on the aspects of design learning that might not be captured so easily in this skill-based learning model: the development of the declarative and process-knowledge of the designer, and the acquiring and use of 'design prototypes.' These aspects of design learning should then, if possible, be used to extend and enrich the general, skill-based learning model of design expertise that we have described in this paper.

There are several means we can use to attack these issues. An extensive literature survey is in order, spanning several disciplines. There is much more theoretical work on expertise development to be found in educational research and in the field of educational psychology. On the empirical front, a detailed longitudinal study needs to be set up. We need to actively follow students in their education, tracing their development from the actual work that they are doing. In this way we would not have to depend on the students being able to verbalize these points in their self-evaluation, and wait until they do so. Designers in practice could be interviewed and other research techniques could be used to trace their development in the 'higher' steps of the expertise development model. In addition to this longitudinal study, cross sectional research could support more in-depth analysis of a specific level of expertise or a specific transition within the model. If we can get a grip on the development of design expertise, this could lead to a number of new developments in design education. A model like this could lead to the development of testing methods that would enable us to more precisely target the position and learning possibilities for every student, at every point in their studies. Design exercises could be made much more specific, opening up the possibility for a much more efficient learning process. Design methods and design tools could be provided to the design student at exactly the right time to foster the next step in their development. The further development of a model of design expertise could thus lead to the development of new, more specific methods and tools for design practice and design education.

The development of such a model is one of the inspirations that will be used for the research programme of a new Design Research group, to be set up at the Faculty of Industrial Design at Eindhoven University of Technology.

### **Explorations in Meta Design Methodology**

The close cooperation between philosophers and design methodologists during this project has lead to a number of observations on the position of both fields. The most important one is that Design Methodology can indeed benefit from philosophical reflection upon its own fundamentals and assumptions. One could defend the thesis that Design Methodology, as a more or less mature field of research and inquiry, now has reached a stage where we need these philosophical explorations in meta-design methodology. We will now present some observations as examples of such meta-methodological reflections.

The first observation deals with the difference and between descriptive and prescriptive models of design, and their possible relationship. In design methodology one can distinguish a number of approaches towards the object of study. Design methodologists analyze designing:

they do *empirical research* in which they observe actual design cases; they construct *descriptive models* that capture aspects of actual designing; and they *develop theories* aimed at understanding and explaining designing. Moreover, design methodologists aim at improving designing: they *normatively evaluate* designing by distinguishing between successful and less successful cases of designing; they develop *prescriptive methods* and *models* for successful designing; and they develop *tools* to help designers use these prescriptive methods and models. These approaches are not independent from one another. Models and theory often guide empirical research on actual designing. And theories of designing may contain evaluative elements about designing.

Some meta-methodological observations can be made. First, one should note that analysis and improvement of designing are in general different projects since the latter necessarily presupposes a normative evaluation for singling out successful design cases whereas the former does not. Descriptive models, for instance, apply equally to successful design cases *and* to less successful ones. A prescriptive model can thus clearly not be a descriptive one as well since then less successful design cases conform also to the prescriptive model.

Secondly, if one wants to connect both projects by, for instance, motivating improvements of designing with an analysis of actual design cases, one should be aware that at some point a normative evaluation of designing has to come in. One can put such norms in by hand or one can include them in one's theory of designing. A theory of designing seems in fact a natural place to include a more normative approach; a proper understanding of designing seems to include an understanding of the differences between successful and less successful designing.

When one looks back into the history of design methodology, it can be noticed that the real-life development of the field indeed did not follow a clean meta-methodological route through the different approaches. Much of the work done in design methodology of the 1960's, 70's and 80's was concerned with the construction of prescriptive models and design tools. These prescriptive models and tools were based upon experiences of designers in everyday professional practice and upon the methods that had already been developed by professional designers. Design methodology served to systematically reflect on these experiences and methods, and to construct meta-models of designing. Later, from the early 1990's onwards, design methodology was enriched by a substantial body of empirical research into designing, first in laboratory settings and later also in practice. Through systematic observation design methodologists improved the rigor of their observational and descriptive basis, but they still focused their reflection and modeling on prescriptive models, methods and tools.

This description of design methodology may be a caricature (exceptions come to mind) but we would argue that there is a lack of interest in theories aimed at *understanding* and *explaining* the how and why of the observed design activities, and a rush from observation and description to prescriptive modeling and the construction of design tools. Consequently it is often unclear how the normative evaluation of designing enters work in design methodology that connects observation and description with prescription.

A second meta-methodological observation can be based upon the paper by Houkes et al. (2002). The account of designing that is given in that paper, is meant as a *rational reconstruction of design*: it is based on descriptive models of actual designing but also explicitly adds elements – use plans – and a norm – rationality – to those models in order to provide richer and normative modeling of designing. And because it is advanced as a reconstruction, it is immediately clear that this richer and normative modeling is not purely descriptive anymore; the account is committed neither to the claim that the description of designing by means of these added elements is true of all actual cases of designing – actual designers may never have deliberated about their work in

terms of use plans – nor to the claim that actual design cases comply to the norm – designers may in real life proceed quite irrationally. Moreover, if recommendations about how to improve designing are formulated by means of the reconstruction – say, by recommending that designers should explicitly consider the use plans of the artefacts they design – it is also clear where the presupposed norms are originating from.

The task of coming up with a theory of designing is ultimately one for design methodology itself. But philosophy can help with stabilizing concepts and with relating descriptive and prescriptive work, and thus contribute to a more stable and clearer understanding of the design activity.

# A Philosophical Analysis of Designing

## Results from the Delft Dual Nature of Technical Artifacts Program

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### 1. Introduction

Designing sometimes yields results that are miraculous from a technical point of view. The first light bulb must have been magical to those who first encountered it, as may be the new 555 passengers Airbus A380 to us when we see it take off from Schiphol Airport. From a philosophical point of view designing is, however, wondrous at all times. Design methodologists typically characterise designing as a process that starts with goals or desires of clients, and ends with a material description of a new product by which the client is helped. Philosophically speaking, goals and desires are intentional concepts by which we describe the thoughts and actions of conscious beings, whereas those material descriptions of products usually are phrased in structural concepts, by which we describe physical objects. Whereas philosophers have for centuries been trying to make some headway in understanding how these intentional and structural ways of describing the world are related, designers, apparently, move freely and systematically between these two modes of describing the world. As part of the *Dual Nature of Technical Artifacts* research program – funded by the Netherlands Organisation for Scientific Research (NWO), and carried out by and large in the period of 2000-2004 at the Philosophy Department of Delft University of Technology – we have analysed design processes from this philosophical perspective. In this contribution we sketch some of the main results.

The starting point of the program is that material technical artefacts – henceforward called simply products – such as light bulbs and airplanes, have, philosophically speaking, a dual nature: they have an intentional nature that is captured by, for instance, the ascription of technical functions to products, and they have a structural nature captured by a physical description of the product. Central tasks of the program were to analyse the notion of technical function, and to capture the relation between the intentional and structural natures of products. Answering these questions lead us first to describing using and designing in terms of what we called *use plans* for products (section 2) and to defining functions of products relative to their use plans (section 3). Secondly, we coupled this description and definition to the more usual descriptions of using and designing (section 4) and the more usual understanding of functions (section 5). Thirdly, we answered our philosophical question by giving at least the conceptual relation between intentional and structural descriptions of products (section 6). We end this contribution (section 7) with presenting a more detailed picture of design processes as they appear from our use plan account.



## 2. Designing as transforming goals into use plans

There is no consensus in the design methodology literature about how to characterise the process of designing. It is often taken as a process in which required functions are transformed into descriptions of the physics of products that can perform these functions (e.g. Gero 1990; Roozenburg and Eekels 1995). But wider characterisations by which designing starts with goals and ends with much more than descriptions of products are available as well (e.g. Hubka and Eder 1998; Eekels and Poelman 1998).

There is, moreover, no consensus on how to define the terms by which these characterisations are typically given. For some authors the term function, for instance, refers to intentions and purposes of designers (e.g. Gero, Tham and Lee 1992), but for others (or for the same authors at later times) to the behaviour of the product itself (e.g. Rosenman and Gero 1998). This forced us, as philosophers aiming at analysing the notion of function as used in designing, away from the neutral role of observing and into a more active one of reconstructing concepts. More precisely, we had to engineer our own definition of technical functions, for philosophical literature too, does not provide for an unambiguous meaning of the term (this literature is dominated by analyses of the concept of function in biology, and the few authors that do analyse technical functions in philosophy already disagree; Neander (1991) associated functions with goals of designers and users, Cummins (1975) takes them as capacities of the products). The definition we arrived at relates functions of products to what we called the *use plans* of these products. So, before giving this definition, we will have to introduce use plans.

Briefly summarised, a plan, a concept philosophically elucidated in action theory (Bratman 1987; Pollock 1995), is an ordering of actions considered by an agent for achieving a goal. A use plan for a product is defined by Houkes and Vermaas (2004a) as a plan in which at least one of the considered actions involves the manipulation of the product. Use plans were initially introduced by Houkes et al. (2002) in order to analyse product using and to establish a relation between using and designing. ‘An agent uses product  $x$ ’ is spelled out as the carrying out of a use plan for the product by the agent as a means to achieving the goal associated with the plan. So, for example, ‘Alice drives her car’ means on our approach that Alice manipulates the car by executing a plan consisting of the usual driving actions for achieving the goal of transportation.

Designing is taken as the source of the use plans available to agents to achieve goals with. On this view, designing is not so much a process focussed on the description of material things, as it is one in which plans are developed: designing starts with a goal; then a use plan is developed consisting of an ordered sequence of actions by which the goal can be achieved; and only if some of these actions involve the manipulation of objects that do not yet exist, new products are designed. So, if a client comes in and explains to the designer that she wants to travel from A to B, the designer does not immediately start thinking about products but first considers a series of actions by which the client can obtain her goal. Such actions may consist of ones in which no objects are manipulated – walking – and may consist of manipulations of objects that already exist – cars – and that not yet exist – say, a teleporter. And only in that latter case the designer starts designing a product as well.

This use-plan account analyses the interaction between designers and users mainly in terms of the communication of use plans and the transfer of products: designers aid users in realising their goals by constructing a use plan to be executed, which includes manipulations of available objects and, possibly, newly designed products. In line with this, designers should not present the relevant plans to prospective users by merely handing over the relevant products;

instead, designers should communicate the actions and goals defining the plan. Presenting just the product would be largely worthless to users. Unless the use plan is highly entrenched or can be communicated exclusively through features of the product, a user who does not know the plan will be clueless.

Our characterisation of designing is revisionary. The concept of a use plan is not a concept one finds in the literature on designing. Also, an agent can already be said to be designing if s/he develops and communicates a new use plan for an existing product. Creating products, usually regarded as the paradigm of designing, is merely a special case on our characterisation. Hence, in order to establish its worth, we have to take up the challenge to show, on the one hand, the usefulness of the revision, and, on the other, its ability to reproduce the usual description employed in designing. We hold the position that the way in which we can describe the relation between using and designing by means of use plans, and the way in which we can capture the communication between designers and user, already makes this concept useful. In the next section we show the usefulness of our revision for defining technical functions.

### 3. Function ascriptions

Using the concept of use plans of products, one can capture functional descriptions of products by the following definition (Houkes and Vermaas 2004b; Vermaas and Houkes 2005; the definition is phrased in terms of the more philosophical term ‘artefacts’):

An agent  $a$  ascribes the capacity to  $\phi$  as a function to an artefact  $x$ , relative to a use plan  $p$  for  $x$  and relative to an account  $A$ , iff:

- I. the agent  $a$  has the capacity belief that  $x$  has the capacity to  $\phi$ , when manipulated in the execution of  $p$ , and the agent  $a$  has the contribution belief that if this execution of  $p$  leads successfully to its goals, this success is due, in part, to  $x$ ’s capacity to  $\phi$ ;
- C. the agent  $a$  can justify these two beliefs on the basis of  $A$ ; and
- E. the agents  $d$  who developed  $p$  have intentionally selected  $x$  for the capacity to  $\phi$  and have intentionally communicated  $p$  to other agents  $u$ .

So, an agent can ascribe the capacity of transporting people on the ground to a car relative to the car’s use plan with the goal of travelling, when the agent believes that the car has this capacity and that this capacity is relevant to the effectiveness of the plan (condition I), when the agent can justify this by, say, experience, knowledge or testimony (condition C), and when the designers of the car indeed designed or selected the car for this capacity (condition E). The labels ‘I,’ ‘C,’ and ‘E’ refer to (idealised) philosophical construals of the meaning of the function concept. The above definition integrates elements of these construals, and for this reason Houkes and Vermaas called it the ICE-definition of function ascriptions.

By this definition a function refers to a capacity of the product itself. But functions are also related to the goals of designers and users via the concept of use plans; the capacity of a product that corresponds to a function of the product is by the I-condition supposed to contribute to the effectiveness of the plan to achieve the goal for which it is designed to be used.

One may wonder whether the definition may be simplified by removing the concept of use plans; one can simply replace ‘use plan  $p$  for  $x$ ’ by ‘ $x$ ’s goal  $g$ ,’ thus freeing the definition from our fabricated concept. Such a more economic version of the definition has, however, the disadvantage that one ends up with an undesirable proliferation of functional descriptions of

products. If, for instance, a product is in part designed for the goal of using up an otherwise redundant stock of the company's electrical components, then the capacity of the product to rid the company of this stock can be ascribed to the product with the simplified definition. By including the concept of use plans – and this shows again the usefulness of the concept – such secondary goals do not allow for function ascriptions; these goals and the corresponding actions to achieve them, are typically not communicated to the users of the product, hence they do not lead to function ascriptions on the above definition.

The C-condition also prevents another undesirable proliferation of functional descriptions, namely ascriptions of functions products reasonably cannot perform on the basis of their physical makeup. Hence, ascribing the function of teleportation to two cardboard boxes simply because someone claims to have designed or selected the boxes for the goal of travelling, is ruled out.

The E-condition emphasises the role of designers in function ascriptions by requiring that the capacities corresponding to a product's functions, are capacities for which the designer of the use plan for the product designed or selected the product.

The above definition is central to the Houkes-Vermaas account of functional descriptions of products, but not exhaustive. A second, and secondary, definition is introduced to cover functional descriptions that refer primarily to roles of products in larger systems and less to the process of designing. A clear example of an ascription of such a functional role is given by the description of a short-circuited electrical system in an industrial plan as an unintentional detonator of an explosion that has taken place in the plant.

#### 4. Types of using and designing

By giving the ICE-definition of function ascriptions we already carried out our central philosophical task of analysing the notion of technical functions. And by doing so, we also captured the relation between the intentional and structural natures of products. By the ICE-definition, these natures are conceptually connected when a function is ascribed to a product: a function refers to a physical capacity of the product itself, and is related to the goals for which designers designed the product and users use it, because this capacity is supposed to contribute to the effectiveness of the product's use plan to achieve this goal. But further research has led to a more enlightening analysis of how functions relate the intentional and structural natures of products. In order to present this analysis in the next section, we first turn to the second part of our challenge, namely to show that our revisionary analysis can reproduce more usual descriptions employed in designing. Here we focus on the use-plan account of using and designing as sketched in, for instance, Vermaas and Houkes (2005), the ICE-definition is considered in the next section.

Our description of *using* of a product as the carrying out of a use plan may seem not to be too eccentric. Users consider products as means to their goals, and on our account this means that they know of the use plans that designers have developed for these products, and that they thus can take the products as objects by which they can achieve the goals that are part of the use plans by carrying out the actions in plans. Designers present these use plans to the users, and this typically does not take place by direct communication, but through the usual channels of manuals, information distributed via marketing, advertisement and sellers, through signs ranging from use-cues and explicit symbols integrated in consumer goods, or through explicit training courses for professional equipment. Users may also ascribe functions with the ICE-definition but this is not necessary; the description of products in terms of plans is in principle sufficient for

users: it says what to do with products and what for. A cleaning agent, for instance, can already be used when the user knows that it yields a clean surface if the cleaning agent is applied to the surface in a particular way. Moreover, if users ascribe functions to products, they do so in rather unscientific, colloquial terms. A user can ascribe the capacity to remove stains to the cleaning agent, which refers to a physical capacity of the substance in non-scientific or technological terms. The knowledge (the account  $\mathcal{A}$  mentioned in the ICE-definition) by which users justify function ascriptions (in order to satisfy condition  $C$  of the definition) may also lack physical or technological depth and consist simply of experience by the user or of testimony originating from the designer.

Our description of designing might, however, be too liberal to reflect the paradigmatic sense of the word. The advantage of this is that we can broaden our analysis; a disadvantage is that the analysis loses contact with its paradigm. Therefore, to reconnect, we start by defining *altruistic expert product designing* as designing in which not only a use plan is developed for a product or products, but also new product(s) are described on the basis of expert scientific and technological knowledge, and the plans and products are made available to other persons. Altruistic expert product designing is designing as it is typically done by professional (engineering) designers. They typically ascribe functions to the products described, do so in considerable physical detail, and justify the ascriptions on the basis of their expert scientific and technological knowledge.

By now weakening or changing the extra conditions that define this first and paradigmatic case of designing, other ‘activities’ concerning products can be identified as designing as well. For instance, if the condition that new products are described is dropped, one has the case in which professional designers and engineers advise clients to obtain their goals with products independently of whether these products need to be described as well or already exist. The designer then develops a new use plan for the products, may need a lot of expert knowledge to do that, communicates the plan to other persons, but need not describe a new product. An example of such *altruistic expert designing* in which no new product was described may be the discovery that Aspirin can also be used by cardiac patients for preventing blood clots. The development of the corresponding new use plan, that is, the right way of administering Aspirin for this new goal, required expert knowledge, but not the development of the drug itself. The designers engaged in such cases of designing typically also ascribe functions to the products they consider, do so in considerable physical detail, and also justify them on the basis of their expert scientific and technological knowledge.

This last case could be included because our account construes designing primarily in terms of use plans rather than products; the following two cases can be included by allowing that the knowledge involved in designing may also be everyday-life or layman knowledge. *Altruistic amateur designing* is the case in which persons that are not professionally trained designers or engineers develop a new use plan for existing products and communicate this plan to others. Candle wax can be removed from cloths by ironing the stains through brown paper, and this defines clever but non-standard use of brown paper. Chairs can be used for standing on, and this is generally seen as improper use of the chairs. These altruistic amateur designers and the people to whom the new use plan is communicated can also ascribe functions. The descriptions of the physical capacities corresponding to these functions will be less scientific or technological, and the knowledge by which these function ascriptions are justified typically consists of experience. The functions ascribed are often compared with the functions products have relative to their original ‘expert-designer’ functions, for instance when it is asked whether chairs also have

‘standing on’ as a function. On our account the difference between this function and the original ‘sitting on’ function is that the latter is defined relative to the original use plan developed for the chair by expert designers, whereas the former is picked up in time by chairs relative to a new use plan that is connected to a well-known alternative way of using the chair.

A final case worth mentioning is what we call *personal amateur designing*. In this case a (lay)person develops a new use plan for an existing product and does not communicate it to others. An example is Simon Vestdijk, the Dutch writer, who used his vacuum cleaner as a means for preventing loss of concentration. While he was working, he switched on his vacuum cleaner to drown out background noises. Vestdijk may have also ascribed a corresponding function to his vacuum cleaner (this ascription may then have satisfied the ICE-definition as soon as one accepts that communication of use plans may include memorising them for later use). And if he did, the description was again less scientific or technological, and the knowledge that justified it consisted of experience. At first sight, this type of personal manipulation of products may be seen as use that does not cohere with the proper way of using the product concerned; it is idiosyncratic or funny use (and altruistic amateur designing is sometimes more positively characterised as innovative use). The use-plan analysis shifts the way in which this manipulation can be understood away from using by designating it as designing. And there are indeed principal differences between the using of products in accordance with the original intentions of designers and according to personally fabricated plans. A user knows that using products in accordance with the original intentions of designers is rational due to the scientific and technological knowledge designers have. The user has, furthermore, a right to assume that this use is rational: if the vacuum cleaner does not clean, he can reclaim his money. The use of products according to personal plans may be rational on the basis of personal experience, but there is no such thing as a legal right to assume that this use is rational. Had Vestdijk’s vacuum cleaner failed at some point to keep him focussed, he would not have gotten his money back. And this is a matter of principle; it is not as if Vestdijk would have had at least some right to reclaim a small percentage of his money.

## 5. Function ascriptions in designing

It can be shown that the ICE-definition of function ascriptions satisfies a number of minimal requirements any account of technical functions should satisfy (Houkes and Vermaas 2004b). As we mentioned, it satisfies, for instance, the requirement that physically unreasonable function ascriptions should be ruled out. A disadvantage of the definition is that it explicitly relates functions to use plans of products and thus, at first sight, does not reproduce the way designers ascribe functions to products. Since the concept of use plans is of our making, designers most probably do not relate functions to use plans. It can, however, be shown that on our analysis designers can to a large extent suppress explicit references to use plans, in particular when they ascribe functions to components of products in accordance with the ICE-definition (Vermaas 2005). Functions are on our analysis again ascribed to those components relative to use plans of those components. These use plans are developed by the original designers of the components and used by designers of the products that contain the components. A component use plan can have the form “compose the components  $c, c', c'', \dots$  in configuration  $k$  in order to obtain a product  $x$  with the capacity to  $\psi$ ”. Relative to this plan the designers of the product  $x$  can then ascribe the physicochemical capacities to  $\phi$  of  $c$ , to  $\phi'$  of  $c'$ , and so on, as functions to these components by the ICE-definition, provided that these capacities physically ‘add up’ to a product with the capacity to  $\psi$ . It can now be argued that designers will interpret this component use

plan, not as a plan that is communicated to them by colleague designers and that consists of actions “compose the components  $c, c', c'', \dots$  in configuration  $k$ ” aimed at the goal “to obtain a product  $x$  with the capacity to  $\psi$ ” but as a technological rule they know themselves about how these component make up the product  $x$ . This rule may have the form: “the composition of the components  $c, c', c'', \dots$  in configuration  $k$  yields an product with the capacity to  $\psi$ ”. By this interpretation, the ICE-definition simplifies to the form (the product as a whole is again referred to as an artefact, and the designer of that artefact is called an engineer):

An engineer  $e$  ascribes the capacity to  $\phi$  as a function to the component  $c$ , relative to the composition of  $c, c', c'', \dots$  in configuration  $k$  of an artefact  $x$  with the capacity to  $\psi$ , and relative to scientific and technological knowledge, iff:

- I. the engineer  $e$  has the capacity belief that  $c$  has the capacity to  $\phi$  in the configuration  $k$ , and the engineer  $e$  has the contribution belief that if  $x$  has the capacity to  $\psi$ , this is due, in part, to  $c$ 's capacity to  $\phi$ ; and
- C. the engineer  $e$  can justify these two beliefs on the basis of scientific and technological knowledge.

In this ICE-definition for function ascriptions to components, references to use plans disappear: a physical capacity to  $\phi$  is ascribed as a function to component  $c$  of a product relative to the composition of the product and relative to a capacity to  $\psi$  of the whole product. The engine of a car, for instance, can be ascribed the function to deliver propulsion relative to the car and the car's capacity to transport people. Hence, explicit references to goals or actions drop out (although it can be argued that the identification of the capacity to  $\psi$  of the product relative to which functions can be ascribed to its components, still refers to the goals and actions associated with the product) and this turns the ICE-definition into one that, in our view, comes close to how designers think about function ascriptions.

For function ascriptions to products as a whole a similar solution is not available, meaning that we have to take such function ascriptions by designers as at least tacitly referring to use plans.

## 6. Functions as conceptual drawbridges

By means of these results we are now in a position to give a more detailed answer to our question of how the intentional and structural natures of products are related. As we already said, function ascriptions connect these two natures, and we can now show that they do so in quite a sophisticated way that is tailor-made for the case of using and/or designing at hand.

Users, as we said, need not ascribe functions to products. Users can stick to descriptions of products in terms of use plans only, and if they do, their descriptions of products refer primarily to the intentional nature of the products: products are associated with plans consisting of goals and actions, and those are all intentional concepts. But when users do ascribe functions to a product, they add a structural element to their description of the product: users then ‘highlight’ one particular physical capacity of the product that makes the product a means to the goals of the product's use plan, and thus contrast it with other capacities of the product that are not relevant for obtaining these goals. This structural element can be captured in rather unphysical, colloquial terms, meaning that users indeed can highlight this structural element without being required to have full knowledge of science and technology. Hence, users can employ the concept of function as an easy conceptual bridge from the intentional nature to the

structural nature of products. This bridge can be used by the user to cross from his or her intentional use-plan characterisation of products and expand the description to structural terms, and this bridge can be drawn in order to ‘cloak’ the structural nature of products.

When designers ascribe functions to products, they highlight the physical capacities of the products that play a role within the use plans for the products. By explaining how these products physically have these capacities, and how these capacities contribute to the effectiveness of their use plans, the concept of function connects the intentional descriptions of the use plans of the products to detailed physical descriptions of the products themselves. For designers the concept of function is thus again a conceptual bridge between the intentional and structural natures of products, but now it seems to be a fixed bridge: functions of products refer to both physical capacities and to use plans. An exception is the ascription of functions to components of products. As we sketched in the previous section, designers may ascribe functions to components relative to the composition of the encompassing product and relative to a capacity to  $\psi$  of that product. By such function ascriptions designers can cloak the intentional use-plan descriptions of the products, and focus on the physical structure of the products that explains how they can perform the ascribed functions.

The concept of function thus provides, by the Houkes-Vermaas analysis, a bridge by which users and designers can connect the intentional and structural natures of products. And the concept also provides a means by which they can separate these natures. Functions thus form a beautifully ‘engineered’ conceptual bridge that users and designers can draw or not draw depending on their descriptive needs.

## 7. Reconstructing the design process

A lot has been said about the instrumental usefulness of our analysis to understanding the notion of function, but it also has more to say on the process of designing itself. Designing, at least when it is taken in the paradigmatic sense of altruistic expert product designing, involves the devising of both a use plan and (a description of) a product. Therefore, it comprises a twofold transition, first from users’ goals to use plans, and, secondly, from use plans to products. In practice, of course, these two transitions are not ordered chronologically; they will typically take place concurrently and in close interaction. Let us look at both of them in more detail.

A design process starts with a given goal from a client and the first thing a designer then needs to do is to come up with a use plan: a series of actions that, if carried out properly, will lead to that goal. One way to do this is to break down the main goal into simpler sub-goals that, if achieved subsequently and systematically, lead to realisation of the main goal – a process we might call *goal decomposition*. Once these simpler goals have been fixed, one or more series of actions are required to realise them. At some point, these actions must involve manipulations of the product being designed. A somewhat stylised example is the design of the first washing machine by William Blackstone in 1874. His goal was, obviously, clean clothes. Given some background knowledge about water, soap, and dirty clothes, he could easily come up with something like the following decomposition of his main goal: (1) bringing the dirty laundry in contact with soap water, (2) have dirt and soap react with each other, and (3) get rid of dirt and remaining soap. The corresponding actions would roughly be: (1) put the dirty laundry in a tub filled with soap water and soak it, (2) tumble the laundry and rub it firmly against each other and the sides of the tub by means of the mechanisms of the washing machine, and (3) empty the tub and wash away the dirty soap water.

Goal decomposition is a crucial step in designing, as it determines the ‘division of labour’ between the product and the user. It establishes what prospective users are supposed to do, roughly how and when the product is supposed to be used, and part of the product’s operational principle. To the extent that a design process involves the reengineering of an existing product or the design of a highly standardised or common product, the available options for goal decomposition will be limited. Goal decomposition can also take the form of automating tasks that were previously carried out by hand. The washing machine is a good illustration: the actions performed by the first washing machines were not radically different from what people had been doing by hand before; it was just that they could now performed more efficiently by operating the machine.

The second transition is from use plan to (the description of) the product. As the ICE-function theory stipulates, a given use plan delimits the desired capacities of the new product and hence fixes its function(s). But once this main function is given, the challenge of the second transition is to realise that function by a material structure and this is where *functional decomposition* comes in. The main capacity of the new product must be analysed into ‘smaller’ and ‘simpler’ capacities; capacities that, if manifested in a programmed fashion, realise the overall function of the product. At some point, functional decomposition stops either because it has reached a point where off-the-shelf solutions are readily available for implementing the sub-function (sub-capacity) or because the decomposing sub-functions are ‘atomic’ and insusceptible to further decomposition. In the former case, the appropriate component(s) can be selected from product guides, catalogues, etc. but in the former case, a new component may have to be developed or invented in order to implement that sub-capacity. Here, knowledge about the properties and behaviour of materials and constructions provided by the engineering and natural sciences can help, but engineering creativity and inventiveness is probably most important. Let us give another example to clarify the idea: the use plan for a bicycle determines the function of the bicycle, i.e. the main capacity (capacities) it is to have. This overall function is then decomposed into sub-functions such as sitting a human person, translating movement of legs to movement of wheels, allowing for steering, and so on. Finally, when sufficiently simple decomposing functions have been identified, the implementations of these functions can be selected, such as the bicycle’s seat, pedals, handlebars, and so on.

We must admit that this picture of designing is still sketchy. In fact, further research on the nature of the design process is still being carried out. Specifically, we are looking into questions about how goal and functional decomposition work, whether there are different types of decompositions, how these two decompositions relate to physical decompositions of products in their material parts, and to what extent it is possible to reconstruct designing as a broadly rational endeavour with identifiable (inference) steps.

## 8. Conclusion

In this contribution we presented a number of results of the NWO research program *The Dual Nature of Technical Artifacts*, as it was carried out at the Philosophy Department of Delft University of Technology. The main results are a use-plan account that provides an integrated description of using and designing in terms of the common concept of use plans, and the ICE-definition that spells out what it means to ascribe a function to a product. This description and definition is revisionary relative to usual descriptions of using and designing and to function ascriptions in designing. We showed that, nevertheless, the use-plan account can reproduce this usual description and that the ICE-definition when applied to components of products, becomes less



revisionary. We also sketched a picture of designing that follows from our account. If we take seriously the idea of a use plan, designers not only devise material products through a process of functional decomposition, they also devise use plans through a process we called goal decomposition.

Research at the Delft Philosophy Department led to other results as well. Ones that are relevant for this contribution are analyses of use knowledge (Houkes 2005), the normativity of functional descriptions of product (Franssen 2005), the social aspects of functional descriptions (Scheele 2005), and the nature of technological explanations (De Ridder 2005). (Many of these results have been presented in Scheele and Vermaas 2003, which is a volume in Dutch.) The use-plan analysis was, furthermore, of use for analyses of design methodologies; in Dorst and Vermaas (2005) and Vermaas and Dorst (2005) it is contrasted with the methodology of Gero (1990). And it is, of course, our intention that it will be of use for other projects in designing as well.

# Human-Centered Design Methodology

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## 1. Introduction

At the conference Design Research in the Netherlands 1995, 10 years ago, our Design Methodology Group was introduced by Kees Dorst with the following sentences: *“The Delft faculty of Industrial Design Engineering has a five-person group working on Design Methodology. Organizationally this group is linked to the department of New Product Development, Section Innovation Management.”* One year later Nigel Cross left and the chair of Design Theory and Methodology remained vacant over the last 8 years. This situation has now changed; since 1<sup>st</sup> October 2004 Petra Badke-Schaub was appointed as Professor of Design Theory and Methodology in the department of Product Innovation Management in the now separate faculty of Industrial Design.

Thus, we want to take the opportunity to dedicate one part of the paper to our research intentions and to our future design research topics (see section 5). The paper starts with a short introductory discussion about the question of a shared understanding of design methodology in the design community. We then present a rough overview of the research of the group during the last years (see section 3) which was mainly related to the analysis of design processes. The fourth section refers to the question ‘how to get meaningful results,’ what are the research methods we are using and going to use in our future research projects (see section 4). Hence, the paper is divided into the following four parts:

1. Design Methodology: a ‘shared understanding’?
2. Studying design processes: what was our focus during the last four years?
3. Research methods: how to get meaningful results?
4. Human-centred Design Methodology: a research programme.

## 2. Design Methodology: a ‘shared understanding’?

If we accept that designing is not a purely intuitive artistic activity but can be taught, we need a body of knowledge which to a certain degree is proven to being relevant for the education of designing and for the support of the designer’s daily work. Thus, design methodology should integrate knowledge which is being developed, applied and evaluated in order to provide support in designing.

Analysing the current situation of design research, the situation gives reason for optimism, when we consider the growing amount of data and studies published in various scientific journals from researchers from different disciplines. The drawback of this situation is that most empirical results are highly restricted to the particular context - the validity of the data has mostly not been established beyond the specific situation in which the data are collected. Thus, we do not know how to combine results and how to transfer the results to other subjects

and situations. At the same time the number of methods, techniques, and design tools being developed is increasing and covers a broad field within and between disciplines.

But although different disciplines propose different approaches to designing in order to obtain optimum results there are similarities related to two issues:

- *General strategies, heuristics, operations* which may guarantee a successful result: The famous work by Descartes 'Rules for the Direction of the Mind' ('Regulae ad directionem ingenii', written 1628, published 1701) refers to some general rules such as the reduction of the complexity of problems. Descartes was convinced that in finding the proper method scientific progress would follow. Nowadays software design, engineering design, architecture as well as physics and many other disciplines recommend to plan your process, to subdivide complex design problems into sub-problems, to evaluate before decide and to proceed from general to particular, from abstract to concrete, and from important to less important.
- *A basic underlying structure* of the process which refers to the main requirements of a given task or problem: There are various models aiming at structuring the design process. A closer look at different procedural models (see for example French 1971; Pahl and Beitz 1984, 1996; Pahl, Beitz and Feldhusen 2004; Roozenburg and Eekels 1995; VDI 2221 1986) reveals a basic underlying structure which can be referred to the principles of the general problem solving theory (Dörner 1972, 1996) as well as to systems-engineering-theory (Hall 1962). The differences are mainly related to the degree of abstractness and generalisation, although newer revisions try to explicitly avoid rigid divisions between the phases and stress the flexibility of the designer (see for example Ehrlenspiel 1995; Lindemann 2004).

Of course, the underlying assumption is that designers following design methodology will perform better than designers who don't. However, we also know from empirical studies that designers in practice rarely follow the basic principles, which methodology prescribes. And it is not necessarily true that their ways of working will lead to a negative design result (Günther and Ehrlenspiel 1999). Whereas if designers are using at least basic principles of design methodology, such as a detailed goal analysis, explicit divergent and then convergent solution search, detailed evaluation of solutions and reflection on the own action and thinking strategies they showed successful results.

Hence, the important question is: Which influences on the designer (and to what extent) do design methodology as a body of knowledge neglect? Which specific factors and constraints lead to different design processes and thus to different outcomes?

The consequence is that there is an essential need to know of how designers work and think, what particular problems may occur in a particular situation and which methods, tools and techniques might help in this situation.

### 3. Studying design processes: what was our focus during the last four years?

As mentioned before there is a need for empirical studies which provide a deeper understanding of design. What is needed is to take a closer empirical look at what designers really do while designing. This look, however, shall be solidly grounded in theory again, taking into account aspects of normative design theories, theories of creativity and problem-solving and cognitive theories of human decision-making.

The past four years have seen the group focussing on aspects of the design process that were previously treated as parts of a whole. The dominant research approach of the group has long been that of protocol analysis deriving from the now famous Delft Protocol Workshops organised by Nigel Cross, Kees Dorst and Henri Christiaans (1994). This research methodology – essentially recording design activity and then analysing the concepts that are being used in that activity – has provided a strong and flexible foundation for the research during the past four years. It has provided a way of keeping the complexity of design processes while allowing researchers to focus on distinct elements that go to make up that activity. The research has also been more closely linked with design education in a number of projects. Research has included the following subjects which will be dealt with in more detail below:

- Reflective practice in design education.
- Sketching during idea generation in the design process.
- Discourse analysis of design processes.
- Ethical decision-making in design.

### **Reflective practice in designing**

The work of Donald Schön (1983) and Larry Bucciarelli (1995) has been a key influence on the group's output for some years and there are now a number of projects using the theory of reflective practice in empirical studies within the group (see for example Kleinsmann and Valkenburg 2003; Valkenburg 2000). A project that was completed successfully in 2003 relating to reflective practice was VALiD – Video Assisted Learning in Design (McDonnell, Lloyd and Valkenburg 2004). This project used the technology of digital video to study the learning processes that are embedded within the design process. The idea was to let a team of designers film their own design process and edit a short film of the design process from the footage. During the process of watching their own footage, selecting 'important' bits during editing and compiling the edited film, there were a number of identifiable learning moments. The 're-experiencing' that the video allowed provided a number of interesting insights into the original process of design.

### **Sketching during idea generation in the design process**

In a PhD thesis and a number of papers Remko van der Lugt (2001) has analysed at how sketching and the idea generation process are inter-linked. Using the method of protocol analysis a number of 'braindrawing' sessions by teams of designers were filmed and analysed using linkography (van der Lugt 2002). This research revealed how ideas deriving from visual information associated to, and built on, earlier ideas in the session. These insights have important consequences for the way of how brainstorming and braindrawing sessions should be used within the design process.

### **Discourse analysis of design processes**

In several studies Peter Lloyd has focussed on the way that designers use words during the process of design. The data for these studies has ranged from a number of different sources including design practice (Lloyd and Busby 2001) to television programmes about the design process (Lloyd 2002) to commentary on the design process (Lloyd 2003). All studies however have critically examined the concepts and assumptions that designers use in designing. The studies emphasise the important role that rhetoric (the art of convincing) plays during even the most technical discussions in the design processes, and particularly the idea of storytelling.

## Ethical decision-making in design

Following on from the studies of discourse has been research into the ethical nature of decision-making in design (Lloyd and Busby 2003). This has been looked at, not at the global level which is traditionally the case, but at the micro level in discussions and conversations that designers have with each other and the ethical assumptions that they use. Results have shown how closely ethical judgments in technical disciplines are related to aesthetic judgements and also how normative much of the discourse in design is.

## Design conferences

The group has also organised two international conferences during the past four years. *Designing in Context: Design Thinking Research Symposium 5* (Lloyd and Christiaans 2001) looked at how the environment of design affects design activity. *The Changing Face of Design Education: The 2nd International Engineering and Product Design Education Conference* (Lloyd, Roozenburg, McMahon and Brodhurst 2004) brought together top design educators from around the world. Papers from both these conferences are available online (<http://www.io.tudelft.nl/iepde04/>).

## 4. Research methods: how to get meaningful results?

The choice for a particular research method depends on the aim of the study, the research question. Or to speak with Homans: “*People who write about methodology often forget that it is a matter of strategy, not of morals. There are neither good nor bad methods, but only methods that are more or less effective under particular circumstances in reaching objectives on the way to a distant goal.*” (Homans 1949).

Our primary focus is to understand designing as a human activity, involving cognitive and motivational processes. Therefore, from very early on the DM group as well as in research collaboration with the Institute of Theoretical Psychology, University Bamberg, the Department for product development of the TU Darmstadt and Munich have used and developed approaches for protocol analysis of design activity (Cross et al 1996). Protocol analysis was used to analyze verbal *and* non-verbal aspects of individual design processes (Günther and Ehrlenspiel 1999; Dorst & Dijkhuis 1995), of interactions of design teams (Stempfle and Badke-Schaub 2002) and of design behavior of teams in the laboratory (Valkenburg and Dorst 1998; Van der Lugt 2005) as well as in the design work environment context (Badke-Schaub and Frankenberger 1999).

One of the main challenges of using protocol analysis is to find meaningful ways to interpret the data. The main emphasis therefore is to create a categorization system relating to the research question. Furthermore the question arises how to divide the whole process into meaningful steps, sections or episodes. Traditional protocol analysis approaches segment the protocol based on time intervals. In analyzing design activity, we have developed alternative approaches for segmenting the data. Valkenburg and Dorst segmented the protocol in moves, which they then coded by means of a scheme based on Schön’s (1983) theory of reflective practice.

In his studies into the role of sketching in creative group meetings, Van der Lugt adapted linkography, a way of analyzing protocols of design activity developed by Goldschmidt (1996). Linkography is based on a structuralist approach, marking the links between moves, and then analyzing the resulting link structure. Goldschmidt’s analysis relies heavily on creating graphical models of the design process, which are then interpreted. Van der Lugt has included some basic statistical analysis of the resulting linkographs.

One of the key limitations of protocol analysis has been the large amounts of data that need to be considered, which limits the applicability outside of the studio. In order to collect and analyze complex observational data more easily, our group has recently purchased a software package for video analysis (Interact), <http://www.mangold.de/english/intoview.htm>, which allows direct coding of video footage. This sidesteps the lengthy process of transcribing the videotapes. In addition, the software package allows for instant shifts back and forth between fragments, what is especially useful in research approaches like linkography, which requires looking for evidence for – or against links between moves. As the transcript itself seldom provides sufficient evidence for links, non-verbal behavior and the circumstances in which remarks were made become very important.

We intend to use this software package to include more statistical analysis of qualitative data, and to allow the analysis of more comprehensive design processes, ranging from quick laboratory-based design exercises to *in situ* analysis of design activity.

## 5. Human-centred Design Methodology: a research programme

### Limitations of design methodology

Although we can state that the proposed procedural models of design methodology are useful, it seems necessary to analyse which modifications are necessary in order to adjust methodology to the designers' needs. Let us take a look at an example: Student teams had to design a mechanical concept for a sun planetarium in a one-day period. This sun planetarium should be able to visualise the way of the sun across the sky for different positions on the hemisphere as well as for different seasons. We have analysed these design processes in detail (Stempfle and Badke-Schaub 2002), but here we only want to illustrate the procedure of the solution finding of one group which is quite similar to group processes we analysed in the industrial context (Badke-Schaub and Frankenberger 1999). This group consisted of five persons with three of them being very active and dominant. Thus, lots of solution ideas were generated. However, as soon as a new solution idea was proposed, the team immediately decided on the fate of this solution idea. From a methodological perspective ideas should be first analysed and then evaluated. The reason is twofold: One is that a premature rejection may discard a good solution idea because it does not seem to fit the current constraints. A second reason is the premature adoption of a solution idea which proves problematic later on because a crucial constraint has been forgotten, facts have been ignored, etc. and only after a considerable time it may turn out that the solution does not work. What might be a reason for this analysis-avoiding-behaviour – knowing that the students have had a basic course in design methodology?

Firstly, we know that humans tend to reduce complexity in order to reduce cognitive load (for an overview see Bannert 2002). Thus, an early evaluation of solution ideas is what we call the 'natural thinking process,' which provides several immediate advantages: If all goes smoothly, a solution can be decided on very quickly what is time-saving compared to time-intensive evaluation techniques such as those proposed by design methodology.

Secondly, a quick solution will not threaten the self-efficacy because the problem seems to be solved easily. The more analysis takes place the more difficult a task usually appears, as the analysis brings up new points of uncertainty. Perceived difficulty of a task and the non-availability of solutions reduce one's feeling of competence and self-efficacy.

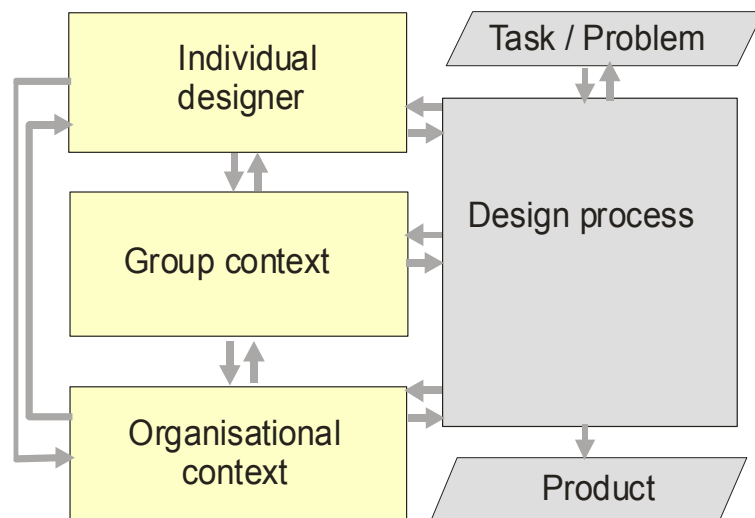
And thirdly, in quite a lot of situations this procedure yields successful results quickly, especially with simple problems; however, the more complex the problem is the more likely errors will occur.

This example highlights some major limitations of design methodology: Whereas the process the designer should follow is explicitly prescribed characteristics of the individual designer such as experience or cognitive overload is not referred to. This is also true for characteristics of the organisational environment such as time constraints, financial constraints, and constraints through multiple projects that must be treated simultaneously. These are reasons, which contribute to the situation that design methodology has not been as accepted in industry as one would expect.

### A research programme

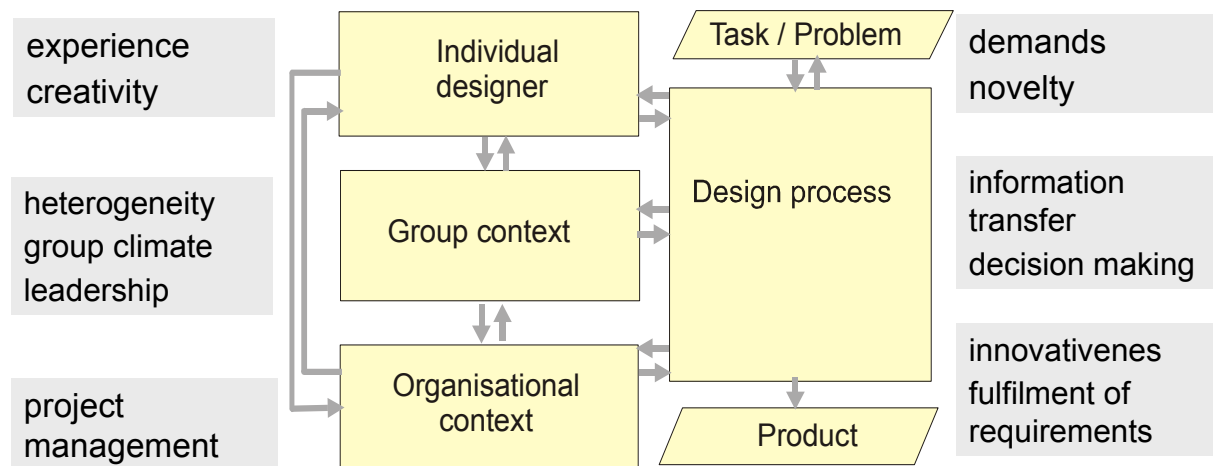
These objections are not new; thus, the question arises: how can we encounter these limitations in a future research programme? We define designing as a form of complex problem solving in an environment with numerous influences which are interconnected. Thus, in order to understand designing and to come up with fruitful support, there needs to be a general framework of design theory. Hence, we need to ‘identify’ this network of designing. That means design research has to encompass the various fields related to:

- the characteristics of the given task or problem,
- the individual designer,
- the designer in the team, group or project context,
- the organizational context,
- the design process,
- and the product as the result (see Figure 1) of this interplay.



**Figure 1: Network of designing.**

The outline of a research program, filling in this network of designing with content, offers various possibilities (see Figure 2); and of course there exists already a body of knowledge related to the different fields - however this knowledge is fragmented and spread over different disciplines.

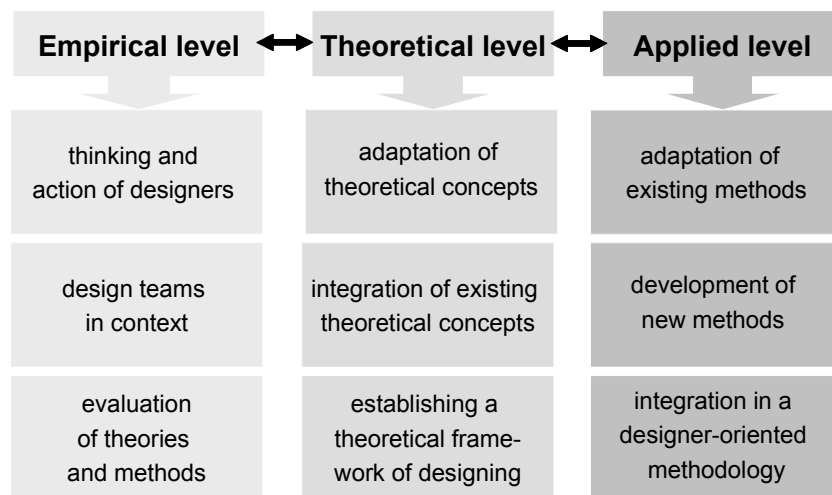


**Figure 2: Network of designing with examples.**

In order to attain and combine meaningful information which allows deriving support for designers we propose an integrated research approach (see Figure 3) which is based on three interrelated columns:

1. The theoretical column: theories and theoretical concepts provide the starting point for design research. Theoretical concepts can be of different nature such as design theory (Andreaassen and Hein 1987; Hubka and Eder 1992; Roozenburg 2002a, 200b) naturalistic decision making (Zsombok and Klein 1997) or cognitive theories (Schaub 1999), depending on the focus of the research question. Of course, a theoretical framework has to integrate proven concepts and has to be adjusted again and again by the empirical data.
2. The empirical column: empirical studies aim at evaluating hypotheses about the thinking and acting processes of designers. As the thinking and acting processes are being changed under specific conditions such as the situation of being part of a teams or working in a specific working environment, these conditions as basic research fields have to be part of empirical analyses. Thereby it is not possible to generate a complete study with all variables included, nor is it possible to investigate each research question in reality. However, a validation of the results has to be set in context, with designers in practice.
3. The application column: the focus on the application of methods includes the adaptation of existing methods as well as the development of new methods to come up with a designer-oriented methodology which supports the designer in his way of designing. Methods not based on theory are less useful because we do not know why they work—and under which circumstances they would probably fail.





**Figure 3: An integrated research approach: synchronisation of theory, empiricism and application in design research.**

Attempting to start with this research program while building on our research and experience of the past years we have set up a first research project ‘Mental models in design teams’ which tries to combine the investigation of individual cognition in the social context. In this project we intend to take a closer look at the development and exchange of mental models in groups in so far that we are interested in the question, how do ‘mental models’ as individual unique constructions develop during designing? Research conducted in cognitive psychology has provided some results that illustrate how mental models establish strategies of thinking under varying conditions. Referring to the practice of designing as cooperative and often as a multidisciplinary activity raises questions related to design activity as informational exchange between team members’ representations. How do design teams establish common mental models and how do design teams integrate different mental models? When and how do design teams modify mental models? These findings could provide the basis for a method which supports design groups to be aware of their mental models and to support the adequate use of mental models.

**Table 1: Research Questions: Mental models in design teams.**

Focus	Question
Individual	How do mental models as individual unique constructions develop during designing?
Group	How do design teams establish common mental models?
	How do design teams integrate different mental models?
	When and how do design teams modify mental models?
Organizational context	How efficient is the use of a guideline supporting the adequate use of mental models in design practice?

Another subject that we see as an interesting addition on the issue of the development of mental models is related to fixation and the ways how experienced designers store their knowledge about solutions and solution principles and how they use it.

Is the output always a variation of former solutions – and if– when is fixation helpful and when and or how get the designer rid of previous material out of his current thinking? What kind of material is especially prone to fixation, which less?

Of course, there are further research topics which would be of major interest but these two ideas may answer the purpose of illustration.

## 6. Conclusion

In this paper we have tried to reveal basic problems of design methodology. As a consequence we have presented a generalized research program and ideas within this framework which should overcome the most important limitation of design methodology, the missing link to the ‘human’ characteristics of designing. Based on the fact that the basic principles of design methodology offer essential support for designers we build upon this framework but focus on the human aspect which is so far neglected in all methodological approaches. Thus, this program reflects a continuity of the former research although it addresses a substantial new dimension: the designer as human being and a pleading for a human-centered design methodology.



# Design, Designerly Enquiry and Design Research

## Exploring Design-Driven Study Approaches in Architectural Research

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### 1. Introduction

This contribution explores – and attempts to chart – opportunities for *design-driven* approaches in architectural research. Starting with a brief investigation into the broad domain of architectural design and its working methods, the relationships between design and scientific methods of research are evaluated. The discourse focuses on instrumental and methodical aspects that may be considered relevant when approaching products and conceptions of design within a research context. It is argued that *designerly* modes of enquiry offer meaningful opportunities for innovative design-driven research. In this context, the perspectives for design-driven research in academic environments are examined.

On the basis of previous experiences with design composition exercises and workshops, eight types of design-driven types of research, divided into two main clusters, are identified and characterised. The methodological approaches addressed in this overview vary considerably, from more or less familiar forms of design based research to more speculative approaches, involving design(erly) activity as an integral part of the research method. This typological mapping exercise reflects upon a number of design-driven research initiatives developed at the Delft Faculty of Architecture – and specifically the Delft Form & Media Studies group – over the last years.

### 2. Design

How should architectural design be considered in a (scientific) research perspective? What are the aims of design activity? Can characteristic methods of design be identified?

The act of designing is a form of creative organisation, which takes place on different ‘levels’ within an overall design concept (often on different levels simultaneously). A design is a ‘work in progress,’ which is gradually developed and refined from an initial idea to a built environment. In the course of the design process a designer generates design propositions, which are judged on the level of functional, structural, material and aesthetic merits, to name but a few. Designers work towards proposals, which offer a fitting ‘answer’ to a specific context, with a given programme and economic constraints. At the same time they endeavour to create authentic, even novel proposals: end products which are experienced as more than a sum of separate solutions: as a synthesis of form, material and space (Kurokawa 1991 even suggests that design elements should be considered to coexist in a state of *symbiosis*).

In their work, designers address a variety of formal themes, such as: order and contrast; size and proportion; rhythm and (inter)space; symmetry and asymmetry; symbol and ornamentation. They (either consciously or subconsciously) exploit the expressive qualities of materials and the effects of light and colour, in order to shape new architectural objects and environments. On a compositional level this may involve creating visual balance and tension

between different, constituting parts, but the design ought never to be perceived as a loose conglomerate, which might start ‘falling apart.’ In a kind of ‘balancing act’ between order and chaos, the designer tries to achieve a form of harmony throughout the composition as a whole.

In contemporary architecture there is a tendency not to adhere to any predetermined, binding themes – or indeed methods – of design, but rather to make choices within a framework of plan-specific design rules developed *per project*. The cultural climate of the twentieth century fin-de-siècle seems to have given rise to a tendency amongst trend-setting designers to keep surprising their audience with ‘original’ solutions in order to stay in the limelight. The present-day architectural ‘landscape’ offers both the familiar and the innovative: convention *and* invention. We bear witness to a constantly shifting ‘parade’ of architectural forms and themes. There is no generally accepted architectural style, no standard set of rules.

Design processes tend to be iterative, following a series of successive design ‘loops.’ At any given point, the ‘state’ of the design is evaluated in relation to previous steps and successively developed further. It is essentially a process of creative *imaging*, as Zeissel (1984) has indicated. Imaging is a form of communication with oneself (and consequently, with other partners in a design team), a way of questioning or verifying the merits of intermediate design ideas and developing new options and strategies. As such, the imaging process is a way of ‘channelling’ inspiration; the designer thinking while doing and reacting directly to ideas as they are being visualised, reflecting, eliminating and refining, subsequently making decisions and documenting the results. By determining criteria (but frequently on the basis of ‘taste’) judgements are made concerning the qualities and potentials of different ideas. Designing is a specialized, unpredictable development process which is largely *visually* generative and reflective – and to a large extent pre-linguistic. Viewed in this light, the *imaging* process, involving the active use of various design media should perhaps be regarded as the most enduring method of design. One might even go so far as to say “the medium *is* the method” (Breen 2000a).

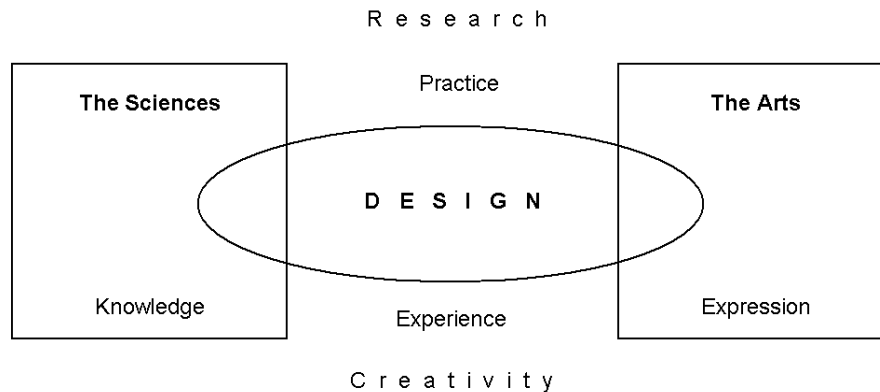
### 3. Design and research

What is the relationship between design and research? To what extent might design products be considered as research output? What are the characteristic aims and methods of design-oriented research?

It may be clear that design is a broad field of enterprise that cannot easily be ‘tied down.’ Working methods and formal themes tend to be determined by personal preferences and constantly shifting cultural, technological, economic, aesthetic and ecological – developments.

Clearly, design processes are not orderly and linear, but unpredictable. To an outsider they may seem haphazard and erratic, even chaotic. This may be one of the most important reasons why design is still frequently viewed with scepticism by more or less traditionally inclined academics. On the other hand, projecting scientific models of thought onto such a complex, varied and layered domain can easily lead to gross reductionism or simplification, in which case the – so called research findings will not be taken seriously by critical design practitioners.

It is important to realise that design practice and design research are activities, which, as it were, move in different directions, back and forth between (historical and contemporary) culture and (technical and applied) science. Architectural design – as a development process – is both imaginative and rational, drawing from a wide range of knowledge and experience, concerning technical, practical *and* cultural aspects. An ‘in-between’ realm: broad and multi disciplinary; traditional as well as innovative; stretching into the domains of the Technical Sciences on the one hand and those of the Arts on the other.



**Figure 1: The in-between realm of design.**

Scholars find themselves confronted with an enormous quantity and variety of architectural artefacts - each with its own specific context and characteristic synthesis of space, form, material and detail. How should researchers set about exploring this extensive field of enquiry?

A design product should not automatically be considered as research output. This can only be the case if scientific criteria are met. A designer is primarily involved in a concretisation process, aimed at reaching a solution, which is – in principle at least – ‘build-able,’ whereas a researcher is involved with the evolvment of knowledge.

Design research may target distinctly different areas of design activity, such as product development (devising new or better building components and technical solutions) or practical applications (aiming at the development of methods and new design tools) but a great deal of design-driven research is aimed at understanding the workings and backgrounds of designs and design thinking. This is essentially fundamental research, even if the subject of study is by definition not ‘pure,’ but complex and applied...

#### 4. Designery enquiry

Which types of study might be considered to be appropriate to the realm of design? What are the potentials for approaches involving controlled design activity in design education and design-driven research?

The designer is involved in problem solving, using his or her imagination to develop - and indeed to predict - a successful final solution. However, design solutions are expressed not so much as answers, but as propositions. The designer’s thinking process is essentially a process of formal transformation. This design ‘searching’ involves specific kinds of active exploration, imagination and evaluation, a characteristic trait for which for which Bruce Archer has introduced the term “Designery Enquiry.” As Archer states: “*The idea of Design as a broad area of man’s concerns, comparable with Science and Humanities, seems to be defensible in pedagogic terms. The idea that there exists a designery mode of enquiry, comparable with but distinct from, the scientific and scholarly modes of enquiry seems to be defensible by the design methods literature*” (Archer 1981).

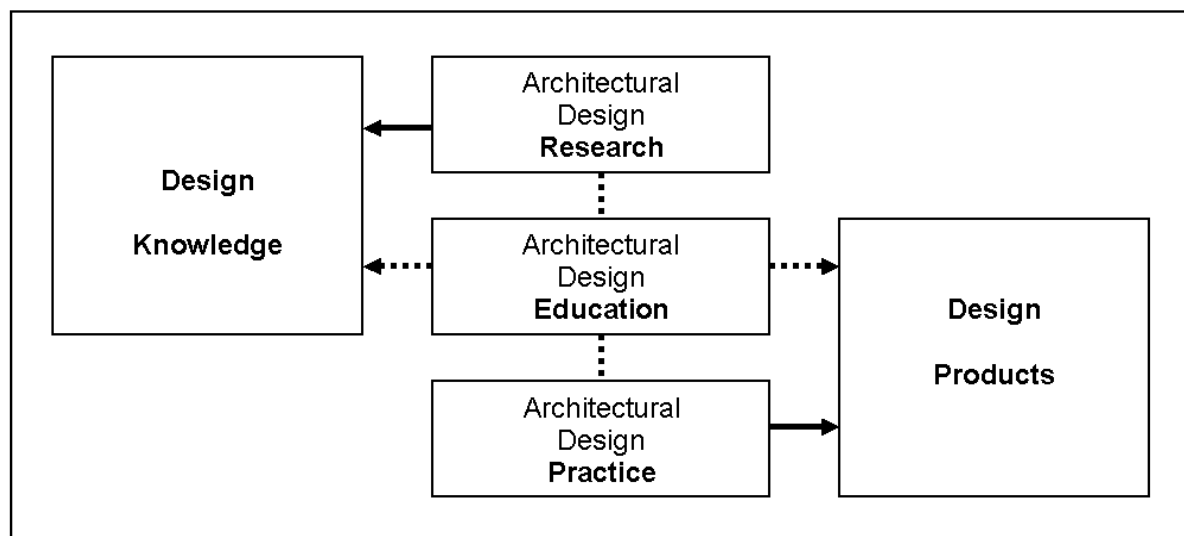
Designery thinking can be considered as a kind of problem solving mental experimentation, which transforms a relatively complex problem into a workable solution, which may be tested, judged and effectuated afterwards. Other activities requiring such foresight, such as setting up workable a planning, developing an educational curriculum or organising a sound research experiment, could also be considered as forms of designery enquiry...

In this context, the term designerly enquiry seems particularly appropriate, precisely because it has a certain, elegant ambiguity. It is a concept which can denote practical designing activities, but also suggests an ‘as-if’ design practice approach, which may be of particular relevance in design education as well as in research experiments.

## 5. Research, education, practice

Which characteristics of designerly enquiry might be considered pertinent for other forms of design-based study, such as education and research?

Whereas traditional design activities are primarily involved with the development of design products and design studies with knowledge, in design-driven education the processes are characterised by reciprocity between the two. In the academic environment, the aforementioned ‘as-if’ design setting is the norm, whereby design and research activities are primarily targeted at the generation of knowledge, insights and skills. Thus, the aim of designerly exercises, integrated into educational curricula, is one of learning *by* doing. For the time being, the results remain ‘conceptual,’ as the students’ propositions are hardly ever realised in built form.



**Figure 2: A comparison of orientations in research, education and practice.**

A traditional approach to the teaching of design involves students - as ‘apprentices’ - to repeatedly carry out integral design tasks under the critical supervision of a ‘master.’ With such an organisation, there is the risk of a ‘black box’ situation, with relatively little transparency on the level of the objective exchange of ideas or evaluation of results.

A pedagogical alternative is to set up clearly structured courses, which incorporate designerly activity, aimed at the *exploration* of architectural design issues. An effective way of ‘channelling’ student activities towards research is by creating a kind of ‘game’ situation. Donald Schön (1992) and colleagues, who have carried out explorative design exercises with considerable success at MIT, have amongst others promoted such a method. The more clearly such tasks and objectives are defined, the more profoundly the students may be made aware of the constraints on the one hand and the creative freedom on the other hand. An advantage of such a structured approach is that in principle results can be compared relatively objectively, whereby the qualities of specific design solutions can be recognised and discussed.

Well-organised design-driven study projects in an educational environment can create a kind of 'laboratory' atmosphere, in which procedures and results can be considered relatively objectively. Of course the disadvantage of projects involving groups of students is their relative lack of experience. However, this is often compensated generously by their candour and lack of 'hang-ups,' which can lead to refreshing viewpoints and surprising insights. Examples of such a thematic, designerly approach in an educational setting can be found in the Delft Form Studies programme (Breen 2001).

## 6. Overview: design-driven research approaches

There are numerous ways in which designs or design processes may give occasion to academic research initiatives.

On one side of the spectrum, design activity may be incorporated into the development of technical applications or product innovations. Such an approach is similar to the practice of research and development, which is common in industry. Such developmental research plays a meaningful role within (technical) university environments and might be expected to be stimulated further in education. A pertinent example of such Development Research at the TU Delft Architecture faculty concerns the evolvement of new forms of structural glazing and façade systems for twisted building volumes; refer to Vollers (2001).

On the other side of the scale we may find the kind of research whose primary aim is to explain the implications of design interventions. The focus could for instance be functional, ergonomic, psychological, societal or philosophical. Such research generally considers design results and processes from a certain 'distance' and makes use of proven methods closely linked to the acknowledged empirical cycles of research. The results may often lead to valuable insights but are not always held in high esteem by design practitioners and teaching staff.

Between these poles the endeavour of design composition studies may be considered the issue of research. Composition research can involve the conception and perception of the overall design and its constituting parts. It may be concerned with the *workings* of design results, but also the *methods* of design, including the utilisation and effectiveness of design media in the development process.

On the basis of experiences in design practice, education and research, an attempt was made to identify relevant paths of study. The following typological overview is divided into two main clusters of - design-driven - research approaches. In the first cluster design results (artefacts and design data) form the hub of the research initiatives, in the second cluster it is the design process that is made instrumental.

Each cluster is subdivided into two sub clusters (A and B), each consisting of two approaches, whereby A indicates research types which are more or less familiar, with specific merits but also inherent shortcomings, and B denotes somewhat less proven, but potentially innovative research procedures, with relatively more emphasis on designerly methods of enquiry.

The projects, which are put forward as being indicative of these eight approaches, are for the most part taken from research initiatives at the TU Delft Architecture faculty in recent years.



## 7. Design-driven research typology

### Cluster 1: Design artefact driven research

In the first category the *outcomes* of design activity are central to the research undertaking. The initiatives discussed are primarily focused on products of design processes (which do not always reveal a very clear line of development).

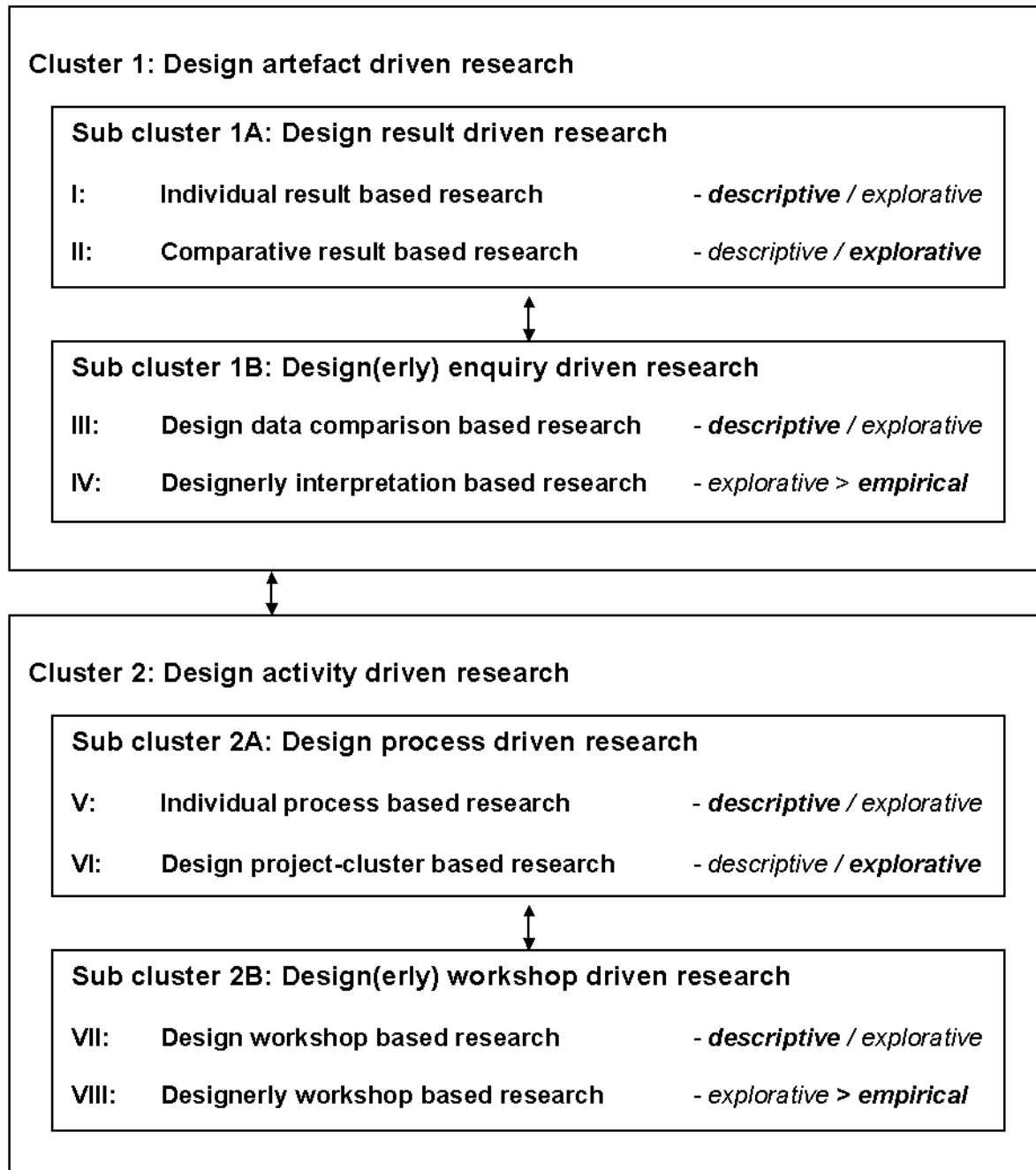


Figure 3: Typological overview of design-driven composition research approaches.

Generally speaking, in these types of study, a design's development cannot be monitored or be 'reconstructed' conclusively on the basis of the process data. The subject and form of such research may vary. The subject matter may consist of one specific design but can also be a concise collection of designs, such as an architect's oeuvre. The research method may include design result analysis, possibly involving relevant references or even comparative studies (sub cluster A) on the basis of tangible results. Alternately, researchers may attempt to get behind the implications and workings of design artefacts by studying intermediate design data or even by 'constructing' alternative design options in order to throw a light on what a design has become (and why) through systematic simulations of what it *might also* or *otherwise* have become (B).

The content of such research will generally come from design practice. The artefacts, which are studied, can vary from emblematic, historic precedents to contemporary products, potentially even including designs created in an educational setting.

The research output can essentially be descriptive, illustrating and communicating the qualities of artefacts considered worthy of study, but might also be more explorative, with the intention of discovering more general 'truths' concerning such aspects as context, design culture, composition or perception.

## **Cluster 2: Design activity driven research**


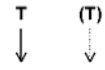





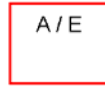







In the second category the design *process* is dominant and tends to form a continuous line from the beginning to the end of the research project, which is as it were constructed around the design's (expected) development.

Generally speaking, a clear notion of the research ambitions should be apparent from the outset, whereby the design development process can be monitored to a large extent. As such, projects of this nature can be said to be process driven and the design process characteristics, results and findings constitute significant a part of the research output.

The content of the research activity is largely determined – one might say initiated – by the designerly 'search' of individuals or groups of designers. The extent to which the designs that are reflected upon are 'let through' into the research project's outcome can vary from an integral, broad representation of designs generated in the process (sub cluster A) to projects with a more rigorous form of scrutiny, filtering and selecting data concerning issues which are at play (B). The design projects, which are the subject of study, may be situated in practice (for instance from competitions) or in an educational environment. Instead of following design processes and their outcomes from a relatively safe distance, there is a preference towards setting up controllable, game-like situations with specific, pre-set tasks and contextual constraints, creating something approaching a 'design laboratory' situation. The search for ways to create experimental design conditions has been a central theme in the Form & Media research programme during the last few years.

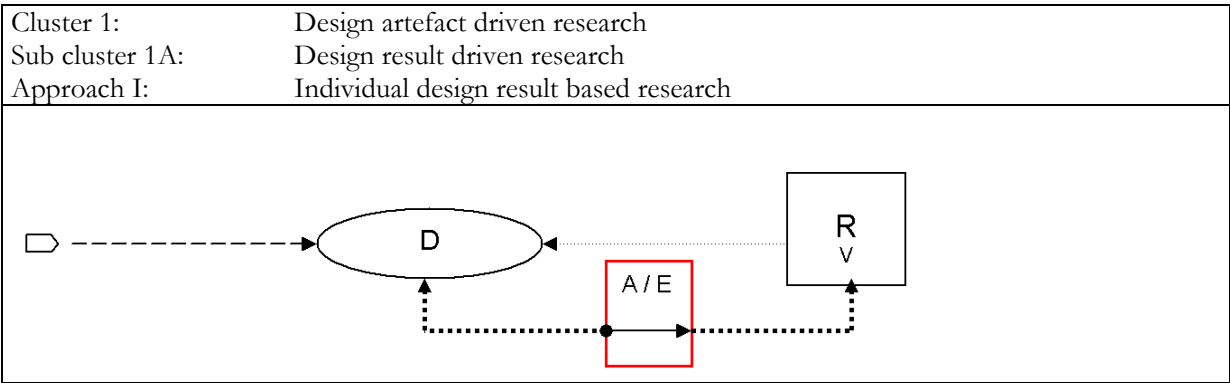
Each of the eight research methods identified here is put forward using a scheme (indicating the impulses and 'flow' of the study trajectories), highlighting procedures. In an accompanying text, some characteristic aspects of study are noted and examples of applications (primarily studies carried out at the Delft faculty of Architecture in recent years) are discussed briefly.

**Table 1: Legend of symbols used in the schemes of design-driven research approaches.**

	Start design process (research initiative)
	Teaching initiative / possible teaching initiative
	Design process (not monitored)
	Design process (monitored)
	Design process (indicating design decision making)
	Design product – single artefact (plus references)
	Design products – collection of artefacts
	Analysis / Enquiry
	Research initiative
	Research relationship
	Project data analysis
	Comparative data analysis
	Designerly interpretation
	Design product as (a part of) research output
	Research project

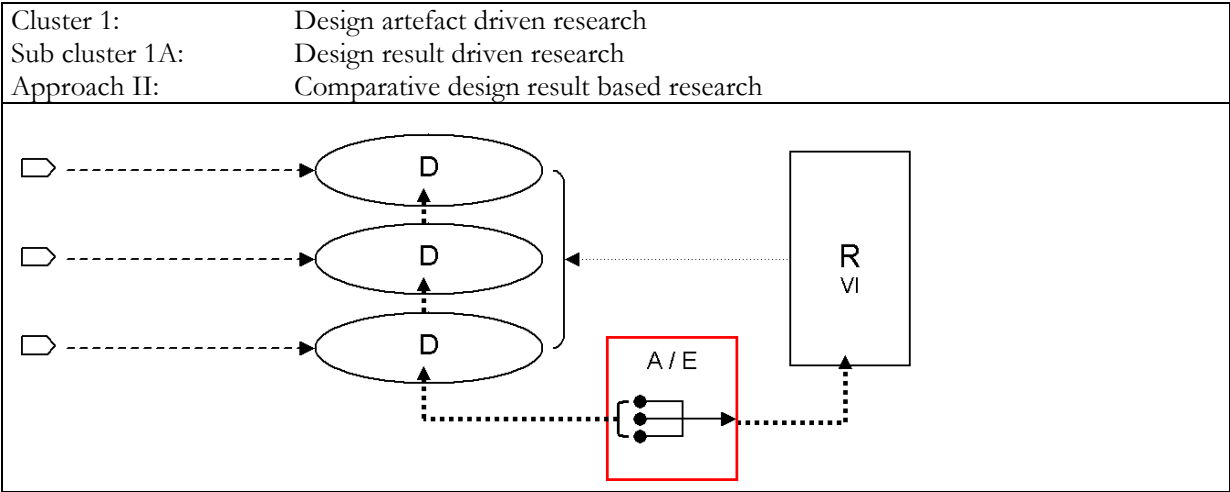
A relatively familiar form of architectural research, whereby the *results* of design processes usually form the departure point for a detailed, methodical evaluation. The subject might be a realised building or ensemble, but may also consist of a collection of design data (drawings, models, written information), referring to a project, which has not (yet) been realised. The method of study usually amounts to analytical evaluation and descriptive documentation of the design artefact, whereby the researcher may try to ‘work back’ through the design data in such a way that light is thrown on how design decisions or working methods have fundamentally influenced the design outcome. Another method is to consider a design from a particular viewpoint, with an open eye for the design’s context and the designer’s motivations and convictions. By comparing the artefact with precedents, or cross-referencing with designs from the same period or with other designs from the same designer or a particular movement, conclusions may be drawn concerning a project’s meaning and its cultural or technological impact.

In such research the definitive design result is usually the dominant factor, whereby the decision-making process is often of secondary importance. The approach is primarily descriptive, intending to uncover relevant background information and to offer insights into the compositional qualities and cultural or historic connotations of the design product that is studied.



**Figure 4: Scheme of Type I: individual result based research.**

As such, the research tends to focus on artefacts, which are considered worthy of mention in the context of historical study or contemporary debate. In such a type of study it is important to clearly define beforehand where the emphasis should be placed, what the reference points of study are to be, in order to create conditions for objective reflection. If this is not the case, the work may come across as journalism rather than being as a scholarly undertaking. We see many studies of this sort, which are carried out and published, frequently in the ‘border zones’ of academic enquiry and descriptive reporting.



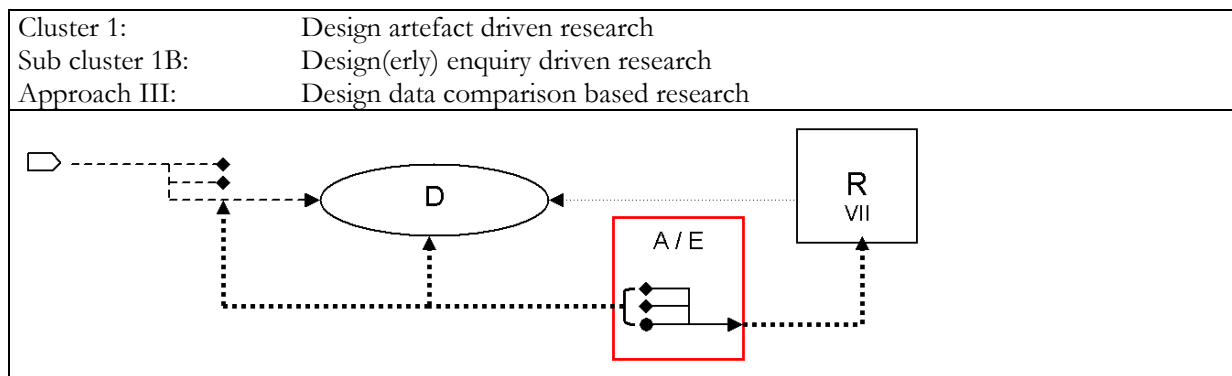
**Figure 5: Scheme of Type II: comparative result based research.**

An approach with has distinct similarities to type I. However, in this type of architectural research the design cases which are studied are usually grouped and juxtaposed in such a way that they may (be expected to) shed a light on each other, to offer insights concerning characteristic similarities and analogies, as well as identifying the crucial *differences* between the objects of study.

Such case-based studies offer an efficient way to study the compositional aspects of architectural artefacts. Exploration of the design aspects of such ‘collections’ of projects or oeuvres can shed a light on the underlying compositional themes and convictions and the effects of different architectural design interventions. Such analytical, comparative research, generally on the basis of built environments and design documents, tends to be explorative in nature, involving not only the description of what there is, but also the identification of distinguishing consistencies and patterns in variation.

The format of output may influence the working methods. For instance: an exposition format may be chosen, in order to allow viewers to make their own comparisons. This means that the material is to be ordered and visualised in such a way that it will facilitate such mental activity. Apart from familiar descriptive methods, more designerly approaches may be employed, for instance by making new drawings, schemes and particularly: models on the basis of existing information. Such an approach may prove instrumental in order to communicate the results to others, but can potentially contribute to the making of discoveries in the context of the research process itself.

An example of a study involving the unbiased investigation and documentation of artefacts by groups of students was the 'Raumplan versus Plan Libre' project, a comparative study focusing on design modes in the work of Loos and Le Corbusier (Risselada 1987). This method has subsequently been applied with some success to further oeuvre studies by research groups organised around Max Risselada, concerning the work of Prouvé, Scharoun, van den Broek, the Smithsons and others.



**Figure 6: Scheme of Type III: design data interpretation based research.**

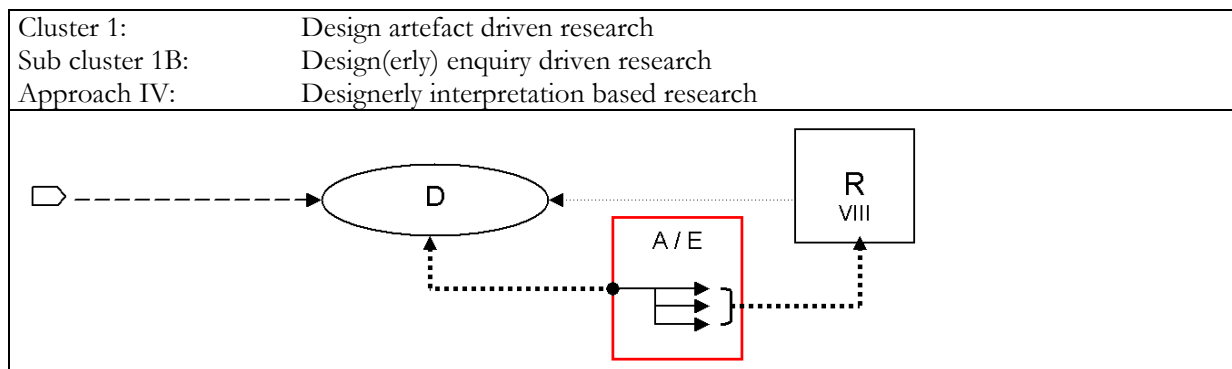
In document-based research it is not only the *end* results of designing activity which count, but it is particularly the design *process* leading up to the final product which is explored and documented.

This may be done in order to add to the body of knowledge concerning the artefact(s) in question, but in addition might be to elucidate on a designer's motives, attitudes or methods. Such research may also have a more general ambition, such as identifying representative design phenomena and their effects. The subject of study could be a specific design artefact but may also consist of a collection of designs with some identifiable relationship.

There are clear parallels between this type of approach and type II. However, apart from being descriptive, such a form of research can often be explorative. The process involves 'reconstructing' design choices from data that may not always be consistent. An example: a 'definitive' design drawing that does not correlate with the photographs of a (possibly demolished) realised building. The designerly interpretation of design data requires a kind of detective spirit, the researcher attempting to uncover what is 'behind the event' (such as the intentions underlying the visible result) of the design in an objective, methodical manner.

The specific aims and methods may vary, depending upon the project at hand. It may be necessary to 'fill in the gaps' and possibly even to extrapolate design developments on the basis of existing data. Alternately, the starting point might be a building, which has been altered, whereby the task is to virtually reconstruct the design as it once was - or indeed, was intended to be.

Research on the basis of design data is relatively familiar. An example of an exercise involving active interpretation by students was the ‘Un-built Loos’ project at the TU Delft’s Architecture faculty. The task was to ‘complete’ house designs by Adolf Loos, which had never been built (a bit like asking students of music to complete an ‘unfinished’ symphony). This potentially innovative project would have deserved to be worked out more convincingly and documented more systematically (Saariste and Kinderdijk 1992). A recent example of a document-driven research project was the international Mel’nikov study, in which the use of physical models played an important role in the compositional ‘reconstruction’ of a series of iconic projects (Fosso, Mácel and Meriggi 2000). For an insight into such a model-driven research process, see: Mácel and Nottrot (2001).



**Figure 7: Scheme of Type IV: designery interpretation based research.**

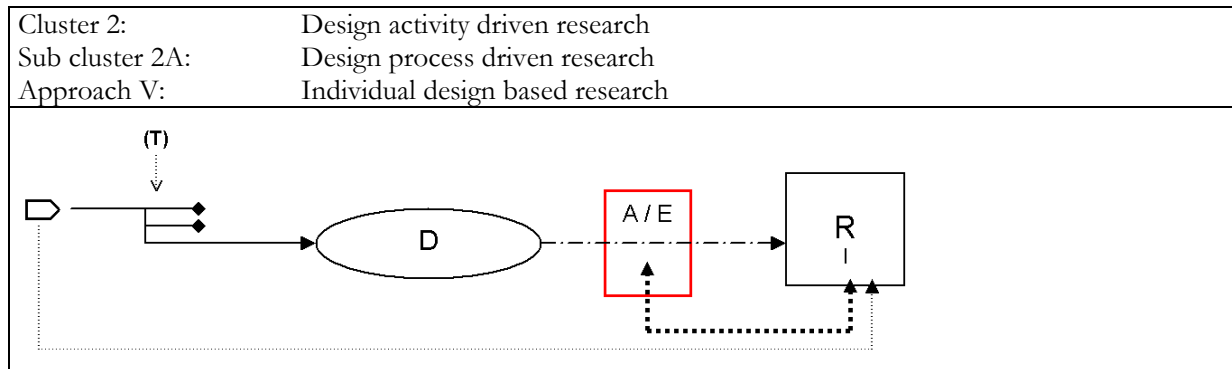
Designery interpretation exercises provide opportunities for the bringing together of research ambitions on the one hand and the kind of design expertise, which is present in the profession (and to a certain extent in the design education environment) on the other. The underlying motives and ambitions of such research initiatives may be to discover more about specific design artefacts, but potentially also to gain insights concerning the ‘science of design’ (which does not necessarily imply considering design as a science).

Such research, involving *designery interpretation* also calls for a ‘detective’ attitude and as such there are parallels with type III. However, in this type of study the researcher generally has less information to ‘go’ on. Such a lack of ‘clues’ means that clues need to be constructed, allowing for design considerations to be played back and forth in a kind of ‘mental experiment.’

The researcher may take a ‘design perspective,’ using designery modes of *enquiry* to ‘get under the skin’ of the design project. In such a way the researcher (or designers invited to take part in a controlled research experiment) can generate ‘simulated’ design options, in order to identify and clarify aspects of real design results. Such designery variations may be developed and compared with the actual result in a relatively systematic way in interpretative ‘cycles’ involving: designery orientation, variation, evaluation and explication. For this to be possible a methodical framework needs to be constructed beforehand and the design aspects that are to be addressed need to be identified and defined in a consistent way. As with the previously mentioned examples of result-driven research, such interpretative projects generally do not start ‘from scratch.’ The basis may consist of one or more design precedents, which will be explored using the working methods of designers but within a methodically transparent research ‘construct.’ Such an approach does not have to stand on its own. Combinations are conceivable, such as with type II (by taking a group of design results as a starting point via cross-referencing and comparison) or with type III (by combining existing information with ‘constructed’ information. More ‘players’

can be involved, as in type VIII. In addition, different combinations of design media can be used and tested in the course of such an undertaking.

Such research is primarily explorative - and will often be carried out in combination with methods mentioned earlier - but empirical research on the basis of *hypotheses* is conceivable. Although this approach is still relatively speculative, it may help bridge the gap between empirical approaches of study and the expertise, which is present in design practice and education.

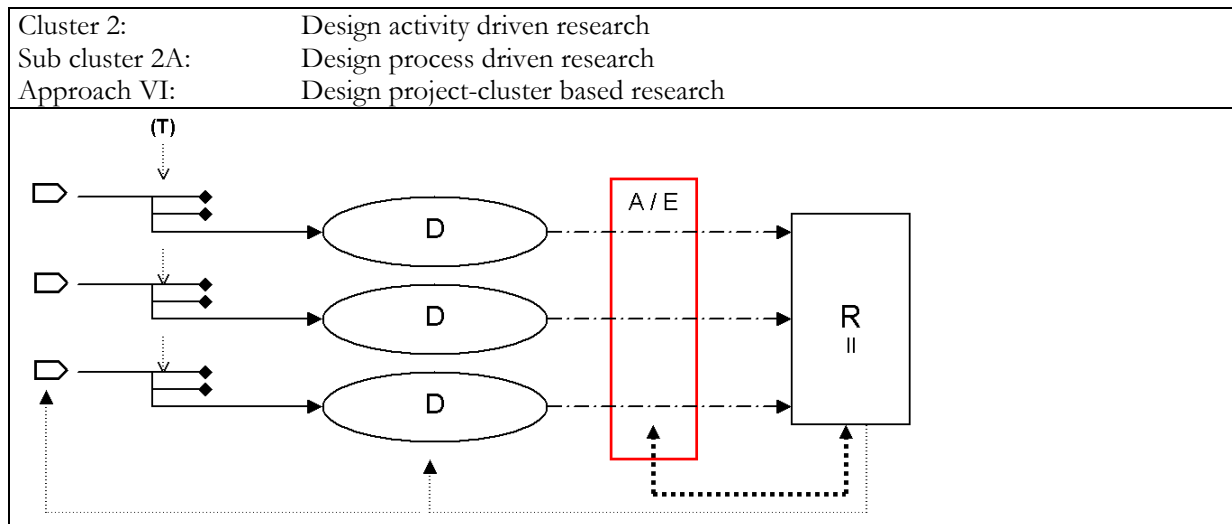


**Figure 8: Scheme of Type V: individual design based research.**

In principle, the initiative for this type of study lies with an individual designer or design team. Usually this means that issues and outcomes of one or more the design processes are collected and documented conscientiously, for the benefit of elucidation – and potentially publication – at a later date. Design sketches and development models, interim options and definitive drawings, as well as photographs of the results may be used to illustrate and communicate the intentions and qualities final product and place it in a broader perspective.

Such a process is usually triggered by *practice*. The basic intention of the designer is to draw up plans that will be realised. Simultaneously there is a kind of ‘self-monitoring’ discipline in view of the imagined scientific potential. Such an approach runs the serious risk of a lack of objectivity. If the designer – who is at the same time playing the role of designer and researcher (sometimes supported by a ‘ghost-writer’) - is not able to keep sufficient ‘distance,’ there is a danger that ‘theory’ is confused with private conviction or design doctrine. In some cases the results amount to an indiscriminate promotion of personal conventions and fascinations. Without sufficient critical consideration, the result may resemble architectural office documentation rather than a serious research product. In recent years there has been a steady outpour of glossy monographs, frequently initiated and sponsored by the offices themselves.

Nonetheless, such approaches can be valuable, because they offer insights into the domain of design decision-making and can often play a meaningful role in design education. Examples of such design centred studies, in which design activity is consciously used as a vehicle and reference point for broader design reflections can be found in the work of design practitioners, such as Hertzberger (1993; 2000), Hoogstad, de Haan and Haagsma (1990), and Holl (1996; 2000) and, to a certain extent, the publications of ‘think-tank’ offices like UN Studio, OMA and MVRDV.



**Figure 9: Scheme of Type VI: design project-cluster based research.**

Design projects involving a *collection* of designers can potentially also form the basis for design research. Such collective activities, with a set of predetermined guidelines concerning context, programme and task can lead to a variety results. In principle, these can nonetheless be compared relatively systematically if pre-determined; binding themes have been specified beforehand.

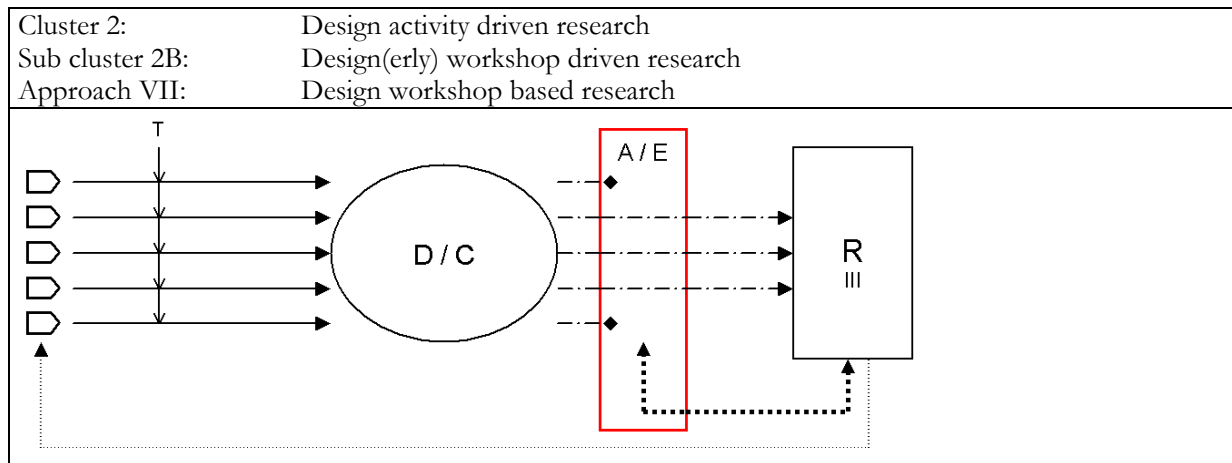
Examples of such initiatives are systematic analyses of professional design competitions, but also thematically clustered design projects in an educational setting, such as groups of diploma projects with a collective theme and comparable context.

Frequently, the design results that come out of such projects are considered to be an integral part of the research output. In some cases, all of the resulting projects are indiscriminately included in project publications, regardless of their relative qualities. For such projects to do justice to their research ambitions there has to some form of rigorous scrutiny and assessment of qualities, preferably on the basis of systematic comparison. On way of doing this is by involving peer groups of qualified researchers or a professional jury.

Projects of this sort all to frequently tend to focus on the undertaking as a whole and to highlight particular themes and cultural developments, rather than offering a objective analysis of the outcomes. The clearer the 'format' of the exercise, the more methodical such an evaluation can in principle become. In many cases the research outcomes are predominantly descriptive. However, if the ambitions and expectations concerning what it is that the projects which are considered are intended to address are specified clearly beforehand, such an approach can become explorative research and potentially even – hypothesis based – empirical research.

An example of such a research ambition was the 'Architectonic Intervention' programme, a series of design studies – based on a number of thematic diploma project clusters – at the TU Delft Architecture faculty. For a summary of the programme and its results, see Klaassen (2001).





**Figure 10: Scheme of Type VII: design workshop based research.**

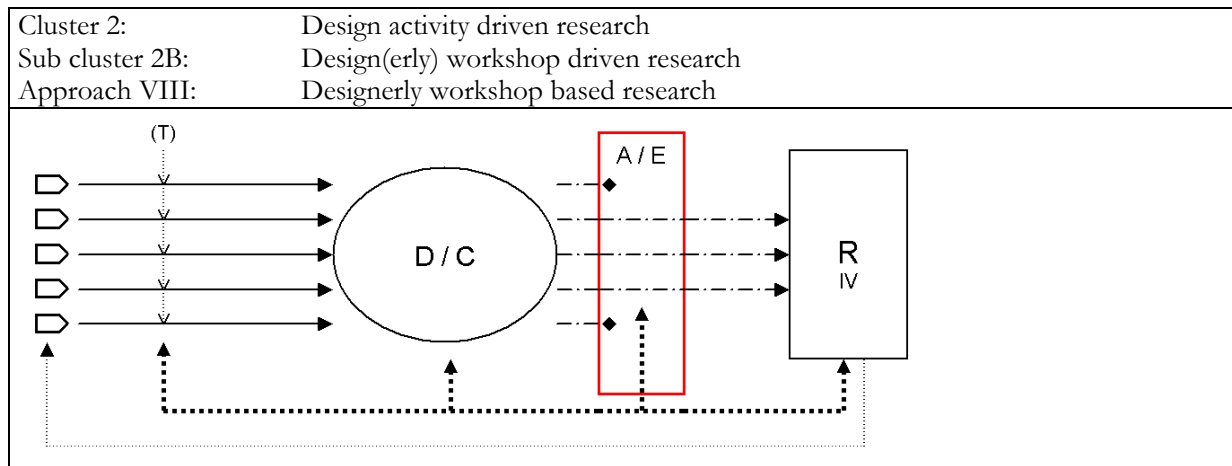
There are distinct similarities between design *workshop* based research discussed here and type VI. However, whilst in this case the design (education) process also plays an important role, the evaluation selection of data has more prominence.

In this context ‘workshop’ indicates a collective project whereby there is more than a loosely binding theme; it means that all participants are set precisely the same task. In the methodological design of such a workshop project, clearly defined rules are set beforehand. There is a clear programme (indicating what is, and what is not expected) and there are conscious limitations concerning the complexity of the task (constraints). The idea behind such a set-up is that by reducing the scope of study, the design work may attain a certain depth, rather than width. In addition, the assumption is that by setting all participants an identical task, the results should in principle become better comparable.

The experience with such projects indicates that such an approach does not lead to identical results, but on the contrary, to a wide range of varied results. From such a collection of design study results, insights may be gathered concerning relevant design themes, recurring motives and the effects of structural and compositional variation.

In this case the (academic) design environment is used to learn more about design attitudes and methods. The procedure is primarily explorative. Design products are not considered as research products (except of course in the light of the individual designerly research of the participants and their learning processes), but as a collection of artefacts, which can be analysed and compared with each other (and with other design precedents) for the benefit of research. The role of the initiators is simultaneously one of ‘curators’ of the project’s creative output and the analysis and presentation of results.

Examples of design-driven projects in an educational setting are Form and Media Studies workshops (and subsequent exhibitions and publications) organised in recent years at the TU Delft Architecture faculty in recent years (Breen and Olsthoorn 1993; 1996; 1999; 2002; Breen 1998).



**Figure 11: Scheme of Type VIII: designerly workshop based research.**

In *designerly* workshop projects the methods indicated in type VII are taken a step further. In this case it not a matter of learning about compositional qualities of designs afterwards, but to target particular issues of interest and *infuse* these into research projects involving active designerly enquiry by the participants, closely monitored by the researcher(s).

Such a workshop –based study requires that the project is set up conscientiously as an experiment, by creating a simulated working environment. Initially – in a pilot study – the tasks may be formulated relatively loosely, in order to explore procedures and gather information. However, the experimental exercise benefits from a more strictly organised research ‘construct.’ The empirical potentials of such a study will be highest if there are clearly defined expectations, laid down in working hypotheses, which can subsequently be tested within the workshop ‘environment.’ Such a ‘game’ situation with preconceived rules, constraints and formats tends to prove beneficial for objective study, creating a platform for systematic comparison of (intermediate) results and in-depth analyses. The working process can in principle be monitored in different stages of the project’s development.

This type of experimental approach may target compositional themes, but may also focus on more methodical issues, such as the influence of different (combinations of) design media.

In principle, such an approach involves setting design tasks, but could in principle also involve group driven designerly studies, as indicated in type IV.

In the context of the Dynamic Perspective research project, the Delft Media Group has been working on ways to develop this type of workshop based empirical research further. Examples of pilot studies are the Imag(in)ing study (Does and Giró 1999) and the Imaging Imagination EAEA conference workshop (Breen and Stellingwerff 1998; Breen 2004). A recent example of a targeted design media experiment, involving closely monitored designerly activity, was the project entitled Virtual Context, a PhD study carried out by Martijn Stellingwerff (2005).

## 8. Perspectives

If we wish to extend the range of design oriented research, then other methods have to be found - or developed - which do justice to the kind creative *variation* that is a characteristic of architectural design. New opportunities for innovative and imaginative design research may be offered by integrating active forms of *designerly enquiry* into education and research. Design-driven working methods offer new opportunities for architectural and environmental design research. The experiences with design-driven exercises in an educational setting and explorative workshop projects, which have been mentioned, indicate that design-driven trajectories deserve to be explored and pursued further. In this context, the methodological component of design-driven research projects should not be underestimated. If results are to stand up to scrutiny by researchers from other disciplines, 'research by design' projects will need to be logically and transparently constructed, as well as clearly and consistently reported.

This exploration of approaches is one of the outcomes of the *Dynamic Perspective* research project (1998 – 2003). These insights are being made instrumental and developed further in the course of the current research programme: *Form and Media Studies*, as part of the Delft faculty of Architecture's Context and Modernity research programme (2003 – 2008). This programme includes four explicitly correlated research topics: Analysis and Development of Theories; Composition and Variation; Production and Visualisation and Experimental Studies.

The typological framework put forward in this contribution, was conceived as a way of creating insight and clarity concerning the aims, media and methods of design driven studies in the context of architectural research. This collection of eight approaches is intended as integral framework of reference. It replaces a typology with six categories, which was evolved and tested earlier on (Breen 2002b).

It has been a conscious choice to, at least for the time being, focus on examples of design-based studies carried out previously at the Delft faculty of Architecture. A next step will be to investigate to what extent the framework may prove to be applicable to other architectural design studies – and potentially to *other* design driven domains of enquiry. It is hoped that researchers of design will feel challenged to make creative and critical use of this 'vocabulary' when developing their own *designs* for imaginative and innovative research projects.

# Ways to Study and Research Urban, Architectural and Technical Design

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## 1. Introduction

Methodology is understanding each other's methods. However, there are more methods of design, study and research than there are designers and scientists. Which of them we can trust (reliability)? Which of them could communicate or justify our results rationally in the scientific community (validity, criticism; these are basic values of science)? (de Jong and van de Voordt 2002b) Which of them could be applied in our own professional motivation? Emotion is our fuel making things move; reason is our oil making things work; criticism is our steering wheel, giving direction. The way to select your own method emotionally and rationally is criticism and debate (de Jong and van de Voordt 2002c). Criticism and debate suppose statements, drawings and texts to be criticised and discussed.

My chair 'Technical ecology' ([team.bk.tudelft.nl/](http://team.bk.tudelft.nl/)) found in the domain of this context-science a rich source of methodological problems similar to those of design related study (de Jong 2003). That is why in the year 2000 my chair got the assignment from the Faculty of Architecture TUDelft (3000 students) to compose a book '*Ways to Study and Research Urban, Architectural and Technical Design*'. This book was published in 2002 and is now obliged literature in Bachelors and Masters of this Faculty, supporting courses in the first, third, fourth and fifth year of the curriculum. Approximately 1000 students made a website on their personal ways to study ([team.bk.tudelft.nl/Education/Education.htm](http://team.bk.tudelft.nl/Education/Education.htm)). This contribution gives an impression of the book's contents. A second volume '*Ways to Precedent Analysis*' is in preparation, filling gaps in the section 'Design research'.

## 2. The book

For the first time 48 authors of the same Faculty explained in one book how they study and research urban, architectural and related technical design and how others do it (de Jong and van de Voordt 2002a).

Two committees of methodology (in 1990 and 2000) studied which kinds of methods are the competence of the Faculty of Architecture TUDelft to be taught. They concluded 8 categories. These roughly became the main sections of the book (see *Table 1*).

**Table 1: Categories of design related study.**

A	Naming and describing	E	Programming and optimising
B	Design research and typology	F	Technical study
C	Evaluating	G	Design study
D	Modelling	H	Study by design

The editors of the book having read all contributions several times decided to standardise only four technical terms throughout the book (see Table 2).

OBJECT OF STUDY			
CONTEXT	<i>determined</i>	<i>determined</i>	<i>variable</i>
		Design research	Design study
	<i>variable</i>	Typological research	Study by design

**Table 2: Categories of design oriented study.**

We speak about study when the object is variable, not yet determined. Electricity was studied in the 18<sup>th</sup> century, but the phenomenon was not yet determined. That happened in the 19<sup>th</sup> century. Then it became object of re-search, as the Americans called the empirical scientific activity since the beginning of the 20<sup>th</sup> century. We followed that use in Europe and degraded the older and more general term ‘study’ as an activity of unexperienced students (Dijkhuis 2002). But any scientist not having the modesty of the beginner in a world of which we only know and understand a negligible fraction, becomes an administrator of still very poor knowledge. Knowing more means doubting more.

Hertzberger (2002) explores the methods assisting in opening up possibilities, instead of determining them. Descartes’ *Discours de la Méthode* (1637) focused on doubt (this classical text, the very start of modernism, is short and very readable. Buy it! It also says something very interesting about Holland, where Descartes lived writing the book). Design study distrusts, like classical sciences, all that is obvious, but does not throw everything overboard all at once. Experience evaporated into routine deserves suspicion of the scientific approach, deeming no pre-supposition sacred. However a culture, certainly a local one, surrounds us with pre-suppositions unbeknown to us; like a fish without knowledge of the water it is taken from, at the same time there is certitude of existing conditions: a table, a bed, a kitchen entails great forms of freedom (cited from the introduction on the section ‘design study’ in de Jong and van de Voordt 2002).

As soon as the object is determined we can re-search it as an empirical fact, with empirical methods (Mácel 2002). Existing drawings and texts are historical, empirical facts after all, subject to design research (de Jong and van Duin 2002) and more designerly (Breen 2002a): typology (de Jong and Engel 2002). But how to study them in a scientific way when we have to *make* them? Before they exist only the context could be studied empirically as a source of the programme of requirements. But the translation into spaces, masses and materials is an other question with many supplementary decisions. We make design studies like Rembrandt and Chopin made studies, but can we do it in a scientific way? The hypothesis of the book is: ‘Yes!’. If it would be ‘No!’, like Priemus (2002) of all the authors most closely seems to state, design courses are not at home at a university.

### 3. Context

Table 2 shows another important term for urban, architectural and technical design: context. The Rector of our TUDelft Jacob Fokkema in his preface agrees with us: there are no disciplines at the TUDelft as context sensible as urban, architectural and related technical design (Fokkema 2002). There are varying political, cultural, economical, technical, ecological and spatial contexts

making scientific generalisation difficult. A good solution here could be a bad solution there. How could we compare technical solutions, buildings, neighbourhoods towns or regions when context can not be excluded by a 'ceteris paribus' (under the same circumstances) supposition? Which types and concepts (Leupen 2002) survive in different contexts in the course of time? Designs surviving changing functions and programmes (part of their context) during the period buildings can exist as a construction we call 'robust'.

Designing means varying a not yet determined object in our head. That is difficult enough, even when the constraints are described properly enough for systematic optimisation (van Loon 2002). But what to do when not only the object is varying, but also the context, for instance the location? (Verheijen et al. 2002) In the book that kind of study is called study by design. In fact the graduate student of urbanism, architecture or building technology searching for an object of study and a location is studying by design. The idea of the graduate project develops in mutual relation between possible object and location. The student starting her or his graduate project is swimming in a sea of possibilities, sometimes for months or even years.

Is there a definitive scientific method for study by design? No. We are searching for it, the book is searching for it and there are examples (Frieling 2002). The simplest way is to keep context for the time being as if determined and vary the object (design study) and then keep the designed object as if determined and vary context (typological research) and the reverse, again and again. Then it is useful to know something about the possibilities of design study and typology until now. Is it the only method? We do not think so. You can invent a new method or use existing methods. If you invent a new scientific method, you get a place in the next edition of the book. However, if you invent a new method you have to prove it to be new and thus read the book first. Otherwise people will say 'We knew that already.'

We speak rather easily about varying the context, for instance the location. But context is more than location, it is also the ecological, technical, economical, cultural and political context. They all vary! How do we handle that? By experiencing the possibilities. The book helps with a scheme (Figure 1).

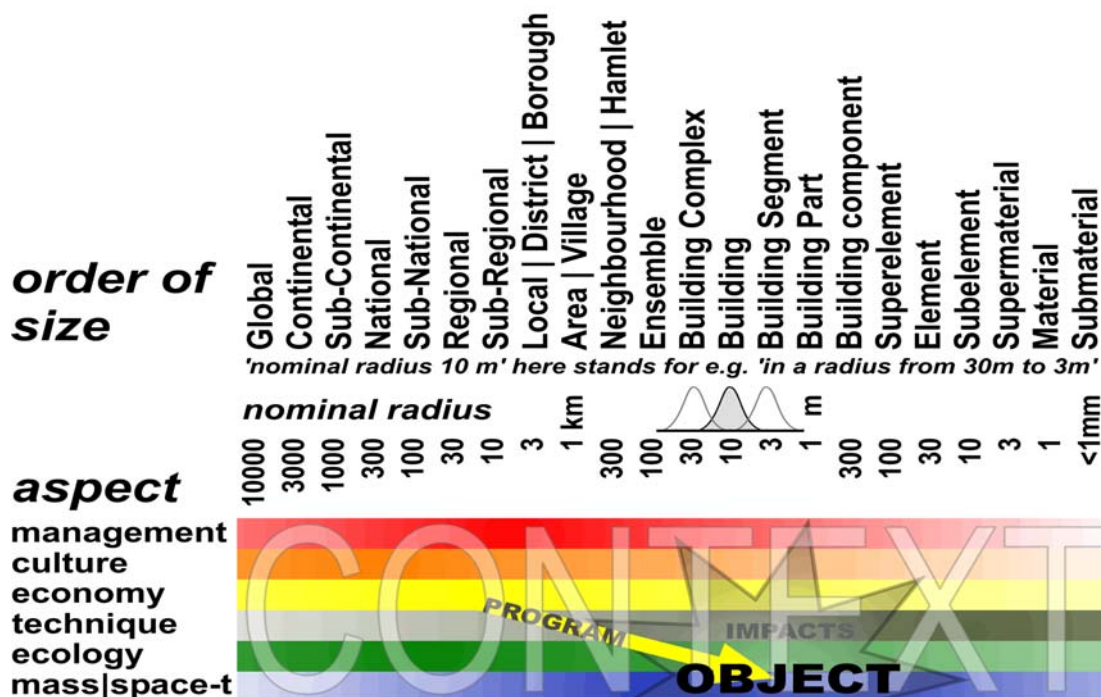


Figure 1: Contexts.

Look for the range of scales where your object of study has its place. The rest is context. Any programme of requirements originates in the context of the future object. But what kind of context is it? The management on municipal level can be an initiator, the neighbourhood can obediently follow. Indicate suppositions like this with ‘!’ and ‘?’ in the scheme on some levels of scale in the upper rule. The surrounding culture could be experimental (>) or traditional (<) and that can be different on national, regional, local or any other scale. The local economy could grow (+), the national economy in the same time shrink (-). The technology could be based on division of tasks (/) on regional level and on combination (x) on local level. In my garden I could develop to more ecological diversity (|) and in the same time more evenness (=) in my neighbourhood if my neighbours do the same. The built up area could be deconcentrated (D) on regional level, but concentrated (C) on local level.

Calculate how many contexts there are possible (de Jong and de Graaf 2002) and you get a feeling of the possible variety of contexts. That is what we learn from ecology as well. To make it worse contexts are changing (perspective). Nevertheless it is important to realise what context you have in mind and hand it over to your judge. When your design or study proposal is judged, your judge could otherwise give a bad judgement because (s)he has an other context in mind for the future. Her or his future is not yours! Moreover specifying the supposed context of a drawing or text as a scientific document makes it better retrievable (de Jong and van de Voordt 2002d).

Retrievability connected with the problem of naming and describing concepts and components of design is a scientific issue of great importance. If you do not communicate your results it will never be part of science. But how do we communicate our (eventually preliminary) drawings for scientific criticism and debate? What kind of accompanying key words do we have to choose to find our drawings back struggling with the same design problems?

What kind of key words do you need yourself to find reference drawings of other designers in a data base according to your problem? Internet is the contemporary answer. But you will not find easily images answering your specific design problem using common key words.

#### 4. Key words

Many methodical aspects you can find back in the comprehensive index of the book. It counts some 10 000 key words and key word combinations. The combinations are syntactically coupled to find back contents of drawings or lines of reasoning. In the index an expression like  $y(x)$ , object(subject) means ‘object y as a working (function, action, output, result, characteristic) of the subject x (independent variable actor, input, condition, cause).’ Syntactic key words give a short and clear representation to criticise validity and reliability of the related concepts used in a study proposal (Figure 2).

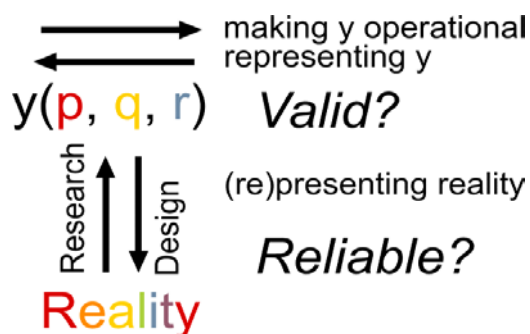


Figure 2: Judging validity and reliability of concepts used in a study proposal.

Suppose you want to make a study proposal. In the index you will find:

study proposal(ability to be criticised)	30	study proposal(drawing code)	29	study proposal(presentation)	29
study proposal(ability to be refuted)	30	study proposal(empirically orientated)	29	study proposal(publish)	30
study proposal(accountability)	29	study proposal(end product)	30	study proposal(referee(external))	29
study proposal(accumulating capacity)	29	study proposal(expressed(image))	29	study proposal(reference(images))	28
study proposal(accumulation(know how, knowledge))	30	study proposal(expressed(verbally))	29	study proposal(representation)	30
study proposal(aim-orientated)	29	study proposal(fascination)	30	study proposal(responsible)	30
study proposal(assignment initiator)	29	study proposal(fascination)	29	study proposal(retrievability)	29
study proposal(bold)	30	study proposal(IAAI)	28	study proposal(risk-free citations)	30
study proposal(book)	30	study proposal(identity)	29	study proposal(scale falsification)	29
study proposal(cliché)	30	study proposal(internet site)	29	study proposal(self-evident aspects)	30
study proposal(concept formation)	29	study proposal(internet)	30	study proposal(study programmes)	30
study proposal(concepts(overlapping))	29	study proposal(key-words)	29	study proposal(sub-projects)	30
study proposal(conditional(position))	29	study proposal(knowledge)	29	study proposal(synergy)	30
study proposal(conference)	30	study proposal(legend)	29	study proposal(theme)	29
study proposal(converge)	30	study proposal(literature lists)	29	study proposal(title(significant))	29
study proposal(daring)	30	study proposal(means-orientated)	29	study proposal(university latitude)	28
study proposal(designing(affinity))	28	study proposal(method)	29	study proposal(website)	30

**Figure 3: 51 Of approximately 10 000 keywords in Ways to Study.**

It is a checklist! You only have to read 3 pages to know how a study proposal could be judged. On those pages 7 criteria are mentioned which appeared to be useful to judge the research proposals in the Architectural Intervention some years ago and graduate proposals for Bachelors and Masters on our Faculty:

1. Affinity with designing.
2. University latitude.
3. Concept formation and transferability.
4. Retrievability and accumulating capacity.
5. Methodical accountability and depth.
6. Ability to be criticised and to criticise.
7. Convergence and limitations.

Graduates and PHD students experimented with these criteria to *make* study proposals. Concept formation (3) appeared to be a reliable first way to make a preliminary study proposal (de Jong and Rosemann 2002), using proper key words representing a personal fascination. They help to make your study retrievable by others accumulating urban, architectural and technical knowledge and know-how from the very beginning (4). Primarily vague key words can be made operational for study and research by coupling them syntactically, adding other key words into full sentences and making the supposed working between them more explicit in hypotheses (de Jong 2002a). Then the book helps to find methods to study these supposed workings and prove them by design or research. That helps methodical accounting (5) and makes scientific criticism possible (6). You can show your affinity with designing (1) and your university latitude (2) by comparing existing drawings (de Jong 2002b) representing your fascination and making their contexts explicit as described in the preceding paragraph. But the proposal should show limitations as well. You have to show how you will get a result in the limited time given (7).

## 5. Conclusion

The book is not made to read all at once. It is made accessible by very many key words to find your own unique way to study. Students have to choose their own preferences. But design students do not read easily. So, the question arose how to build an interesting course on methodology for designers. A classical exam with questions about the book did not succeed. Instead we asked the students already in the second semester Bachelors to publish their earlier work in a personal website, making it retrievable and convincing for others, to make a proper



bibliography and iconography. We added other practical assignments to cover the contents of the book like ‘Compare at least two images fascinating you professionally in a scientific way,’ ‘Make a study proposal for your graduation’ or ‘Criticism other websites in the same course’

(*team.bk.tudelft.nl/Education/Education.htm*). Raising questions by practice is better than answering them before they arose. In the Masters and PHD phase the emphasis moved to debates about differences in language games between designers, empirical researchers and managers (de Jong 2005a), about differences between research, design study and art science (the object of a newly founded Faculty in the University of Leiden; de Jong 2005b), about the difference between probable, possible and imaginable futures, about the boundaries and suppositions of imagination itself.

The book approaches its second edition, time to think about drastic improvements. You, dear readers are invited to help by criticism and lacking contributions.

## **Part Two: Design Processes**

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# Design Research at CME in Twente

## Perspectives on design processes

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### 1. Introduction

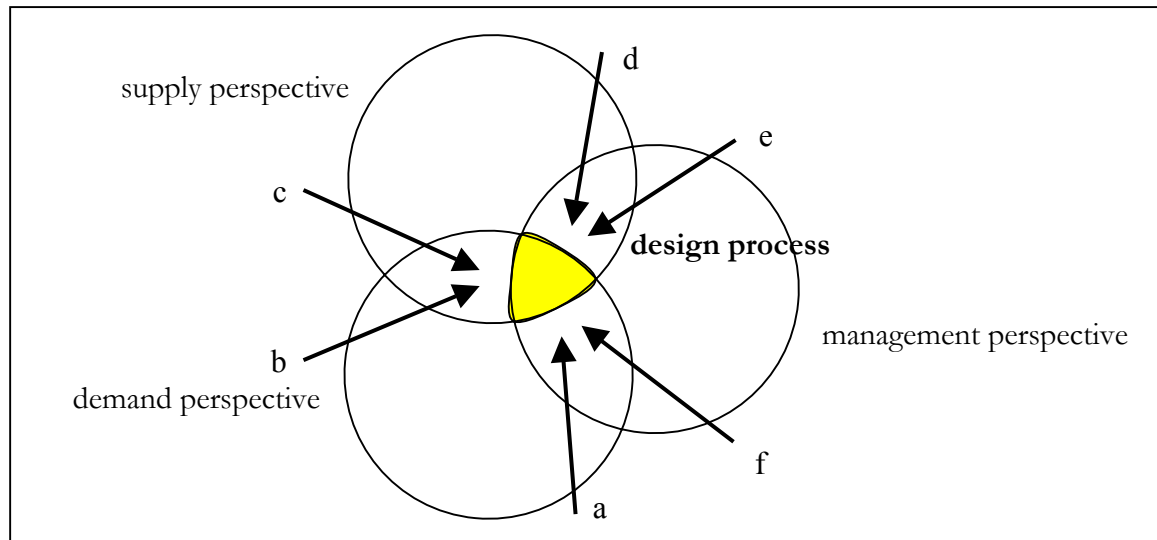
The Construction Management & Engineering (CME) group of the faculty of Engineering Technology at the University of Twente focuses on the need to acquire better insights into the mechanisms governing innovation in the building process and its environment. Its research program concentrates on the management and governance mechanisms of construction processes, the interfaces between planning and design, and design and realisation. The program integrates various insights from different disciplines: technology, public and business management, and design (management), and the development of innovative construction processes and materials. Design research is a central core of this research programme, aiming at improving the effectiveness and efficiency of design processes in general and more specific in construction industry.

Currently, the design research group consists of Geert Dewulf, professor of planning and development, Isabelle Reymen, assistant professor design management, Karel Veenvliet, assistant professor design management, and the following researchers, partly involved: Saad Al'Jibouri on constructability and risk management, and Joop Halman, Andreas Hartmann, and Hans Voordijk on innovation processes, platform driven development and (new) product development, and Henny ter Huerne on design processes.

In this paper, an overview is given of the research perspectives, central theoretical focus, and future directions of the design research group of CME.

### 2. Research perspectives

Research in the CME group looks from three main perspectives to design processes, namely the demand perspective, the supply perspective, and the management perspective. The same holds for the research on designing. We look at the design process from three perspectives, namely the demand perspective (the user), the supply perspective (the designer and engineer) and the management perspective (the manager), as illustrated in Figure 1. Our research focuses on the overlaps between the perspectives, namely for each perspective the overlap with the other two. The research is performed by the staff members as mentioned in the introduction and by Ph.D. (and master) students. For each of the perspectives, we discuss our results and Ph.D. projects. Finished master projects (in Dutch) are given as an illustration of our research.



**Figure 1: Perspectives on design processes, with focuses on the overlaps.**

### 3. The demand perspective

The demand perspective looks at the relation between the user/client and the design process. More specific, we focus on design management from the demand side and on briefing.

#### **Demand perspective: design management/demand**

Design management/demand focuses on managing the design process from the demand side (a combined user-manager perspective). Important topics are:

- User participation and collaborative design (Dewulf and van Meel 2002, Dewulf and van Meel 2003, De Graaf and Dewulf 2004, Reymen et al. 2005).
- Role and selection of designers:
  - Master: Selection of designers in the Building and Utility sector. A study into the development of an instrument for the selection of designers in the construction process (*Selecteren van ontwerpers in de B&U sector. Een onderzoek naar het ontwikkelen van een instrument voor de selectie van ontwerpers binnen het bouwproces*), by Gerwin van der Panne (2004 – 2005), supervision by Dewulf and Reymen.
- Design communication:
  - Ph.D.: Design communication: Communication on values between stakeholders (to be started, PSIB: Proces en Systeem Innovatie in de Bouw project), supervision by Dewulf and Reymen.

#### **Demand perspective: briefing**

In briefing we study the interface and interaction between the demand perspective and supply perspective:

- Design quality (Dewulf and van Meel 2004).
- Key performance indicators and value management:
  - Ph.D.: Key performance indicators: From values to performance criteria (to be started, PSIB project), supervision by Dewulf and Al'Jibouri.

#### 4. The supply perspective

Much research concentrates on the supply perspective. Topics in the overlap between the demand and supply perspective are mass customisation and engineering to order. In the overlap between the supply and management perspective, we focus on design management from the supply side and on constructability.

##### Supply perspective: mass customisation

Mass customisation researches process and product approaches that offer large variety for the user and that are designed and constructed economically:

- Possibilities and limitations of platform driven design and development of products (Halman et al. 2003, Halman 2004). More information about this research program can be found on the website of CME.
  - Ph.D.: Modular consumer-oriented housing construction, by E. Hofman (since 2004), supervision by Halman and Voordijk.
  - Master: Role of the government in consumer oriented building in Dutch housebuilding. A benchmark between platform driven design and construction in general theory, shipbuilding and consumer oriented building in governmental organizations (*De rol van de overheid binnen consumentgericht bouwen in de Nederlandse woningbouw. Een benchmark tussen platform gedreven ontwerpen en uitvoeren in de algemene theorie, de scheepsbouwindustrie en consumentgericht bouwen binnen de overheid*), by Wouter van Drie (2003-2004), supervision by Halman, Voordijk, and Reymen.
  - Master: Role of the supplier in consumer oriented building in Dutch housebuilding. A benchmark between platform driven design and construction in theory, automotive industry and supplier industry (*De rol van de toeleverancier binnen consument gericht bouwen in de Nederlandse woningbouw. Een benchmark tussen platformgedreven ontwerpen en uitvoeren in de theorie, de auto-industrie en de toeleveringsindustrie*), by Robert Dalenoord (2003-2004), supervision by Halman, Voordijk, and Reymen.
  - Master: Platform driven developments in Dutch construction industry. Study into platform driven developments looking at theory, Dutch construction industry and consumer oriented building from the perspective of builders (*Platformgedreven ontwikkelingen binnen de Nederlandse bouwindustrie. Onderzoek naar platformgedreven ontwikkelingen kijkend naar theorie, de Nederlandse bouwindustrie en consumentgericht bouwen vanuit het perspectief van bouwbedrijven*), by Arjen Roosen (2003-2004), supervision by Halman, Voordijk, and Reymen.
  - Master: Role of the architect in Dutch consumer oriented housebuilding. Study into platformtheory, aircraft industry and consumer oriented building from the perspective of the architect (*De rol van de architect in de Nederlandse consumentgerichte woningbouw. Een onderzoek naar de platformtheorie, de vliegtuigindustrie en consumentgericht bouwen vanuit het perspectief van de architect*), by Mohammed Bodra (2003-2004), supervision by Halman, Voordijk, and Reymen.

- Master: Modular consumer oriented building. A study as a starting point for a modular consumer oriented building principle (*Modulair consument gericht bouwen. Een onderzoek als een aanzet voor een modulair consumentgericht bouwprincipe*), by Erwin Hofman (2003-2004), supervision by Halman and Voordijk.
- Master: Process improvements in consumer oriented housebuilding. A study into improvements concerning efficiency and effectivity in the buying process of consumer oriented building projects (*Procesverbeteringen in de consumentgerichte woningbouw. Een onderzoek naar verbeteringen ten aanzien van de efficiëntie en effectiviteit in het koopproces van consumentgerichte woningbouwprojecten*), by Arjan Horstman (2004 – 2005), supervision by Halman, Reymen, and Voordijk.

### Supply perspective: engineering to order

Engineering to order uses value engineering and value management as theoretical basis to improve (construction) design and engineering processes:

- NAP/DACE project (Nederlandse Apparaten/Dutch Association of Cost Engineering): concentrates on certifying Value Engineering for Construction in the Netherlands, based on European Directives. Involvement by Veenvliet
- Master: Manage the managing of the design process. Expectations concerning the throughput time of civil design projects (*Beheers het beheersen van het ontwerpproces. Verwachting t.a.v. de doorlooptijd van Civiele Ontwerpprojecten*), by Roderick Roelfs (2000-2001), supervision by Al'Jibouri and Veenvliet.

### Supply perspective: design management/supply

Design management/supply studies how the design process can be managed from the supply side (a combined designer-manager perspective):

- Design reflection (Reymen 2003) and design expertise development of designers (Dorst and Reymen 2004, Reymen et al. 2005, van Overveld et al. 2003). Part of this research is performed in collaboration with the Technische Universiteit Eindhoven and Imperial College London.
- Composition (Peeters et al. 2004, Peeters et al. 2005), and management of design teams (Faissal et al. 2004, den Otter and Reymen 2005):
  - Ph.D.: Relating design team composition to design processes and effectiveness, by M.A.G. Peeters, performed at Technische Universiteit Eindhoven (since 2001), supervision by Rutte, van Tuijl (TU/e), and Reymen.
  - Master: Integral designing. Communication and collaboration in multidisciplinary design teams (*Integraal ontwerpen. Communicatie en samenwerking in multidisciplinaire ontwerpteamen*), by Faissal Kanjaâ (2002 - 2003), supervision by Veenvliet and Reymen.
- Design co-ordination (product and process co-ordination), and design integration:
  - Master: Co-ordination in the design process. Study into the co-ordination process between design disciplines of complex railway projects (*Afstemming in het ontwerpproces. Onderzoek naar het afstemmingsproces tussen ontwerpdisciplines bij complexe spoorprojecten*), by Jan Mors (2002 – 2003), supervision by Reymen and Veenvliet.

- Master: Co-ordination by 3D modelling. Study into the use of 3D modelling in an organisation to improve co-ordination (*Afstemmen door 3D modelleren. Een onderzoek naar het gebruik van 3D modellen binnen een organisatie om afstemming te verbeteren*), by Dominique Dankaart (2004 - 2005), supervision by Reymen and Veenvliet.

### **Supply perspective: constructability**

Constructability focuses on the interface between design and realisation (Langkemper et al. 2003, and Veenvliet and Wind 1992):

- Ph.D.: The Organisation of Integrated Object Design in Construction, by Karel Veenvliet.
- Master: Application of Constructability on the building process of inner-city infrastructure (*Toepassing van Constructability op het bouwproces van binnenstedelijke infrastructuur*), by Jeroen Langkemper (2002 – 2003), supervision by Al-Jibouri, and Reymen.

## **5. The management perspective**

The management perspective on design processes focuses on topics rooted in organisation studies, applied to designing in the construction industry. We distinguish three levels in this perspective, namely project level, corporate level, and branch level. They are closely connected, but differ in the way they look at the design process. The project level focuses on characteristics of a building process organisation (project characteristics and dynamics). The corporate level focuses on the building organisation (business characteristics and dynamics). The branch level focuses on the building sector (inter-organisational characteristics and dynamics). The overlap between the management and supply perspective focuses on supply chain management and logistics (project, corporate and branch level) and design management from the management perspective (project and corporate level). On the overlap between the management and demand perspective, innovation management, risk management, planning and control are our topics (project, corporate and branch level).

### **Management perspective: supply chain management and logistics**

In supply chain management and logistics, the focus is on the operations management perspective of the supply chain, more specific the management of information flow through the supply chain:

- The use of ICT (Adriaanse et al. 2004):
  - Ph.D.: Preconditions of the inter-organisational use of ICT in construction projects, by Arjen Adriaanse (since 2003), supervision by Dewulf and Voordijk.

### **Management perspective: design management/organisation**

Design Management/organisation studies the design process from the management perspective. Possible topic in the future will be:

- Design alliances.



### Management perspective: innovation/risk management, planning and control

The research programme in the area of planning and risk management is intended to provide stakeholders with tools and support mechanisms for their decisions (Al-Jibouri and Mawdesley 2002, and Mawdesley et al. 2003).

- Managing innovation (Hartmann and Girmscheid 2004 and Hartmann 2004).
  - Ph.D.: Managing innovation in project based organisations, by Jasper Caerteling (since 2002), supervision by Doree and Halman.
- Design tools for risk management (Keizer et al. 2002):
  - Master: SCRUM in real estate development: by more chaos less uncertainty? Study into possibilities and limitations of design methodology SCRUM for the managing of uncertainty in real estate development (*SCRUM in Projectontwikkeling: Door meer chaos minder onzekerheid? Een onderzoek naar mogelijkheden en beperkingen van ontwerpmethodiek SCRUM voor beheersing van onzekerheid in projectontwikkeling*), by Sjoerd Blokpoele (2004), supervision by Dewulf, Reymen, and Veenvliet.

## 6. Central theoretical focus

Systems engineering is our central theoretical focus on design processes; it comes back in each perspective, of course from a critical point of view. As Veenvliet (1997) states: “*Systems engineering (SE) is a requirements driven way of controlling the design process. It is the discipline of translating customer requirements into a specification of components which, when combined together, will satisfy the requirements. This is usually done in several phases.*” In Veenvliet (1999), he adds: “*Systems Engineering is an integrated approach which bridges the gap between project management and the product to be developed. The SE concept takes care of a goal-directed structured and multi-disciplinary design process and a coherent set of design and management principles, techniques and tool especially for a customer order driven engineering.*”

- COINS project (Civil engineering Objects and Integration of processes and Systems). One of the objectives is to improve the interaction between design and construction during the development of civil engineering objects, so waste will be diminished. Concepts and approaches of the development process, like concurrent engineering, systems engineering from the industry and constructability and lean construction from the construction industry are studied to describe and compare the way interactions manifest during projects. Involvement by Veenvliet
- Master: Systems engineering, RAMS and Arcadis. Study into the integration of Systems engineering and RAMS and the applicability in the Arcadis design environment (*Systems engineering, RAMS en Arcadis. Een onderzoek naar het integreren van Systems engineering en RAMS en de toepasbaarheid in de Arcadis ontwerpomgeving*), by Maarten Stoutenbeek (2004 – 2005), supervision by Veenvliet and Reymen.
- Master: To an integrated project approach for infrastructural projects. Study into the integrated application of Prince2 and Systems engineering for complex infrastructural projects (*Naar een geïntegreerde projectaanpak voor infrastructurele projecten. Een onderzoek naar het geïntegreerd toepassen van Prince2 en Systems engineering voor complexe infrastructurele projecten*), by Paul Hendrikx (2004 – 2005), supervision by Veenvliet and Reymen.

## 7. Conclusions and future directions

For our research group, writing this paper was a learning experience in the sense that we now created a structured overview of our research activities. In the future, we want to reinforce our focuses. A main goal of our design research is, as mentioned in the introduction, improving the effectiveness and efficiency of design processes in general and more specific in construction industry. A second goal is to develop insight in design processes for educational purposes. A third goal, but not least, is to obtain a prominent position in (some fields) of the international (building) design research community. To obtain these goals and to strengthen our research, we do need collaboration with other research groups in the Netherlands (and outside the Netherlands).

We think, for example, about strengthening the demand perspective with knowledge about architectural design and management (for example, with TUDelft and ADMS of the TU Eindhoven). For the supply side, collaboration can take place on mass customisation with TUDelft and TU Eindhoven. For our management perspective, collaboration with management faculties can improve our research (for example BBT at UTwente and TM at TU Eindhoven). Also collaboration with industrial design faculties might offer advantages for both parties. Currently, we do not focus on the development of tools, but they are necessary to operationalise our knowledge for design practice. For each of the perspectives, design tools should be developed (likely in collaboration with others); for example, tools for user participation, design collaboration, decision support, and design management.

Researchers who like to participate in our research program are invited to contact us. We can exchange knowledge about the state of the art in research and education (including own publications and courses) and developments in practice, develop project proposals for Master and Ph.D. students, make joint publications and develop joint courses.



# Experiences With Collaborative Design by Constructing Metaphoric Objects

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## 1. Introduction

This chapter describes a number of initial results of the author's PhD study entitled: 'A guide for preparing and facilitating multidisciplinary, collocated design meetings as a means for building design improvement.' This study consists of the following research tasks: studying what a systematic approach to a design meeting means; studying how a design meeting can be prepared and managed; developing working methods that create and share knowledge and developing a design guide.

The design process for a design meeting will be modelled as a collection of related preparatory and design activities, executed by managers, facilitators and designers with the aid of design tools and management plans. The model is based on existing insights and theories of cognitive processes such as perception (verbal, visual and tactile), communication, (creative) thinking, (experiential) learning and (interdisciplinary) collaboration.

This study is part of the Strategic Design research programme process cluster of the Knowledge Center for Building and Systems (KCBS), a joint project conducted by the Netherlands Organisation for Applied Scientific Research (TNO) and Eindhoven University of Technology (TU/e). The center's mission is to improve insight into the underlying principles of integral design processes to decrease investment risks and ensure the sustainability of buildings.

## 2. Problem

Research shows a growing tendency among customers and end users to expect better fulfilment of their requirements. This means that stakeholders in the building industry are being confronted by custom work in joint project forms and the search for comprehensive solutions to problems. The various specialists will have to work together synergistically to produce an effective response. (AWT 2000; ARTB 2000)

A case study of design sessions showed that designers were more interested in coordinating and planning tasks than creating and sharing knowledge (Van Gassel 2002; 2004). In the initial phase of the design process, a lot of aspects had to be considered due to wastage and loss of value during the life cycle of a building project (Rutten and Trum 2000).

Researchers believe that designers who work together effectively produce more knowledge and share more tacit knowledge, and that it is necessary to organise and manage the design process (Friedl 2001). The literature contained indications that working methods that involve different specialist designers who want to learn from one another and practise their new-found knowledge lead to innovative concepts (Quanjel 2003).

### 3. Research questions

The aim of the PhD study and the problem described in the last paragraphs is a reason to develop a specific working method as a means to helping designers to create and share more knowledge during a design session. The design of this method is based on a survey study of the subjects: collaboration during face-to-face design sessions, knowledge creation and sharing and working methods. A short description will be given in paragraphs four and five.

Paragraph six contains a description of the working method, which is referred to as the Handstorm method. This method was developed by testing it in six design sessions. To gain insight into how the method works, we formulated two research questions:

1. Do the designers get to work with this method?
2. Is the method well designed?

The experiences of the tests are discussed in paragraph ten and conclusions for further research are drawn in paragraph eleven.

### 4. Collaborative design

One of the first issues in developing a method for collaborative design is to convey an understanding of what the term *collaboration* means. Kvan (2000) distinguishes between the terms collaboration and co-operation. He notes that *co-operation* relates to working together for mutual benefit, while *collaboration* relates to working together to achieve shared goals. The main distinction between the two forms of working together, according to Kvan, is the creative aspect of collaboration (Van Gassel et al. 2004).

Participants in collaborative design sessions in a multi-disciplinary team will make their own design thinking transparent and are able to listen with interest and respect to one another. They are willing to learn from one another and realise that this is the only way a good and integrated design result can be achieved. The organisation of the design process is crucial here and had to be organised effectively.

### 5. Design session and working methods

A design session is a prepared activity executed by a group of designers to work on the design task with the help of a facilitator and design tools. The designers sit at a table or work together remotely. ICT tools are required for the latter situation.

In 'The creative workshop method' Emmitt (2004) distinguishes five types of workshops:

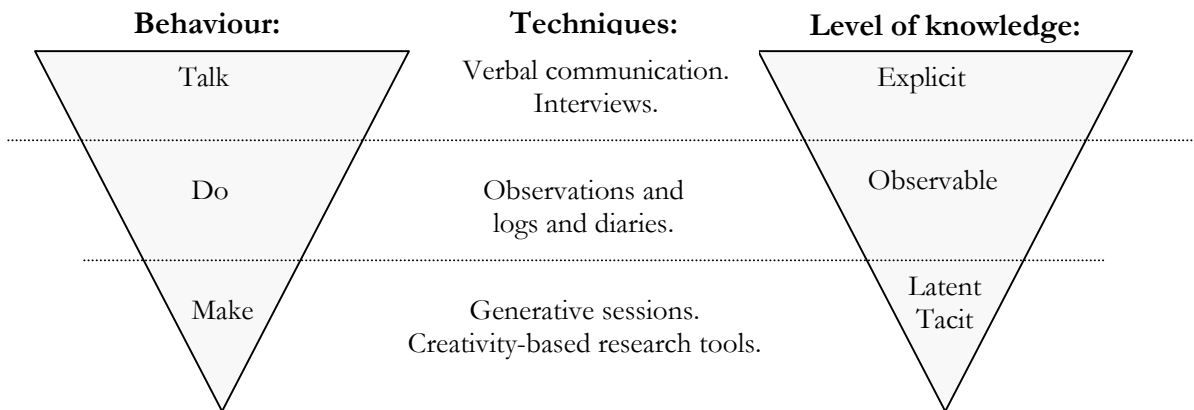
1. (partnering) building effective relationships: teambuilding, common goals, ethics in co-operation, roles and partnering agreement,
2. vision: basic product values, knowledge and experience, whole life approach,
3. realism: fulfilling project values, design alternatives, project economy,
4. criticism: presentation of conceptual design, value reflection,
5. design planning: production information, delivery, value engineering,
6. planning for execution: process plan to map the various production activities.

The research will focus on the 'vision' type of workshop, where the designers sit at a table. This type of workshop required a shared understanding between the designers of the product and process. In his comment on the 'vision' workshop Christoffersen (2004) mentioned the following aspects: frame and process, dreams and visions, value debacle, value base and evaluation of the 'building effective relationships' workshop.

By harnessing people's creativity, Sanders en William (2001) identified several forms of human behaviour: Say (say, think), Do (do, use) and Make (know, feel, dream).

Each level of knowledge (explicit, observable, tacit and latent) requires a carefully chosen technique (interviews, observations and generative sessions, Sleeswijk Visser et al. 2004).

Figure 1 shows the relationships between what people are expressing, what kind of knowledge and what techniques are preferable.



**Figure 1: Different levels of knowledge of experience are accessed by different techniques (adopted from Sanders en William 2001 and Sleeswijk Visser et al. 2004).**

Sanders writes: 'The creativity-based research tools enable creative expression by giving people ambiguous visual stimuli to work with. Being ambiguous, these stimuli can be interpreted in different ways, and can activate different memories and feelings in different people. The visual nature liberates people's creativity from the boundaries of what they can state in words. Together, the ambiguity and the visual nature of these tools allow people much more room for creativity, both in expressing their current experiences and ideas and in generating new ideas.'

Creativity techniques make tacit knowledge of designers explicit. Root-Bernstein et al. (1999) used a trans-disciplinary view to define creativity: '*Creative thinking in all fields occurs preferably before logic or linguistics come into play, manifesting itself through emotions, intuitions, images and bodily feelings. The resulting ideas can be translated into one or more formal systems of communication such as words, equations, pictures, music or dance only after they are sufficiently developed in their prelogical forms.*'

To express the latent and tacit knowledge of the designers, creative thinking with the aid of creative techniques is useful for a vision-based session. The purpose of a 'vision' design session is to reach an agreement between the different designers about the process and product. This means that the designers create and share knowledge. In educational terms, they learn from one another. A generative or creative technique to help achieve this purpose should be a philosophy called 'serious play.' Serious play is a serious activity to create innovative ideas. Schrage (1999) describes the essentials of serious play as follows: '*Serious play is about improvising with the unanticipated in ways that create new value. Any tools, technologies, techniques or toys that let people improve how they play seriously with uncertainty are guaranteed to improve the quality of innovation. The ability to align those improvements cost-effectively with the needs of customers, clients, and markets dramatically boosts the odds for competitive success.*' John Varney (2005) gives a special meaning to Serious Play, SERIOUS

refers to the left brain (logical, analytical, fragmentary, mechanical, efficient) and PLAY to the right brain (imagination, pattern-forming and recognising, holistic, organic, effective).

Papert (1999) says, '*Constructionism is the idea that knowledge is something you build in your head. Constructionism reminds us that the best way to do that is to build something tangible – outside your head – that is personally meaningful. Further that knowledge is best constructed in a social context where the participants make something sharable.*'

In his inaugural lecture Martens (2005) says that people use two complementary means for communicating ideas, opinions and interactions. *Descriptions* for spoken and written languages and *depictions* for gestures, drawing a picture, images and sketches. The last means is helpful for forming opinions and ideas, where the opinion is not determined by externally agreed interpretation. In our view, it does not stop by drawing pictures, but constructing objects is also a helpful means. It is probably a matter of tactile intelligence or tactile thinking as a counterpart to conceptual thinking.

A long time ago, Donald Schön (1992) told us that '*Design knowledge is knowing-in-action.*' Constructing with materials helps the designer express the knowledge that he cannot say.

The above insights into how to design in a group show us what is important in the development of a working method:

- to use the rational and tacit knowledge of the designers,
- to use the left and right brain alternately,
- to be willing to learn from one another,
- to construct together an object as a reflection of doing and seeing,
- to tell stories about the constructed object, and
- to give a (metaphoric) significance to the object.

## 6. The Handstorm method

The points summed up in the previous paragraph are the basics for further development. The Handstorm method is part of a design session plan with the following steps:

- to imagine oneself in the problem, to get a feel for the problem,
- to formulate the design task,
- to generate new visions by constructing a metaphoric object,
- to formulate an answer to the design task.

Step three, the construction phase, comprises the following activities:

- to construct a metaphoric object with special materials together,
- to explain what you are doing and to give meaning to the objects,
- to listen to the meaning of the other designers,
- to present the meaning of the object to one another,
- to describe the meanings.

The activities 'constructing an object and telling a story about it' are an attempt to inspire and stimulate the designers to work in a rational and emotional way. The opportunity to get innovative and share solutions should be greater (Bijl 2002).

In step four, the designers had to translate the meaning of the constructed object into an answer to the design question; the imagination will transfer into reality. We call this step the resociating phase.

In this method, the designers first combine to construct an object with specific materials. We have chosen to construct objects because it is an activity that the designers can do together, at the same time, on one object. We experimented with three kinds of materials:

- materials with a very specific meaning, such as puppets, cars, trees and animals,
- voluminous and meaningful material normally used in architectural prototypes,
- materials from the GEOMAG construction system, consisting of short and long magnetic rods, steel spheres and plates ([www.geomag.com](http://www.geomag.com)).

## 7. Testing the method

Tests have been carried out on the Handstorm method in order to check whether it works. We describe the last design session in more detail. In this session, five students of our faculty participated as designers and a lecturer facilitated it.

The facilitator explained the problem: the reception area in the faculty building had the following problems: bad climate, the view of the entrance is bad, too much draught, little privacy for the receptionist, not enough storage room/storage space. By asking for more details on the problems, the students got more of a feeling about it.

In this session, we chose the 'Key Words Technique' for defining and refining the problem in question. In this technique, the basic structure of the question is: 'in what way might *somebody* do *something* with/to/for/about *something*?' (Daupert 2004). In a writing brainstorming session, alternative words were generated for somebody, something and something. This led to a number of possible questions (see Figure 2).



**Figure 2: Formulation of the design task.**

After structuring and discussing these questions, a design task was formulated as follows: *Design an ergonomic reception area for the receptionist*. With the help of the GEOMAG materials, the students combined to construct an object that represented a metaphoric solution to the design task (see Figure 3). One of the students presented the object to the other students and the facilitator. During this presentation, the students also took notes of some interesting ideas (see Figure 4). In the last part of the session, the students described the requirements for a reception area which will not have the problems described above.





**Figure 3: Constructing a metaphoric object together.**



**Figure 4: Presentation of the constructed object and noting the ideas.**

## 8. Method for answering the research questions

The following method is used to answer the research questions. Every session is documented by keeping a diary, gathering the design questions, describing the materials and design results and taking pictures of the designed metaphoric objects. To understand opinion of the students, we let them fill in a questionnaire with the following questions after each session:

- Did they like to design in a group?
- Is it easy and attractive to construct an object?
- Did designing in a group give more results?
- Did the students learn from one another?
- Is it easy to formulate an answer to the design task?
- Are the designers satisfied with the result?
- Did it take a lot of energy to participate in the session?

We made a video of the constructing and resociating phase of the last session.

## 9. Answers to research questions

About 50 students participated in five sessions. They all filled in the questionnaire. See Table 1 for the results.

**Table 1: Results of the questionnaire.**

Question - Statement	N	Scores on a scale of 1 to 5.					Average
		Scores in %					
		1	2	3	4	5	
Did you like designing in a group?	48	0	1	1	15	31	4.6
		0	2	2	31	65	
Did you find it easy to construct the object?	25	0	0	9	10	6	3.9
		0	0	36	40	24	
Did it appeal to you?	14	1	0	3	5	5	3.9
		7	0	21	36	36	
Designing in a group gives more results.	48	5	5	11	12	15	3.6
		10	10	23	25	31	
Did you learn from one another?	28	0	3	6	7	12	4
		0	11	21	25	43	
Developing an answer to the design task was difficult.	29	2	13	5	8	1	2.8
		7	45	17	28	3	
Were you satisfied with the design result?	48	5	12	12	9	10	3.1
		5	12	12	9	10	
Did you have the energy to concentrate during the session?	30	2	2	3	12	11	3.9
		7	7	10	40	37	

By observing the constructed objects during the design sessions, we also came to the conclusion that materials with too much meaning did not generate many innovative ideas during the session. The video observation showed that ideas generated during construction were not mentioned in the resocation phase, and the students did not have the energy to formulate concrete answers to the design task.

## 10. Discussion

The students were interested in participating in this kind of design meeting: they like it, find it easy and attractive and they learn from one another. 'Developing an answer to the design task was difficult' is a question that scored 2.8, the lowest of all. The students were also not really satisfied with the design results, which scored 3.1.

Observations told us that a lot of ideas were generated during the construction of the metaphoric object, but during the resociation process, not many of these ideas were transferred to an answer to the design task. An idea, which should improve this resociating process in coming sessions, is to record the construction phase on video and show it to the designers to capture the ideas that were discussed and probably get more results.

All the students enjoyed designing in a group. Most of them found it attractive to construct an object, but it was not easy to present the object and to formulate answers to the design task. The group did not really feel satisfied about the results.

## 11. Conclusions

The two research questions for these experiments were: will the designers work with this method and is the method well designed?

The method used in the observed sessions works to a certain extent. To get the designers more involved in the resociating process, the activities for step three should now be as follows, where the first four activities will be recorded on video:

- to combine to construct a metaphoric object with special materials,
- to explain what you are doing and to give a meaning to the objects,
- to listen to the opinion of the other designers,
- to present the meaning of the object to one another,
- to *watch the video* and then describe the meanings.

The method will work better if the materials have no meaning, the materials from the GEOMAG construction system are suitable and will stimulate metaphoric meanings.

The coming research will entail providing answers to the following questions: does the answer to the design question give enough content to start the next step in the design process (fulfilling project values, design alternatives and project economy, the Realism workshop according to Emmitt)? and how to measure the extent to which the designers create and share more knowledge with this method in comparison to a traditional working method such as brain-writing, for example.

# Strategic Briefing

## Explicating the core of the design as a cognitive artifact

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### 1. Introduction

A building as a concrete material artifact is the outcome of a stage of an evolutionary process. Previous stages successively end with artifacts of less material substances. A design, for example, is a semi- material artifact: a drawing on an external sketchpad. Prior to this stage, there is another stage involving the conception of the design as an immaterial (mental) artifact in the internal sketchpad of the client and the designers' working memories. In other words, the conception of the strategy represented in a sum of underlying structures of concepts in a certain order that can be translated into mental images representing the design main concepts.

In the past, the master builder implicitly performed this stage. In today's common practice, it has almost been lost because it is hardly anyone's specific responsibility in a multidisciplinary design context. Moreover, there are no models or tools to help replicating it, although we are nowadays more than ever in urgent need of regulating an important complex information hinge between the client and the mono-disciplinary design team members. The reproduction of this stage is therefore especially important when working collaboratively. The core of the design challenges as a mental artifact can be represented in the internal sketchpad of the client and designers' working memories and can therefore be comprehended at the start of the design process by which all participants form a common reference and a shared memory. However, the core of the design, in order to be represented in such an effective form, has to be in a certain format, which is not the thousands of pages of the traditional brief because our working memory cannot deal with this large amount of necessary and unnecessary information at the start of the project. Only a few chunks can be simultaneously activated in the working memory in a way that can represent the whole design problem, and the strategy reflected as a set of the underlying structures for concepts that need to be developed in a certain order. This is an action to combine the concept of limits to the immediate memory span and the cognitive processing capacity of the brain as an information-processing machine or the *concept of chunking*. In this paper, we will try to discuss a theoretical basis for designing a tool, which can help explicating the design as a mental artifact based on this core concept, and also we will try to illustrate the state of art in this particular research area followed by recommendations, which indicate some future researches.

### 2. Vision toward a solution

Our approach for explicating this stage suggests in fact a return into the natural intuitive way of thinking by designing. For instance, if you were asked as a client how do you like your future building (house, company...) to be, your mind will be invited to create some shortcuts of mental

images, pictures or what we articulate in general as concepts. If you were asked to try to order the same shortcuts that you have created before, but this time considering your priorities, the result you get is a series of shortcuts of mental images, in a certain order. The sum of these mental images in an order, which reflects priorities, is simply what we call the Strategic Brief.

The creation of underlying structures of these mental images belongs to the realm of the responsibility of human cognition (Sternberg 1999). Providing a tool, which can help to produce the cognitive underlying structures of these mental images can therefore lead to the generation of mental representations and ultimately external representations. Dym and Brey (2000) have therefore proposed that design representations should be understood as cognitive artifacts for generating mental representations and (ultimately) novel external representations. Explicating the process of producing the underlying structures of concepts that need to be developed in order is what we call Strategic Briefing. From this notion, this project takes its title. The Strategic Brief in this cognitive format can then form a common background, a shared memory, and a reference for collaboration. By holding it in their memory, participants will be able to understand their positions in the context of the whole, and also will be able to decide which of these mental images are more related to each of their specializations.

Providing a tool, which can help producing this Strategic Brief means reaching the climax by filtering and encoding the essentials of the design problem representation. This suggests that the building design process should start with a minimum of relevant information, which can be accrued into the underlying structures of concepts representing the core of the design. This implies first trying to explicate the minimum of this relevant information that can be accrued into mental images, and also to explicate the mechanism that allows their intertwining to take place.

This will be a shift in briefing from the recent data centric approach into a concept centric approach, which will help to regulate an important complex information hinge between the client and the mono-disciplinary design team members. It is therefore one of the most important activities at the very beginning of Strategic Design Process (introduced by P.G.S. Rutten in his Inaugural Speech at Eindhoven University of Technology, 1996), which concerns the integral multidisciplinary design processes of buildings and aim among others at lowering the risks of mismatches in time between actual and desired performance.

### **3. Identification of our research area in literature**

In literature, several authors recognize this central PhD Project problem illustrated in this paper. Oxman (1995) mentioned that in the recent decades two dominant research directions have been developed. One of them is how to explicate the cognitive processes, which can lead to the conception of the design as a cognitive artifact, including all related research areas like symbolic representations, intuition, the process of design cognition and the manipulation of representation as a cognitive capability in design. Hamel (1995:53) argued that describing the development of the design problem conception is a question that still needs to be answered. Simon (1996:133-136) launched an open question that is also still needs to be answered. This question is about finding a way in which the theory of design may be viewed in relation to other knowledge like psychology: man's relation to his inner environment or man's relation to the complex outer environment in which he seeks to survive and to achieve. However, up until now there has only been limited success. The reason is that staying in only one field of science will not help attaining this aim. Beheshti (2000) mentioned at least ten areas that define the agents of design, and can describe the study of creativity and cognitive activities of design like: philosophy, psychology, logic, epistemology, ontology, aesthetics, etc. This means that significant results in these research

areas are needed in order to invoke a discussion on fundamental principles of design thinking, and to allow gaining insight into the nature of the design as an innate human faculty. Therefore, there were no direct available means, theories, or methods in the literature, which can help achieving our objective. Research by design or a combination of an integral, holistic, intuitive understanding based on axioms and well-known information, and also on existing knowledge in the realm of design studies, cognitive (psychology) science, complexity theory, and the theory of dynamic systems may therefore be the only way to achieve our objective of synthesizing a theoretical basis for the tool design. Designing in general, and designing of this tool in particular, implies first accessing the inside using well-known information and axioms, trying to synthesize in order to form unknown knowledge, which is in our case the tool. This is a totally different approach from the usual scientific research, which starts making measurements, collecting and analyzing data in order to conclude a formula. For explaining the design of the tool and the consistency of the logic, we would like to summarize how we started from axioms and well-known information and ended by the theoretical basis for designing the tool.

#### 4. Theoretical basis for designing the tool

The well-known information and knowledge that we start with is basically related to Simon's argument (1996) that the artificial world may be considered the result of the interface between our inborn needs (for buildings), representing the inner environment, and the context in which we find ourselves, representing the outer environment. This interface is only possible by engaging our sensing systems because everything we know about the world comes to us through our senses (Gasson 1974). When generating concepts, we argue therefore that individuals can only satisfy their needs through their sensing system, by making or breaking relations between the inner environment and the outer surrounding environment (Al Hassan et al. 2002). Making or breaking relations between the inner and the outer environment requires us as human beings to use or not to use one or more of our sensing organs because everything we may need, or we may like has to be searched by our sensing systems, and everything we may need or like has to be found in our environment. This is in fact symbolization of the human needs (for buildings) or *what to find*, the means of our sensing modalities or *how to find*, and the outer environment or *where to search*. By performing a link between these elements (*what to find*, *how to find*, and *where to search*), our minds start generating this artificial world in the form of underlying structures for concepts, which can be translated in later stages into concepts and then into a physical reality. An example, one can say that a building has to have an Aesthetics value related to Seeing relevant to a certain Community (*Museum on Greek style*) or a building has to have a Recognition value related to Smelling relevant to a certain Organization (*Bakery or Flavor shop*). Just by mentioning such a set of words, you recognize that your mind is invited to start imagining something, i.e., it starts generating concepts.

Generically speaking, we can say that each possible concept that our minds can generate has to have at least these three basic elements. This could explain the mechanism of how our minds can encode the simplest form of an underlying structure of a concept, which is a mental map of *what*, *how*, and *where to find*. Explicating the drivers and the process of encoding underlying structures for concepts, in addition to how constraints influence this process would provide the theoretical basis for designing a tool, which can assist the production of the strategic brief, as a sum of underlying structures of concepts in order, representing the core of the design as a cognitive artifact.

### The process of designing the tool

Designing the tool, which can assist strategic briefing has to deal with the following steps:

- The first step that has to be made is toward explicating the phenomena of generating concepts. This implies defining which kinds of things belong to the three main elements, the human needs, the sensing systems, and the outer environment, and then to develop three taxonomies corresponding to each of them. This means that we need first to discuss the taxonomy of the human needs (for buildings) or the inner environment, the taxonomy of the human context or the outer environment, and the taxonomy of sensing systems.
- The second step is to explicate the process of linking between these taxonomies, which is in fact the process of generating underlying structures for concepts.
- The third step is to explicate how constraints influence the process of generating underlying structures for concepts or the strategizing process.

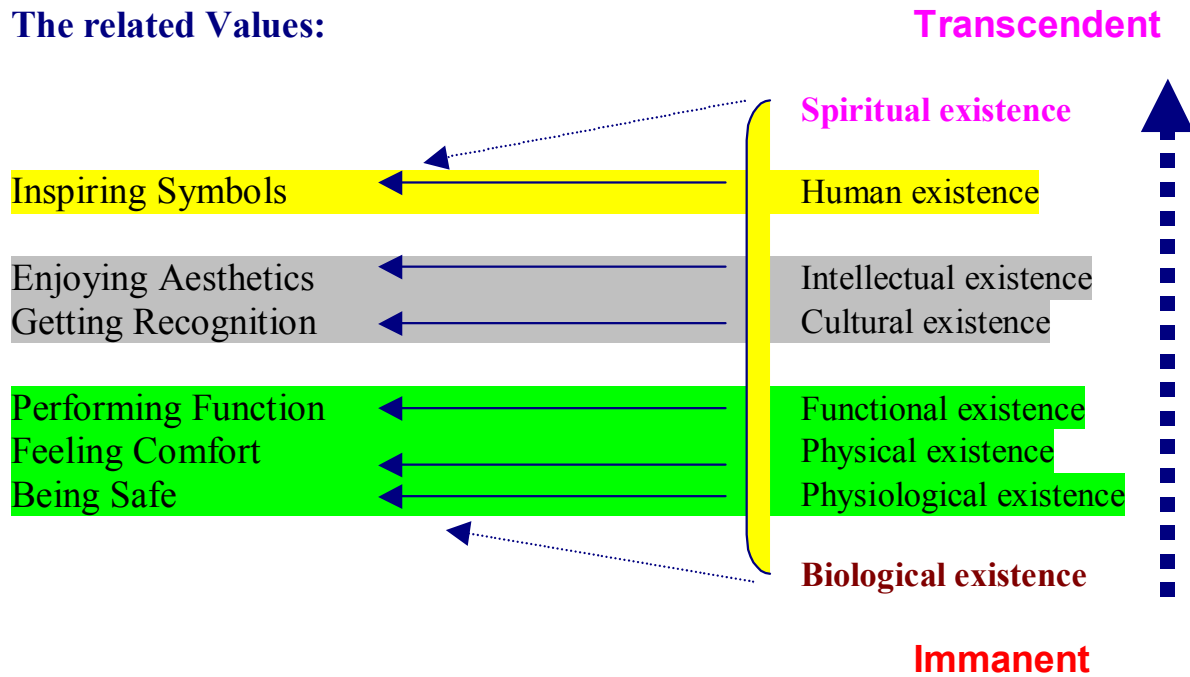
Performing these steps will form the theoretical basis for designing the tool.

### A taxonomy of human needs (values)

Because the design as a cognitive artifact can relate to many different needs that a design can accommodate, the tool should necessarily be based on a general theory of human needs that forces designers to systematically think about and develop corresponding design concepts.

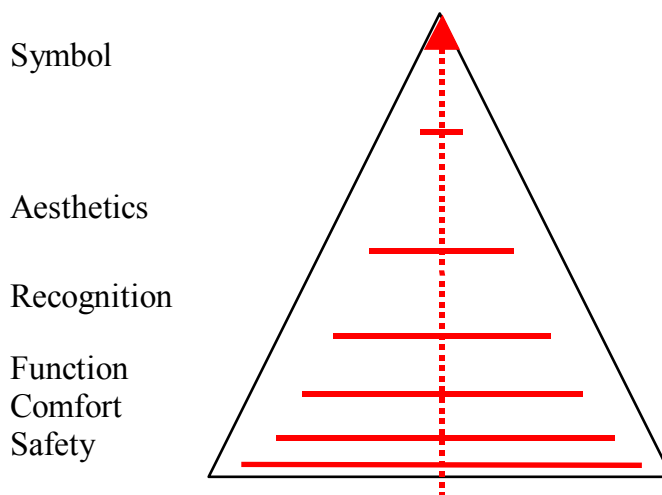
Abraham Maslow's theory (1943) states that people are constantly motivated by needs, which he diagrammed in his famous model of the human hierarchy of needs (there are many other theories, but we preferred to mention Maslow because he was the founder of the concept of the human hierarchy of needs). However, by analyzing this model we find that it does not recognize the difference between the kinds of existences and the awareness of them, which give birth to what he called needs, and the recognition of these needs, which reflects what we call values. Also, Maslow's model is limited to human needs in the social context, while our interest is in human needs for buildings. This requires us to reconsider this model, develop a generic model of human needs, and then derivate a particular model, which can fit the human needs for buildings. As a result of this reconsideration, we argue that the origin of these sharply distinguishable and shared human needs is related to different kinds of existences of human beings, which we have arranged as follows: the biological, physiological, physical, functional, cultural, intellectual, human and spiritual existences (Figure 1). Seeking to survive or to enjoy one or more of these levels of existences means first bringing this driven awareness as a value to the conscious mind (Ross 1985). Sternberg (1999), emphasizes therefore the cognitive nature of these human needs, and argues that the concept of mental representation is fundamental to cognitive sciences. These values arranged in the same order correspond to the awarenesses of these different kinds of existences are as follows: being safe, feeling comfort, performing function, getting recognition, enjoying aesthetics, and inspiring symbols (Figure 1). As portrayed in Figure 1, this spectrum of driven awarenesses, which reflects the basic human needs, varies from *Immanent to Transcendent*. The awareness of these needs at the lower levels, like safety and comfort, are immanent, have short-term effects and a high frequency. In contrast, the higher levels like getting recognition, enjoying the aesthetics, or inspiring symbols are more transcendent, have long-term effects and an indirect feeling of need.

## The related Values:



**Figure 1: Human being different levels of existence and the recognized values related to each of them.**

This can be simplified and reflected in a taxonomy of human values, which can related to designing of buildings as illustrated in Figure 2.



**Figure 2: A taxonomy of human values related to the design of buildings.**

This taxonomy reflects the human beings' awareness of needs for buildings of three types:

- Material well-being: like satisfying the biological, physiological, physical, and functional necessities. These basic necessities can be translated in the field of design into safety, comfort and better using or functioning of buildings.
- Psychological welfare: such as getting recognition, being told for something, (related to audible thus), followed by intellectual (related to visible), such as enjoying the aesthetics of buildings.
- Mental prosperity: like being (mentally) inspired by the symbolic meaning of buildings.



### A taxonomy of the human environment

The human environment or the context in which a human being's mind finds itself, and where it searches to fulfill the needs are arranged as follows: Individual body: (you, biologically and physiologically), Family: (a group of individuals), Organization: (TU/e), Society: (the Netherlands), Community: (European Community), Globe: (the World), and the Universe. Human values (as reflected driven awarenesses of needs) can therefore be searched and experienced at different levels (Figure 3).

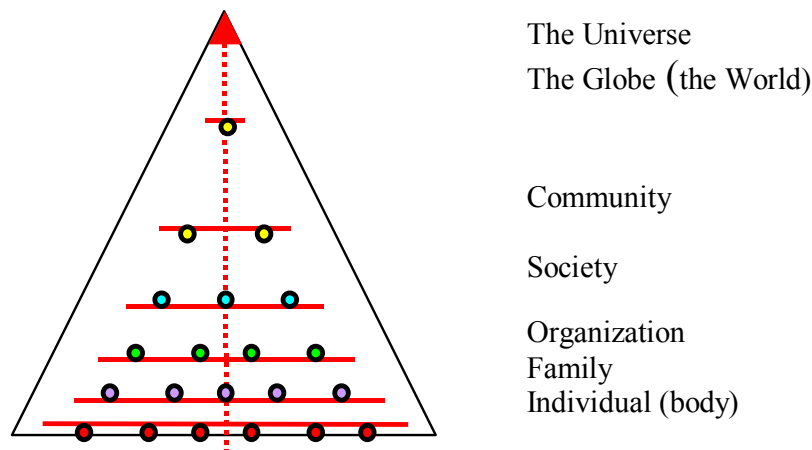


Figure 3: A taxonomy of human environment.

### A taxonomy of sensing

Sensing systems are human equipments necessary for interacting at all levels of the environment for satisfying different kinds of awarenesses of existences (values) (Figure 4).

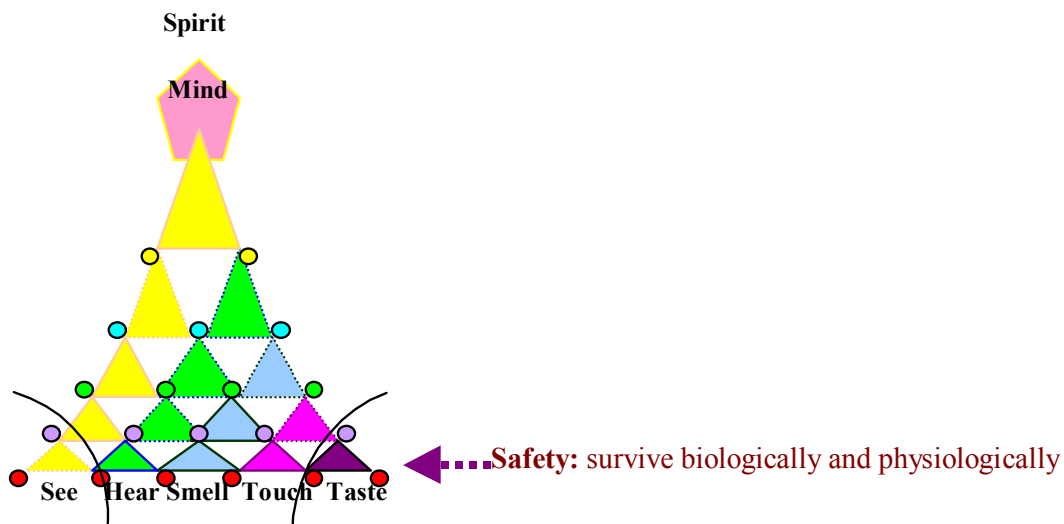
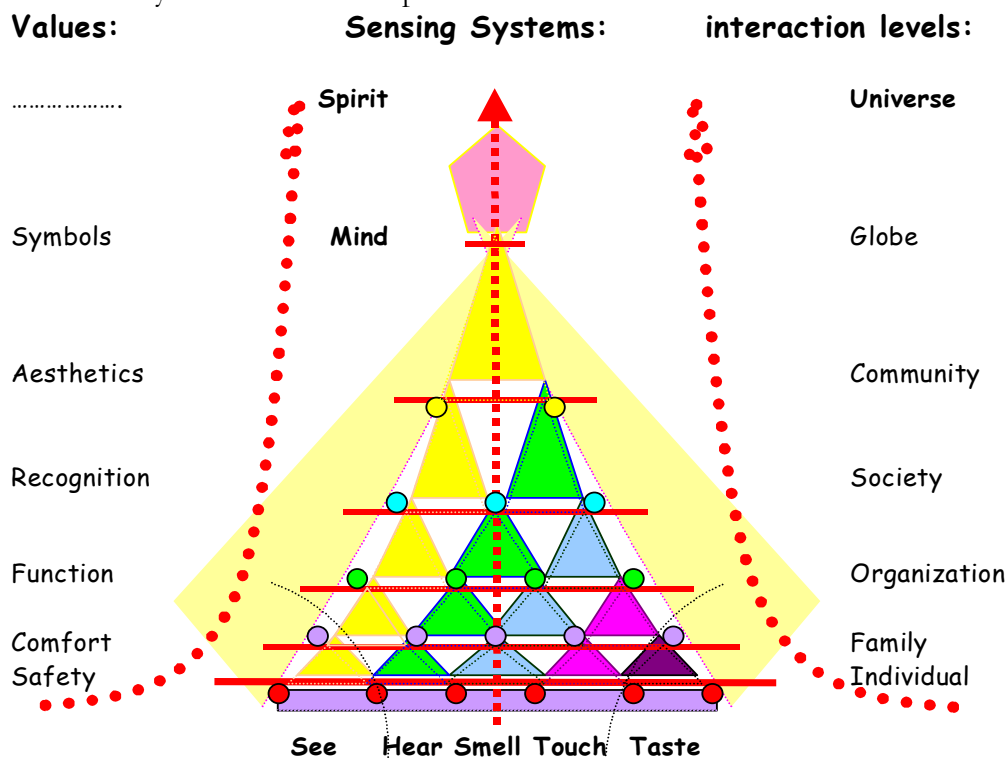


Figure 4: A taxonomy of sensing systems.

The first five are taste, touch, smell, hear, and see. The sixth one is the mind, which is the sense of the total encoded or decoded sensory information (Harth 1995). The seventh one, which is the spirit, will be out of consideration by the further discussion in this paper (Figure 4). To satisfy their awareness of needs (values), human beings are urged to interact with the environment. For

the purpose of survival at biological physiological levels at the basic lowest level, for example, human beings may need to interact with all sensing systems like when they eat. When eating, we taste, touch, smell, hear, see, and mentally inspire (Figure 4). In the opposite, human beings try to protect themselves and to ensure their safety at the biological physiological levels, for example, from experiencing the pain of an interaction with the environment while most or all-sensing systems are engaged like being victims of buildings collapses.

It is important to note here that the levels of interaction correspond to the engage sensing organs, and to the successive higher levels of perceiving the values (Figure 5). By an interaction at the family level we use one sense less than at our individual level. The sensing we loose in order, when we go higher is: taste, touch, smell, hear, and see, correspond to approximate ranges of the sensing, and to the natural and gradual awareness. At each level up, we miss one sense until we leave the realm of the sensing system into the mind, where the encoding and the decoding of the total sensory information takes place.



**Figure 5: The different interactions with the environment in relation to the values and to sensing organs concerned.**

By striving to achieve higher values, human beings use less sensing modalities (Figure 5), which also means interacting less consciously. For example, seeing on the lowest level is different from seeing on the fifth level. Seeing on the lowest level (mostly combined with other sensing modalities) is supporting the aim of surviving, and the quality of escaping danger, which is in our case Safety, while seeing on level 5 is just for seeing, e.g., seeing to enjoy Aesthetics. Only human beings can be affected when missing these higher values, over a long span of time.

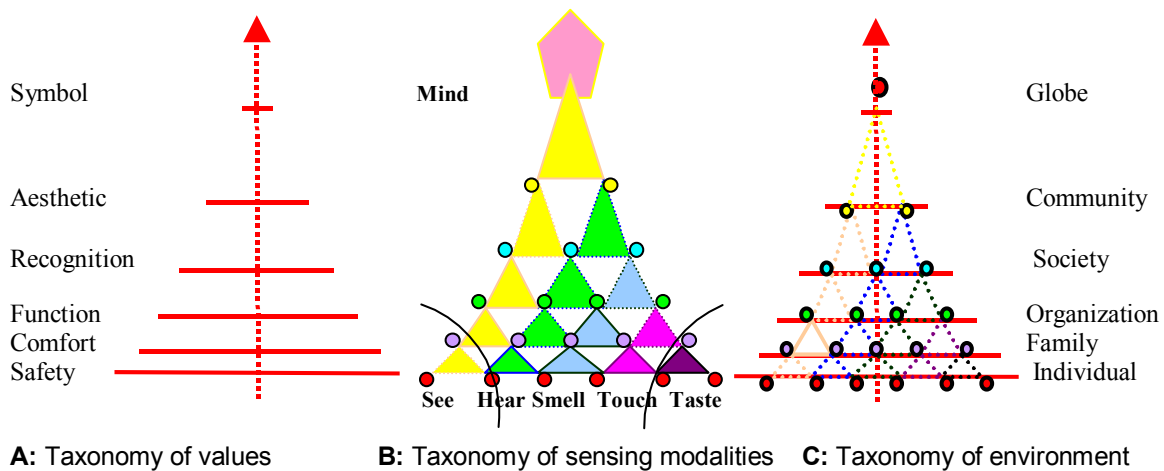
Having discussed these three taxonomies of the human values, the sensing modalities, and the environment allows us to discuss the process of linking them. This will introduce what we call the Self-Graph for generating underlying structures of concepts.

### The Self-Graph for generating underlying structures of concepts

The above three mentioned taxonomies define the components of what we like to introduce as the Self-Graph (Figure 6). These components are as follows:

- *A*: A taxonomy that reflects the awareness of certain kinds of existence articulated as a value.
- *B*: A taxonomy of sensing modalities concerned in the interaction with the environment for satisfying certain values.
- *C*: A taxonomy that represents the levels of interactions with the environment, where the values can be searched.

The recognition of a certain value at a certain hierarchical level of the Self-Graph activates a certain sensing modality. In turn, the sensing modality activates a certain level of interaction with the environment. For example, that your building has to have a symbolic value related to seeing relevant to a certain society (Figure 6). This process of linking between components that belong to the three taxonomies of the Self-Graph, which we will call Synergizing, describes the mechanism of encoding the simplest form of an underlying structure for a concept.



**Figure 6: The Self-Graph components.**

The Self-Graph that holds the three taxonomies of human beings' values, sensing, and the environments, and the mechanism of relating them will then work as a "*center of narrative gravity*" (Harth 1995). This center, which can be used for intertwining the client's brief as a set of underlying structures of concepts, contains what Akin (2002) called the "*conceptual variables and the schemata that provide the underlying order and structure for an architectural design.*" However, we still need to discuss how external constraints influence this process of generating underlying structures for concepts, or the process of generating concepts in scarcity.

### Generating concepts in scarcity

In their dreams, people can think as they like and develop any concepts they like. To our dreams, there is only one restriction: our internal mental preference, which can be related to our kinds and levels of intelligence. In most other situations, the contexts in which we live define different constraints such as ideological, social and/or pecuniary, which can restrict the process of generating concepts. Because of that, designers need to take into consideration the different clients' preferences, and also their different external constraints. The concepts, which can be

generated by the same person when choosing in abundance (variety), are therefore different from those he is generating when choosing in scarcity (Hoebeker in Boonstra 2004). When choosing in abundance there are no external constraints, e.g., no ideological, social and/or pecuniary restrictions. When choosing in scarcity, the situation is different; usually we reconsider the concept resulting from choosing in abundance, by taking into consideration the external constraints. The reconsideration changes the underlying structures of concepts and their orders, which can take place at two levels as follows:

1. If the product that we are going to design has more than one value, or even all of them like the case of the design of buildings, while the resources are limited, for example, if you want to have a house while your resources (money) are limited, you will look more for the functioning, the comfort and the safety of your building, whereas other value like aesthetics or symbols may become simply non-existent or be pushed into the background. This means that the most prepotent value will monopolize and the less prepotent values will be minimized, even forgotten or denied. Maslow (1943) argued therefore *"It has been observed that an individual may permanently lose the higher wants in the hierarchy under special conditions."* This means that by encoding the brief we need first to prioritize between these values: safety, comfort, function, recognition, aesthetics, symbol in terms of personal preference or/and urgency (internal or/and external constraints), so that the most preferred/ urgent one will have the priority and so on. Prioritizing between these values results in restructuring the underlying structures, i.e., it will redefine the quality and the final conception of the product as a whole on the highest level.
2. The associations between values (in cases of a product with more than one value) add attributes, which can define other values and direct the searching. For example, if you say that your building has to have a Symbolic Safety related to Seeing relevant to the whole Globe, then you have better specified in which direction the symbolic value has to be searched. In other words, 'Symbolic' has to be related to Safety, thus when seeing the building, the building has to tell us that it is safe, and this impression has to be perceived by everybody on this globe. A different example is that the concept that needs to be developed is Symbolic Function related to intuitive Mind decoding relevant to the whole Globe. In other words, the function of the building has to be symbolically interpreted by the mind in the same way globally. This process of associating between each value to the other values, which defines the direction of searching we will call Synthesizing (in order to discern which of these two values is the main value and which contributes to the definition of the direction, we will give the main value an adjective state, while the second value(s) stay as they are in the noun state(s)). These extra two dimensions add two elements to the simplest form of an underlying structure for a concept:
  - The first determines the relations between all values in a process of Prioritizing;
  - The second determines the relations of each value to the other values in a process of Synthesizing, which defines the direction of searching.

This is in addition to the previous relations of each value in a certain sensing system, and on a certain level of interaction with the environment or the process of Synergizing. Here we like to add that the synergizing defines the quality of each concept that belongs to the final product. For example, in the previous example, if we reduce our ambition to develop the same concept but on an organization level or on the individual level instead of a global level, then the invoked concepts will qualitatively lower. In conclusion we argue that the process of generating concepts in scarcity contains the following cognitive operations:

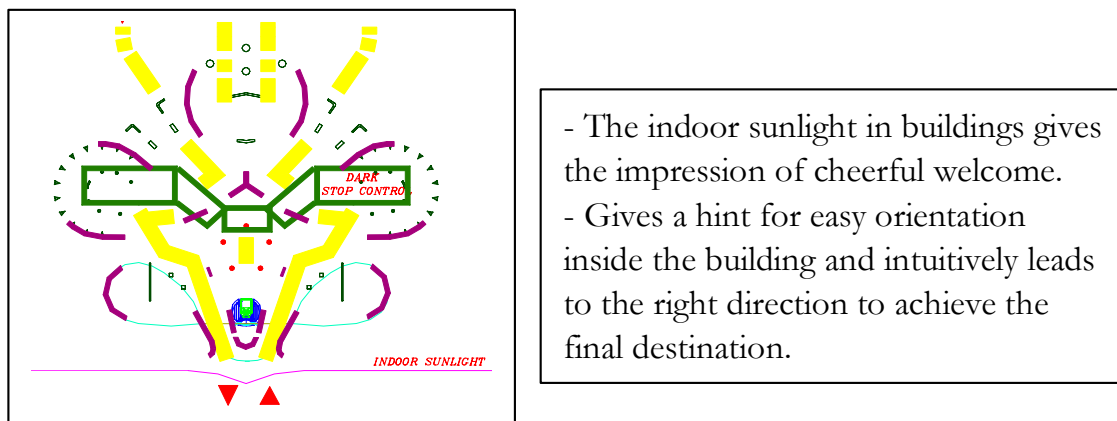
1. Prioritizing between the main set of values.
2. Synthesizing between each value and other values.
3. Synergizing of each values (synthesis) into a certain sensing system, and into a certain level of interaction with the environment.

These cognitive operations add procedural knowledge of how to achieve to the declarative knowledge of what to achieve. In other words, the manipulations of the original Self-Graph structure as a result of the cognitive operations: prioritizing, synthesizing and synergizing, resulting in a cognitive artifact that defines what and how to achieve: the content and the process, which are in fact the two sides of strategy (Bowman et al. 1997).

By introducing the Self Graph and the mechanism of generating concepts in scarcity we explicate the process of generating concepts' underlying structures in general. By explicating this process we performed the theoretical second basic step for designing the tool. However, we still need to relate this mechanism of generating underlying structures of concepts to the design of buildings. This is because the design problem may have many levels, for example: city level, whole building level, or workplace level.

### Encoding the core of the design

Relating each underlying structure for a concept to a certain level of the building design problem (City, Building, Building section, or Work place level), adds an extra dimension to the simplest form of an underlying structure for a concept. An underlying structure of a concept will become like: Functional Comfort, related to Mind intuitive decoding, relevant to the whole Globe, the design problem is on the Building sections level. Figure 7 is an example for developing such an underlying structure of a concept. The Building section(s) in this example are the departure and arrival halls in an Airport Building complex.



**Figure 7: Example of underlying structure.**

Figure 7 shows an example of developing the following underlying structure: Functional Comfort, related to Mind intuitive decoding, relevant to the whole Globe, the design problem is on the Building sections level (the departure and arrival halls in an airport building complex).

In this concept you recognize that using daylight for natural orientation preserves the feeling of spontaneity and directness from the main entrance till the visitor's destination. This can direct the movement of passengers to their different aims, which means comforting the functioning of the departure and arrival units. Buildings with uniform light level confuse this intuitive natural orientation.

The next section will explicate the strategic briefing process for encoding the core of the design as a synthesis of underlying structures for concepts.

### The strategic briefing process for encoding the core of the design

The Strategic Briefing Process for encoding the core of the design as a cognitive artifact contains the following operations:

1. *Prioritizing*: By prioritizing we mean grading the values: Safety, Comfort, Function, Recognition, Aesthetics, Symbol in terms of personal preference or/and urgency (internal or/and external constraints), so that the most preferred/ urgent one will have the priority and so on. This defines the design problem on the highest level as a *system of values*. This ordered set of values defines what drives us to design or *why* we start generating concepts.
2. *Synthesizing*: By synthesizing we mean making associations between the values beginning from the highest value or the value marked as number one, and the rest of the values, then the value marked as number two and the rest of the values, and so on. Making associations between the values therefore creates motives (value with direction of searching) necessary for directing the search, as to say 'I want Symbolic Safety,' for example. This will transform the system of values into a *system of motivations* or *what* to find.
3. *Synergizing*: By synergizing we mean relating the system of motivations into sets of sensing organs and the levels of interaction with the environment. Both define the *how* and the *where* to find. Saying that you want symbolic safety for example, will directly invoke two questions:
  - How do you want to perceive this symbolic safety in your building? For example by seeing or by hearing or...etc.
  - With whom do you want to communicate this symbolic safety? With only you, your family, your organization, a certain community, or the whole globe?
 This will transform the system of motivations or the what to find, into a *system of orders*, with two components of *how* and *where* to find. We also must not forget to decide at which level the design problem has to be solved, i.e., which architectural units we have to consider in our solution.
4. *Symbolizing*: By symbolizing we mean mapping the results of the previous processes by connecting *why* to search, *what* to find, into *how* to find, and *where* to find for each architectural design unit (City, Building, Building section, or Work place level). An example of such an encoded order is the following mental map of an underlying structure of a concept of designing an Airport Building: Develop a concept: Recognized Function, related to Seeing, relevant to the whole Globe. The design problem is on the Whole building level, i.e., the building function has to be visually recognized and means the same for everybody on our globe: Airport & Fly. Designing the roof of the airport building complex to look like flying wings, a bird, or any other form related to flying can invoke similar impressions (Figure 8: shows an example of developing the following underlying structure: Recognized Function, related to Seeing, relevant to the whole Globe. The design problem is on the whole building level: the airport building complex.).

Symbolizing therefore is the last stage of the encoding process. The result of symbolizing is a symbolic representation of the design challenges or what we call the strategic brief.

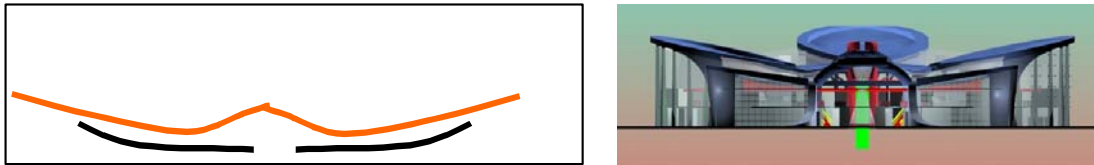


Figure 8: An example of developing the following underlying structure.

## 5. Benefits

The Strategic Brief, which represents the design as a cognitive artifact as a set of underlying structures for concepts, can support the focus and the effective searching by the designers. Holding an underlying structure for a concept like an outline of a searched concept in the memory activates the mechanism of selective positive feedback (Harth 1995), which allows this outline to become sharper with other information fading into the background. Designers will become better focused, and their search for concepts becomes easier and more effective. Furthermore, reaching this climax by encoding the essentials of the design problem and representing it in a symbolic format will encourage designers to deal with this problem intuitively. This means solving the problem first by formulating the strategy that is in fact the core of the design solution, which indicates the following: the conceptual process design, the concepts that need to be developed, the product's expected quality, an estimation of the time needed, the capability of the designers who can translate these underlying structures for concepts into concepts, and finally an estimation of costs (Figure 9). This means a comprehension of the design solution on the highest level or the comprehension of the core of the design. Cross (2004) emphasises that “*the successful design behaviour is based not on extensive problem analysis, but on adequate ‘problem scoping’ and on a focused or directed approach to gathering problem information and prioritising criteria.*” Dorst (2003:117) also concludes that the strategy that seems to work the best is to pose or identify priorities, solve the high-priority problem and adapt all the other solutions to this ‘core design.’

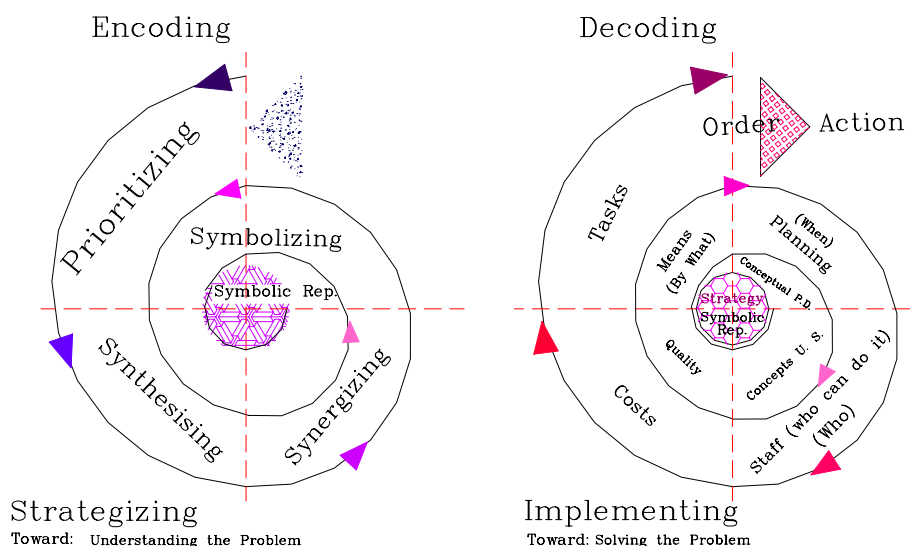


Figure 9: The intuition between the symbolically encoded design problem and the decoded strategy.

The creativity is then in formulating the question, more than in answering it, and thus, in what Glegg (1969) describes as “*the secret of inventiveness is to fill the mind and the imagination with the context of the problem.*” This is what we mean by the encoding of the design problem in an abstract symbolic format. Relaxation means giving intuition a break to decode the problem by transforming the symbolic representation into a strategy, which is in our view the same thing but opposite in direction (Figure 9).

Designing this tool therefore adds a significant contribution to the debate on how to access the designers’ creative minds. It provides a mechanism for forming a problem scope, a shared memory and a reference for collaboration. Every participant will understand his/her position in the context of the whole by deciding which of these concepts is more related to his/her specialization. Mao-Lin Chiu (2002) emphasizes the importance of developing such a tool by saying: “*We need a process model of collaborative design to describe the context of the design tasks, which is important for all participants to understand his/her position in design collaboration.*”

## 6. The state of art and future research

The theoretical basis explained in the previous sections has been translated into an application protocol and a tool in order to lead the future users step by step from their first acquaintance with the design problem to the creation of design main concepts. Further, for illustrating the applicability of the tool in practice, a multidisciplinary group of students in the Master phase worked on a project. The group’s design was evaluated according to many points of attention and criteria, before the process as well as afterwards, including the resulting building design. Based on analysis of the results of evaluations, made by the participants in the test group, we conclude that the tool provides a mechanism that enables us to repeatedly attain a unique common design problem representation articulated as a synthesis of underlying structures for concepts in a certain sequence. The content and the sequence of these underlying structures define how and when each design team member has to contribute to the whole design process. This leads to a more effective use of design team capabilities, and forms an essential basis for organizing efforts, directing and harmonizing the search for collaborative solutions. Moreover, the test showed that working with abstract knowledge by dealing with concepts instead of data can help to avoid information overload in the early phase of design by means of the following:

- It can simplify the transformation of information between the client and the participants on the one side and between the participants’ themselves on the other side.
- It provides a mechanism that enables us to repeatedly attain a unique common design problem representation, and to form a shared vision.
- It allows for the possibility to make very important decisions at the earliest phase when starting a project and forms an essential basis for organizing efforts toward collaborative solutions.

In conclusion, we argue that successful design behaviour is based on adequate problem conception and on a focused strategy for gathering project information.

This ongoing PhD project illustrated in this paper is expected to be finished this year. It is expected to offer a significant contribution to the field of design theory and research, design management, design education, and to the education systems in general, because it delivers from a data centric approach towards a concepts centric approach. It is a step forward to the natural and intuitive way of human working, which is highly needed nowadays for the effective transforming of knowledge. Continuation of this research could therefore take place in many



fields, especially in fields related to design theory and management, design education, and to education systems in general.

For design theory and management this PhD project is an early step toward understanding and explicating the cognitive processes, which can lead to the design as a cognitive artifact because it relates the design to the field of knowledge representation. However there is still a work to do in order to scientifically prove and improve the two hypotheses that we used to underpin the designing of the tool: the Self-Graph and the Strategizing Process. This is a field of science where researchers and designers from cognitive psychology and design together need to work on. Further, all kinds of organizations are nowadays more than ever in urgent need to open up the possibility for the underestimated intuitive encoding and decoding of information. Discriminating between what is necessary/unnecessary, or relevant/irrelevant of this overload of information to a certain problem is becoming more and more complex process. This makes decision making difficult, especially in the early phase. The step that we made by explicating how a design can be comprehended as a whole, and also solved as a whole is very important for the development in this direction. Strategic management studies can therefore benefit from it, because making decisions on a strategic level implies seeing the whole picture, while *“western culture has progressed so rapidly in science and technology and it has become very good at breaking problems into pieces. Unfortunately, it wasn’t very good at putting it back together”* (Carnmer 2000). Putting it back together is only possible by learning how to abstract knowledge, filter and encode information, which can be supported by training using visuals.

For design education, this tool would be a good instrument to use in design teaching, because it helps teachers to make openings to different possible solutions, especially in the early phase of design where students usually struggle to make a start. It also encourages speculations about the tool’s appropriateness for being generalized and applied in a wider field like industrial design, or the design of vehicles. Practically, especially designers can use the concept of encoding and decoding knowledge because creativity implies accessing the inside, which is only possible when learners are trained to encode and decode knowledge and also are trained to use visuals. Training to use visuals would be a good preparation in basic education systems, which can support the ability to encode and decode knowledge in higher education levels. Elaborating these concepts in practical trainings will therefore be a good proposal for further research. This work may also be very important to the development of artificial intelligent design help instruments because *“the future direction for CAAD research lies in the understanding of the mapping between designers’ cognitive thoughts and their external representation.”* (McFazean in Segers 2004).

# Design Communication and Collaboration

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## 1. Introduction

The work described here is based on three common recognitions. Firstly, support for design communication and collaboration is at least as important as support for the actual design activities. Secondly, metadata serves as an important means to improve design communication. Thirdly, the educational context provides an excellent environment to test the effectiveness of such support. Below we describe three research projects that all focus on design communication and collaboration in an educational (and professional) context. The InfoBase project is an educational project that aims to employ ICT means to support educational processes in which (architecture) students are encouraged to learn from one another and work together, at their own initiative (Stouffs, Tunçer and Sariyildiz 2003). Primarily, it concerns the use of metadata as a means to improve the quality of design and the development of a metadata system, named KeySet, that serves to provide each design product with a unique key of keywords. The second project is a PhD research project that considers the use of a model for collections of visual design documents to support design communication in the conceptual phase of design. Specifically, it investigates a methodology for creating, managing, and collaborating on architectural knowledge structures based on a separation of meaning and organisation. The third project is also a PhD research project, which considers the social impacts of collaboration technology in the field of distributed design. Specifically, it investigates the effectiveness and efficiency of the use of collaboration technology in distributed design environments.

## 2. The use of metadata as a means to improve the quality of design

The development process of InfoBase, a multimedia learning environment to support group work and discourse, has been characterised by two ‘revolutions’ that have signified a breakthrough in the operation and acceptance of InfoBase among architecture students.

The first revolution concerns the application of the idea of *‘improving quality by converting better observations out of the original observations by repetition.’* This idea has its origin in andragology (Groen 1981; De Zeeuw 1985) and poses that professional activity must be geared towards improvement or otherwise abandon its interference. Improvement only takes place when one

actively enforces (claims) the desired improvement as quality of the solution. Additionally, a solution always has many dimensions and an improvement will be robust if one can lay claims *simultaneously on multiple dimensions*. In short, the better claims target multiple dimensions simultaneously, are active and rest upon previous qualities that they attempt to improve. The application of this train of thought on design provided an excellent point of departure for the organisation of the communication (we prefer: *correspondence*) system in InfoBase. Since claims are active, by definition, they acquire the form of metadata. In this way, they automatically provide the characteristics with which the design can be stored in a database (InfoBase). However, this exactly turns out to be the ‘secret of the trade.’ Design and metadata form the two sides of the same sheet of paper. The insight that design itself is actually the active process of assigning metadata, and therefore there are no fixed criteria concerning the assignment thereof, is only achieved in the course of the study and forms the passage to real professionalism.

The second revolution concerns the formation and introduction of the didactics with which the use of InfoBase could be made accessible (and also acceptable and appealing) and the design of the actual tool with which the metadata could be generated. The didactics and the tool (which we named KeySet) are organised in such a way that the circularity that arises in the processes of designing and assigning metadata with respect to one another, remain hidden in a first instance. Initially, assigning metadata is introduced by us as an ordinary activity: one learns to assign the ‘right’ keywords to one’s design. The metadata tool is conceived in such a way that later in the study it becomes clear how it works: that a design relates to the already existing designs and that the point is to represent this relatedness through even ‘better’ keywords finds expression in metadata. Assigning keywords is a process without a beginning or an end. below, we consider these two revolutions and narrate how we learnt to perceive InfoBase in terms of a complex adaptive system and how this helped us to permit chaos and self-organisation.

### **System theory to the aid: complex adaptive systems**

InfoBase is at the onset an ordinary database, albeit a technically advanced one. It does its work correctly but is otherwise as dead as a dodo. In order to bring it to life, we consulted both system theory (Prigogine and Stengers 1984; Zeeuw 1985) and epistemology (Saussure 1916; Foucault 1966). This led to a special observation: *knowledge is a form of information delayed under the cloak of appreciation*. Knowledge is appreciated information and comes into being through as many simplifications as are necessary to let various people understand the information. Bringing to life a collection of data is therefore also a matter of imposing (social) constraints onto the system. Bringing a database to life means to constrain the database in such a way that it becomes understandable to most users. In order to breath life into InfoBase we decided to consider InfoBase as a complex adaptive system (Kooistra, Stouffs and Tunçer 2003). InfoBase acquired the constraint that it must represent simultaneously the means and the result of social processes that are the consequence of the exchange of information among architecture students in a specific phase of their study. The complexity paradigm implies “systemic inquiry to build fuzzy, multivalent, multilevel and multidisciplinary representations of reality” (Dooley 1997). InfoBase signifies such a representation.

The starting point that every design from architecture students is considered unique, in principle, introduces chaos into the database. Every design that is submitted ‘queries’ InfoBase; it forces InfoBase to position the design. Since every design is unique, each design receives a position that does not coincide with any other. In this way, InfoBase ends in ‘chaos,’ unless a constraint is imposed that applies simultaneously with the input of data. In the case of InfoBase,

this constraint is imposed with the aim that students are encouraged to learn from one another and work together, at their own initiative. This introduces the principle of order and, with it, that of simplification. The uniqueness of the designs that are positioned in InfoBase through their own metadata are placed under the constraint of human communication. “*Order arises from complexity through the process of self-organisation,*” say Prigogine and Stengers (1984). The obligation that correspondence must be able to take place in InfoBase can in this respect be regarded as self-organisation. InfoBase can be considered a self-organising system exactly because the content is placed under the condition of a human concept that can be exchanged through correspondence. As regards content, InfoBase concerns an infinite (unique) collection of constructive and objective qualities: designs, facts, plans, terms and so forth (images, models, drawings, texts, etc.). As regards process, InfoBase concerns a collection of relational and subjective qualities: the students are as a group responsible for relating the contributed constructs and objects through moderation, validation and encoding of the information. It is expected from them that they express their personal opinion over these constructs and objects. In this way, the content of InfoBase changes once more and the process repeats itself.

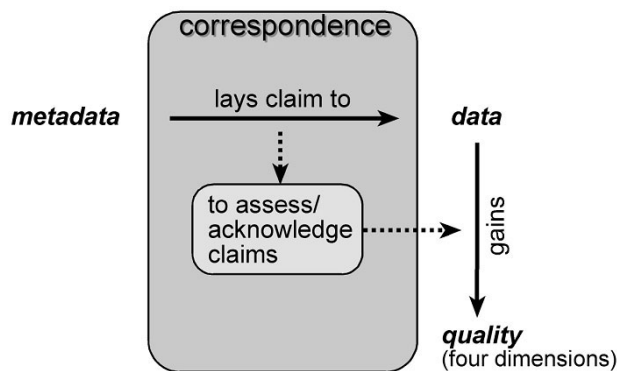
### The use of metadata

In the context of bringing InfoBase ‘to life’ we converted the idea of ‘improving quality’ into a didactic model (Kooistra, Stouffs and Tunçer 2003). This didactic model aimed at serving as a container for metadata that can be used as a design backbone. However, we did not want to pursue extensively the theoretical notions that come along with the functioning of a complex adaptive system. Therefore, we posed in a general sense that metadata derive their action from their association to data and from the relationship they maintain with this data. We said that this action consists of the fact that the metadata lays claim to the data collection to which it is associated. Furthermore, we propounded that a claim can be denoted as successful if the data collection gains quality as a result of this claim (i.e. the association of the metadata to it). We also considered that the design process manifests itself in this way; the designer lays claim to a data collection in such a way that this data collection gains quality. We provided the following simple example: a designer claims that a collection of surfaces signifies a house. This claim will succeed only if the concept of a house really occurs in this claim, that is, other designers or persons are willing to consider the collection of surfaces that has been denoted as a house to be a house. Laying claims in the form of metadata is the engine of the (design) information process (Figure 1: diagram denoting the various stages in an information process and the influence of the use of metadata on this process: information gains quality as the result of the association of metadata to this information).



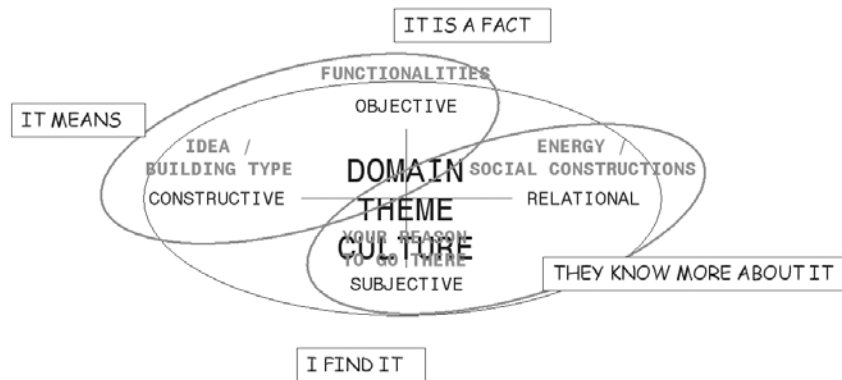
Figure 1: Diagram of stages in an information process.

We further stated that the system for assigning metadata must be both robust and flexible. Robust means that the designer's claim must be recognised and acknowledged by other designers (through correspondence) (Figure 2: diagram denoting the role of correspondence in the process of associating metadata to data: metadata lay claim to data; if these claims are acknowledged, the data gains quality as a result). The system must also be flexible because, throughout time, the need for designs changes. For example, the claim to have a house designed hasn't changed throughout the centuries, however, the product of the claim has evolved with the state-of-the-art of technology, society and culture.



**Figure 2: The role of correspondence in the process of associating metadata to data.**

Applied to the context of an architectural education, we formulated the didactic model as follows: The goal is that we want the student or future architect to learn to lay claims on data collections in such a way that a vehicle arises with which this student can travel as a designer through time and space. The approach is that we teach the student to handle and use metadata along four quality dimensions (Figure 3). On the specification of these four dimensions we stated, in an abstract way, that there are constructive, relational, objective and subjective quality claims (Groen, Kersten and de Zeeuw 1980; Kooistra 2002). The constructive qualities (ideas) denote the will to make a *better* product, in the case of InfoBase, the will to improve a design. It is a form of desire that stems from the comparison with products that are already present. *This can be better!* A better idea however has no quality if others are not prepared to adopt it. This means that one needs to specify the idea in a way that convinces other (architect) designers. That introduces the objective qualities. The idea must be made concrete. There is no idea without the description of the objective, perceptible and for others repeatable elements of which the idea consists. Alas, objectively perceptible elements have no concrete meaning if they are not related to the culture within which they have to function. That introduces the relational qualities. Within a culture, a concrete design must answer the expectations, wishes and demands of producers and consumers. In their knowledge, people are joined in various economies from which one cannot escape just like that. However, there is a form of escape. This introduces the subjective qualities. People are indeed tributary in their economies but this doesn't mean that they don't have a personal emotion to it. In turn, this connects again to the constructive qualities. It is the desire for *another* (better) design that starts the process anew. Subjective quality is indeed economically the least powerful in the system; nevertheless, it forms the difference. For that reason, subjective quality stands in opposition to objective quality. It does not coincide with everything that is already there. As a result, KeySet is a metadata system of which desire forms the structure. This desire is an eternally slipping desire that stems from the way in which man has made himself understandable. Every solution to an idea means letting the idea itself behind (Kooistra 1998).



**Figure 3: Diagram denoting the space formed by four dimensions of socio-cultural qualities and their interpretation for architecture.**

We agreed that in the first year of the curriculum, we would be concerned mainly with the use of the model. Further on in the curriculum, the focus will turn to the handling and steering by the student himself of the vehicle that the model defines. In this way, it is as if the student goes through the process of handling an existing prefab vehicle to designing, building and handling one's own vehicle.

### The use of KeySet

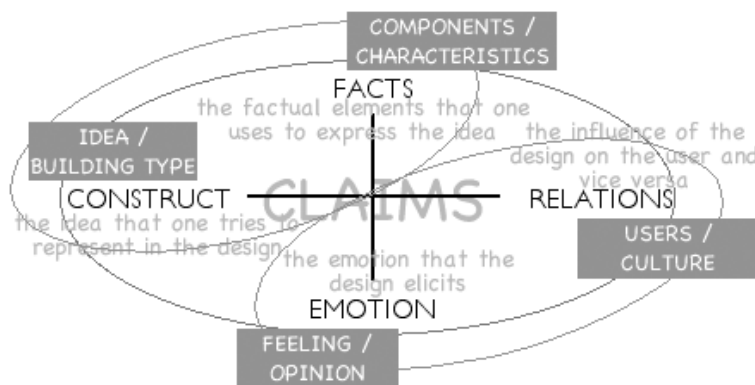
In September 2003, we started with an implementation of this model in the first semester of the BSc Architecture curriculum. Specifically, we introduced the students to the use of metadata when submitting course work in a computer modelling workshop (Kooistra, Stouffs and Tunçer 2004). For each image of the model they submitted they had to specify four claims corresponding to the four quality dimensions. For each dimension, a small set of keywords was provided from which the student had to choose one. A search tool provided access to the resulting collections, Figure 4: the search tool applied to the results of a first semester modelling workshop of Parc de la Villette “follies.” The selected keywords are “circular” (constructive), “pavilion for the purpose of recreation and relaxation” (relational), “front view” (objective) and “spatial” (subjective).

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The figure shows a screenshot of a web-based search tool interface. At the top right is the 'InfoBase' logo. The interface is divided into several sections. On the left, there are two vertical panels for selecting keywords. The top panel is labeled 'constructive' and contains a list of keywords: 'cirkelvormig', 'driehoekig', and 'vierkant'. The bottom panel is labeled 'subjective' and contains a list of keywords: 'dicht', 'gesloten', 'lelijk', 'licht', and 'mooi'. Below these panels is a 'zoeken' (search) button. In the center, there is a large diagram similar to Figure 3, but with additional text and labels. The central circle is labeled 'CLAIMS'. Surrounding it are four ellipses labeled 'FEITEN' (top), 'RELATIES' (right), 'GEVOEL' (bottom), and 'CONSTRUCT' (left). The 'CONSTRUCT' ellipse contains the text 'IDEA / GEBOUWTYPE'. The 'FEITEN' ellipse contains the text 'COMPONENTEN / EIGENSCHAPPEN'. The 'RELATIES' ellipse contains the text 'GEBRUIKERS / CULTUUR'. The 'GEVOEL' ellipse contains the text 'EMOTIE / OPVATTING'. The central diagram is surrounded by several text boxes containing descriptions of the search results. On the right, there is a panel labeled 'objective' with a list of keywords: 'achteraanzicht', 'bovenaanzicht', 'linker zijaanzicht', 'rechter zijaanzicht', and 'vooraanzicht'. Below the central diagram, there is a row of five small images showing different architectural models. Each image is labeled with a title and a timestamp: 'vooraanzicht ruimtelijk cirkelvormig' (jverduin 13-10-2003 13:58), 'vooraanzicht ruimtelijk cirkelvormig' (tango 17-10-2003 13:20), 'vooraanzicht ruimtelijk cirkelvormig' (mhemmes 24-10-2003 16:02), 'vooraanzicht ruimtelijk cirkelvormig' (reintjes 26-10-2003 16:01), and 'vooraanzicht ruimtelijk cirkelvormig' (kpæsschen 28-10-2003 14:19).

**Figure 4: The search tool.**

Students appreciated the formation of a cooperative database composed of their submissions, encoded using metadata and searchable accordingly. Students used the search tool to search either collection using one of the sets of claims they used to encode their own submissions. However, the introduction of the four-dimensional model proved to be too elusive and students, in general, did not achieve an understanding of the meaning and role of each dimension and the relationships between them. Important information for us came from an evaluation we performed using a questionnaire to the students, and which showed us we were on the right way. In connection with the results of this evaluation we reconceived the system for assigning metadata. The following changes are most important: We gave the system a name, “KeySet,” and with this name reduced the system to a mere tool (one which the students will only distinguish to be a complex adaptive system in the course of their education). We renamed the dimensions to construct, relations, facts and emotion (Figure 5 presents a diagram of the KeySet dimensions as provided in the interface; it denotes the space formed by the four dimensions of claims and their interpretation for architecture. This diagram is presented to students as a memory aid when they lay claims on their submission) and added a help page to the system in which the tool is explained and examples are given.



**Figure 5: Space formed by four dimensions of claims.**

The *construct* constitutes the idea or collection of ideas that one tries to represent in the design. The construct claims that the design best fits this idea or ideas. This corresponds to constructive qualities. Abstract examples are living, working, playing, learning, etcetera. Concrete examples are building types: house, office, workplace, theatre, school, city hall, parliament, and so forth.

The *relations* constitute the influence that the design has on the user and, vice-versa, the influence of the user on the design. Relations claim that the design fits in the social life and culture of the intended user. These correspond to relational qualities. Examples concern considerations to the use of the designed object by inhabitants, workers, visitors, students, townsmen, parliamentarians, etcetera.

The *facts* constitute the (f)actual elements that one uses to express the idea(s) (e.g., materials, techniques and forms). Facts claim that these elements give expression to the idea(s) and create a robust entity. These correspond to objective qualities. Examples concern the robust combination of materials, techniques, forms, and so forth.

The *emotion* constitutes the emotion that the design elicits from the designer or the audience. The emotion claims that the design satisfies a certain contributed value. This corresponds to subjective qualities. Examples are beautiful, ugly, functional, transparent, cold, etcetera.

By scoring a design that is placed into InfoBase with appropriate keywords on the dimensions, the (unique) code of this design comes into being with which the design is labelled. With that, justice is optimally done to the design. At the same time, a problem also arises. Since the assignment of keywords is relative – it is after all always about interpretations – care must be taken that the assigned code is also communicative. KeySet mediates technically and strategically in this. Technically, KeySet has a search programme that can retrieve all keywords and combinations of keywords that have been entered in various ways for adaptation or reuse. Strategically, KeySet is put into the (BSc) education in such a way that the student learns to handle the relativity of the system and use it to its fullest extent, without having the feeling that one is left to his or her own devices when it comes to learning to deal with the language of architectural concepts. This is achieved by setting up KeySet in the first year of the BSc curriculum in such a way that the possibility to make up one's own keywords is limited. In this case, each dimension is either completely closed (a fixed keyword) or linked to a limited menu of choices, or linked to an online architectural thesaurus with fixed architectural terms. In this way, the internal communication within the database is promoted – which is still desirable at the start of the study – while it is clear from the beginning that each design is unique and deserves to have this uniqueness honoured in a metadata system. In the second and third year, the correspondence between the designs and the management of the database is regulated primarily by the students themselves.

Last year, we started an extensive scales evaluation of the use of InfoBase and the included metadata instrument KeySet. This evaluation is carried out as part of a longer-term international research into the use of computers in learning situations. The evaluation concerns the use of ICT in general and the use of KeySet as an instrument to assign metadata in particular. This research is conducted by means of two scales: the *Subjective Computer Experience Scale* (SCES) and the *Subjective E-platform Experience Scale* (SEES). These scales are designed to measure the attitude and experience with respect to computer use (SCES) and the use of ICT as work and learning environment (SEES) (Kooistra et al. 2004). SCES is an internationally validated scale. It measures subjective computer experience, which can be described as “a private psychological state reflecting the thoughts and feelings a person ascribes to some existing computer event” (Smith Caputi and Rawstorne 2000). SEES is a scale that we designed and tested ourselves in previous research. It measures the subjective assessment of experiences with ICT applications in education (the KeySet section of the scale measures the subjective assessment of experiences with KeySet applications in education). The measuring was repeated before and after a second semester computer modelling workshop. The correlations found between the SEES ICT and KeySet factors and the variance analysis conducted has clarified the strategy that we think that needs to be followed (Kooistra et al. 2005). Make students more familiar with dealing with metadata (KeySet) and they will find it worthwhile and also rather fun. The latter not only depends on whether the instrument is profiled appropriately but also on the courses or workshops in which it is included.

## Conclusions

InfoBase is a technically advanced database. In comparison to previous versions, satisfaction about the technology has also strongly increased. The addition of the KeySet instrument to InfoBase gives the database extra dimensions. It makes InfoBase into both a didactic and strategic instrument. Didactically, InfoBase with KeySet is well equipped to teach students what it means to share information, to handle metadata and to understand chaos and order in their



combination as essential factor for the information content in a database. Strategically, InfoBase presents a very interesting link between education and profession. The fact that students learn to share information in a professional way during their education, enables them to continue this (academic) attitude in the architectural discourse upon graduation as a professional (alumnus).

Using the idea of a complex adaptive system has greatly helped us to analyse the force field that is present in a cooperative database. We were able to take a more open position with respect to allowing chaos to enter the system, knowing that this identifies the uniqueness of the submissions. However, because we do not equate the permission of chaos to the preaching of it and, in the context of educational, we also have an obligation to teach the students how the field of tension between chaos and order behaves, we have introduced a few constraints that can be considered as the simulation of the actual idea of self-organisation. These constraints concern both the requirement of communicability and a description of the dimensions according to which the metadata must be generated for a design. We emphasise that the assignment of metadata is always chaotic (everyone understands differently and provides different explanations) and that this only changes when one unleashes the constraint (delay) of communication/correspondence and self-organisation takes place in the form of the adaptation of the keywords to one another. We propound that the final lesson is that establishing relations, even though it yields appreciated knowledge, at the same time costs information (uniqueness disappears).

### **3. Information modelling in architecture**

The main question of this research is: How can we support design communication in the conceptual phase of design using a model for collections of visual design documents?

Architectural design is a complex process that involves a large amount of information with numerous dependencies. This information is commonly represented and communicated in a collection of design documents of various formats. Many document management applications exist that are also used in architecture, but these are not suitable for the early, conceptual stages of architectural design.

Needed is a visual, flexible and extensible environment that supports creativity and that enables the collected information to be reused in further projects. Flexibility is necessary in inputting and retrieving the information. When using such an environment, and especially in the early stages of design, one is not necessarily interested in a specific document, but in search of a collection of information related to a concept of interest, or one may be just browsing through images to get new ideas - creative coincidences. The document structure and the organisational structure must be extensible in order to be able to reuse the information.

A unified representational framework is necessary for such an application (Tunçer, Stouffs and Sariyildiz 2002). We have developed a methodology that entails the separation of meaning and organisation. Meaning, or semantics, is structured as a flexible and extensible semantic network of concepts and relationships that acts as a backbone for knowledge organisation. This network can be defined by a user or a group, can be project or institution specific, and defines a common language among users. This definition of a network has been integrated into the InfoBase system. The organisation, or the documents, can be divided into smaller components. Each item is associated with one or more concepts from the semantic network. The methodology offers a flexible and extensible framework and a rigorous recipe to create, manage, and collaborate on architectural knowledge structures. An environment that implements this methodology offers a flexible and extensible framework for creating and managing architectural knowledge structures.

The use of such a system in education and practice also entails process and organisational issues concerning the users and their organisation. The use of the system must be embedded in the organisation and supported by the managers/educators of the organisation. The highest threshold for the actual use has been found to be the initial acceptance of such a system. Users generally find the system and its functionality useful and innovative, but if it does not produce visible benefit to their work, or impedes too much on their daily work routine, they tend to abandon the use. Therefore, the user interaction and interface design must also incorporate the specific process of the design task and culture of the organisation. This makes it necessary for the process knowledge to be incorporated in the design of the software from the very early stages on. If the embedding into the organisation is not complete, the actual success of the system will also be limited.

Four case studies in architectural education and practice have been implemented using the results of this research, using the InfoBase structure and scripts (Figure 6). The first one is the Analysis Presentation Tool - 3 Ottoman Mosques. This is a web-based environment implemented using XML technologies that serves to model, present, search and browse extensible and semantically rich precedent libraries. This was implemented as a test case. The second case study is the Design Analysis Network (DAN). DAN is a web-based educational environment that aids precedent-based analysis of design projects. The result is an extensible and semantically rich precedent library. This was used in the 2<sup>nd</sup> year design studio of our education. The third case study is the Blob Inventory Project (BLIP). BLIP is an integrated web-based environment that serves to model and retrieve conceptual early phase design processes of free-form buildings and serves as a design aid. This was used in a masters course in our education. The final case study is the Design Map. Design Map is a web-based knowledge management environment being used in a real life professional project by a project team in the architectural office MECANOO.

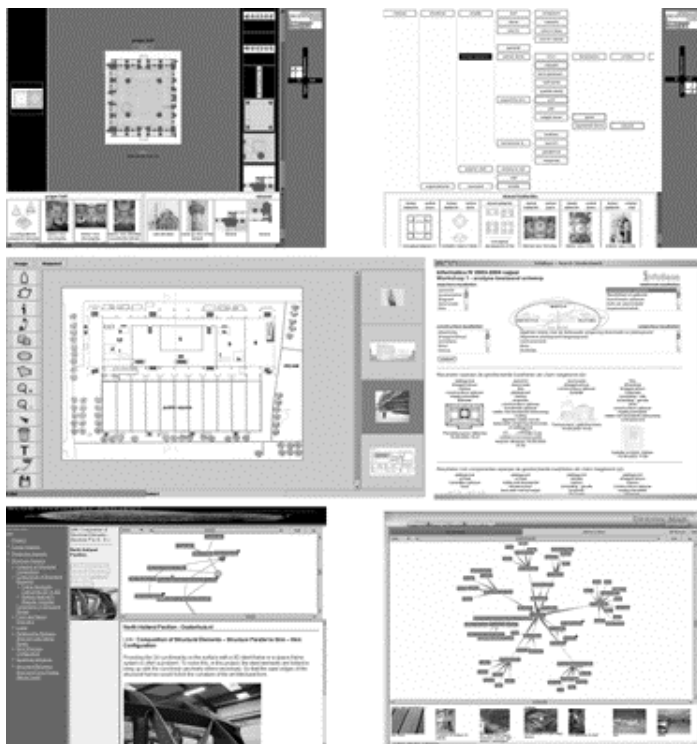


Figure 6: Four case studies in architectural education and practice.

#### 4. Collaboration technology in distributed design

The main question of this research is: How can we increase the effectiveness and efficiency of collaboration technology use in distributed design environments? Collaboration technology is closely related to the terms CSCW (Computer Supported Cooperative work) and Groupware (Munkvold 2003). CSCW originated during a workshop at Digital in 1984, where a group of researchers focused how IT (Information Technology) could support collaboration (Grudin and Poltrock 1997). One of the earliest works applying the term Groupware is the book *Groupware: Computer Support for Business Teams* edited by Johansen (1988, cited in Munkvold 2003). There suggestions are presented how to apply collaboration technology for supporting team collaboration. Later, the application has broadened from originally supporting workgroup or team level to organisation wide applications such as document management and knowledge management systems. Therefore, the term collaboration technology better represents this wider focus and the term groupware has gradually faded (*Ibid*). However, in the literature it is still possible to see the use of these three terms, synonymously. In this research the term collaboration technology implies computer support for collaboration at group level and organisation level.

Collaboration technologies are changing the world of work. The consequences of these technologies in work environments have been a research issue for a decade or more and have attracted researchers from academy and practice. Although early discussions about the impact of these technologies were technology oriented, with the recognition of their social impact on work environments, the social dimension is also added to these discussions. The focus of this research is on social impacts of collaboration technologies in the field of distributed design. Design is collaborative by its nature. Therefore, collaboration technologies can bring a lot of opportunities to improve the collaboration during the design process. However, despite the robustness of technologies being developed, effective use of collaboration technologies has not yet been a part of the daily routine of designers. The aim of this research is to identify the sort of enablers and disablers that facilitate the effective use of collaboration technologies. Some examples of these enablers and disablers are the attitude of the designer towards technology, the culture of the organisation where the technology is implemented, and the extra work load that is required from the designer for the effective use of the technology.

In order to answer the main question following key questions are asked:

- What is the current state of collaboration technology use in distributed design environments; what types of collaboration technology are used; what are their functionalities?
- What sorts of problems are encountered in the course of collaboration technology use?
- What sorts of team characteristics affect the use of collaboration technology in design environments?
- What is the influence of current organisational structures on the implementation and use of collaboration technology; what sorts of strategies are developed for their effective use?

So far, this research is conducted both in an educational and a professional context. The research results that emerged in the educational context have identified the major items concerning the use of collaboration technology on the team level and the broader institutional aspects (Akar et al. 2003; Akar et al. 2004). Together with these items, a literature review and the interviews conducted in certain international design companies have revealed major dimensions which could be effectual on the collaboration technology use in distributed design environments. In the final stage of the research a prescriptive framework will be developed for the effective and efficient use of collaboration technology in distributed design environments.

# Integral Design Methodology for the Built Environment

## “Learning by doing” workshops

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## 1. Introduction

Preservation of energy resources and environmental impact limitation are key issues of modern architecture. Sustainable building will be the major guiding principle for renewal of building and spatial planning practice.

The building industry has identified a need to integrate sustainable energy systems in buildings. In current practice, sustainable energy systems are often treated like an add-on component that is designed after the building design has been completed. Many researchers see this as the cause of the poor use of sustainable energy in general. In order to overcome this problem, there is a need to develop a specific approach for design optimisation of sustainable energy components. Moreover, synergy between sustainable energy components with construction and HVAC-systems should be achieved.

In the planning of their own new office, Kropman, one of the major Dutch mechanical and electrical contractors, wanted to show their design and engineering capabilities. It had to be innovative and so they decided to design an office building with a flexible construction and notable use of sustainable energy (Zeiler 1999). To make this possible, they developed a sustainable IFD (Industrial Flexible Dismountable) building concept. It has been developed with TNO Bouw and the architects Quanjel and van Eck of the architectural office ‘Van den Broek en Bakema.’ Also the design process itself was a topic of study. During the design process of the Kropman building, technical students and high-potential engineers did sub-investigations on specific building aspects. Furthermore, TNO Building and Construction Research supported the design-decision-processes. The results of this new approach are called “Duurzaam Flexibele Proces Integratie” – sustainable flexible process innovation (Zeiler et al. 2000).

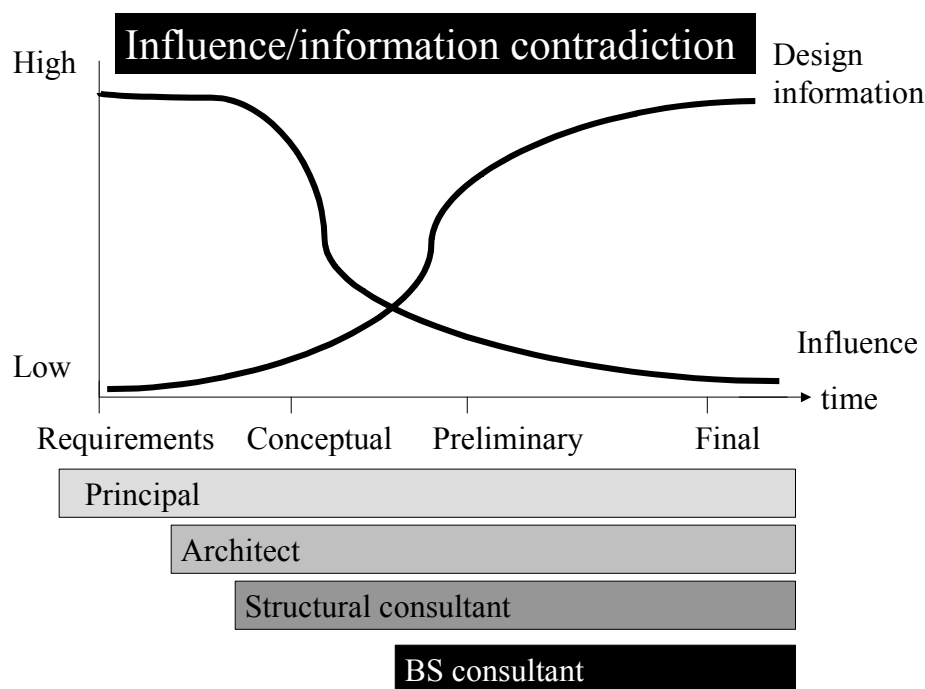
A “thinking in levels” approach was introduced in which the design and decision process are improved by structuring them at different levels of abstraction. At each level in the design process different decisions have to be taken. One of those decisions is the application of sustainable energy systems and components. However this is rather complex to integrate in the early stages of building design, instead these systems and elements are often added during the

final design stages. This results in sub optimal solutions and often leads to complete rejection of proposals to use sustainable energy systems and components at all.

*“Though it be madness, yet there is method in it” – Shakespeare, Hamlet 2,2,208.*

The studies of the students on specific building aspects, led to new insights that were used in the conceptual design phase, resulting in a more fundamental insight into the information flow in the design process. At the early design stages, usually only conceptual sketches and schematics are available, often rough and incomplete. Architects tend to develop their designs in a drawing-based, graphical way (prototypes are used to investigate the design concepts). It is important to mention here that (building) design is a creative process based on iteration: it consists of continuous back-and-forth movements as the designer selects from a pool of available components and control options to synthesize the solution within given constraints. As the design proceeds, more information and detail will be developed.

But the dichotomy of this system is that at the early stages of design there is little information, even though nearly all the important decisions have to be made at this time, as Figure 1 shows.



**Figure 1: Influence/information contradiction at the early stages of design (den Hartog 2003).**

As a mechanical contractor, Kropman, is normally only confronted with the resulting quality of a design process. Designing their own office gave them the opportunity to approach the design process at a different stage. As principal of their own office, they used the design process to investigate the influence of introducing knowledge of building services consultants into the early conceptual stages of the design process. Furthermore, even at the requirements stage of the design process the influence of the building services consultant could be effective.

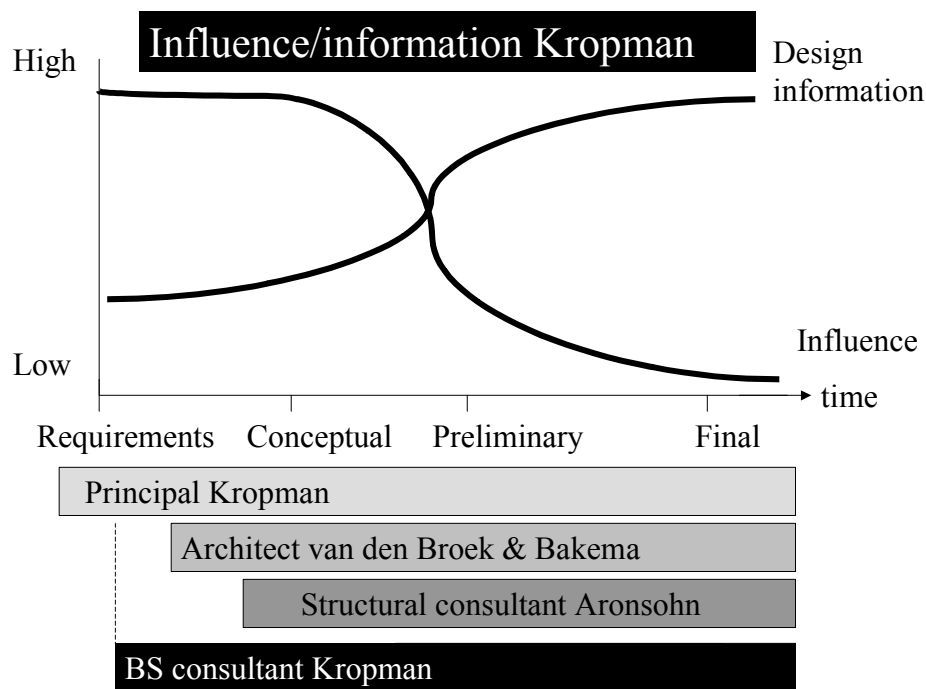


Figure 2: Influence/information within the Kropman project.

During the process there was a strong focus on implementing sustainable energy solution and their optimal integration with the construction of the building. The conceptual design and the final realisation are shown in Figure 3.



Figure 3: Conceptual design and final realisation of the Kropman office.

The application of new innovative construction products and methods in this project demonstrated their potential; and the project reached the status of a demonstration project within the IFD programme of SEV (Stichting Experimentele Volkshuisvesting (Groenedijk et al. 2000). However, for genuine added value and a further decrease of project risks, further improvement of the early, conceptual stage in the design process is needed.

## 2. Integral design methodology

Besides designing the Kropman project, one of the design team members was chairman of the steering committee Climate technology of the TVVL (Dutch Society for Building Services). During this period he was asked questions about the investigation of problems concerning comfort and health in buildings. Instead of treating them with an 'end of pipe solution' approach, where only the effect is treated and not the cause, the real source of the problems was investigated. These problems resulted from mistakes made during the design process, so it was logical to investigate the design process itself. The parallel between the activities within the Kropman design process and the TVVL activities led to a combined effort. The architect and building services consultant of the Kropman project took the initiative to get in touch with the Royal Institute of Dutch Architects (BNA) and Delft University of Technology (TUD). In year 2000, BNA, TVVL and TUD participated in the research project Integral Design. This project primarily aimed at the reduction of failure costs. The idea of the participants was that, by optimising the design process, fewer mistakes will occur and fewer unnecessary costs will arise. The project had to unfold ways to investigate and implement an integral approach for building design. This integral approach encompasses the built environment from initiative to design, construction and real estate management as a seamless whole. This seems to contradict with the subdivision of the construction industry in phases, in which parties operate with opposing interests, resulting in disintegration and waste. The coordination of these independent phases, scales, decision-makings and disciplines are crucial to the creation of a built environment in which the people concerned feel comfortable. This is the core of the integral approach. Integral design is meant to overcome, during design team cooperation, the difficulties raised with the early involvement of consultants. This is achieved by providing methods to communicate the consequences of design steps between the different disciplines on areas such as construction, costs, life cycle and indoor climate at early design stages. The aim is to support all disciplines with information about the tasks and decisions of the other disciplines. Supplying explanation of this information will improve understanding of the combined efforts (den Hartog 2003).

### Abstraction

When attempting to integrate sustainable energy aspects into design decision-making, the process must identify opportunities of sustainable energy. Instead of developing new design methods, this research study attempts to utilize existing architectural design characteristics and decision making for the introduction of sustainable energy – resulting in good building designs. This implies defining a methodology that acts as a bridge between architectural elements, such as shapes and materials on the one hand, and sustainable energy use together with the aspects of indoor climate issues such as overheating and ventilation on the other.

During design support, it is important to transfer the essentials of the proposed structures and mechanisms, without overloading other member of the design team with unwanted details. This information control can be achieved by use of abstraction. So far, many building teams have been sending their partners detailed drawings, thus relying on the addressees to make the necessary abstraction themselves. With the increasing use of product information models, it is now possible to incorporate multiple abstraction levels in the design representation. Abstraction is the mapping from one representation of a problem to another, which preserves certain desirable properties and reduces complicity (Giunchiglia et al. 1997). Abstraction is the selective examination of certain aspects of a problem. The goal of abstraction is to isolate those aspects

that are important for a particular purpose and suppress those aspects that are unimportant (Rumbaugh et al. 1991). This enables representations to take an appropriate (abstract) form that matches the needs of the design specialist, thus saving much time and confusion.

Throughout the different levels of abstraction, the description of the building design gradually becomes more and more detailed. The various levels of abstraction should be considered as representations of a particular view on the total information available for a design.

This integrated design model must:

- be able to distinct related information,
- support distinctions related to the different levels of abstractions (views) by being structurd into corresponding sub-models,
- ensure the satisfaction of consistency and completeness constraints linking different levels of abstraction in the design process.

Design, as a solution-evolving process, involves activities of searching, analysing, manipulating and structuring information about the problem to be solved. Generating new information, and evaluating and communicating information are major activities within the process. Design normally has a very dynamic nature, with a tendency to *ad hoc* actions, which should be supported by design aid systems.

Design is the key discipline that brings systems into being. In the engineering sciences, a lot of approaches have been developed to structure and optimise design processes: concurrent engineering, value engineering, design for manufacturability, systems engineering, quality function deployment, strategic design, etc. To develop our required model of design support, an existing model from the mechanical engineering domain was extended: Methodical Design (van den Kroonenberg 1979, de Boer 1989, Blessing 1994). The methodical design process can be described at the conceptual level as a chain of activities which starts with an abstract problem and which results in a solution.

The original methodical design process is extended from three to four main phases, in which eight levels of functional hierarchical abstraction, stages can be distinguished. A feature of our extended model of Methodical design is the occurrence of a four-step pattern of activities in each stage. In system theory the same activities are proposed for decision processes as can be found for the design process, see Figure 4.

System Theory	Activity	Methodical Design
Definition Demands	Generate	Problem definition
Synthesize Analyze	Synthesize	Working principle
Evaluation Decision	Select	Detail design
Implementation Application	Shape	Realisation

**Figure 4: Comparison between system theory and methodical design.**

### Functional Decomposition

In order to survey solutions, engineers classify them according to various features. This classification provides the means for decomposing complex design tasks into problems of

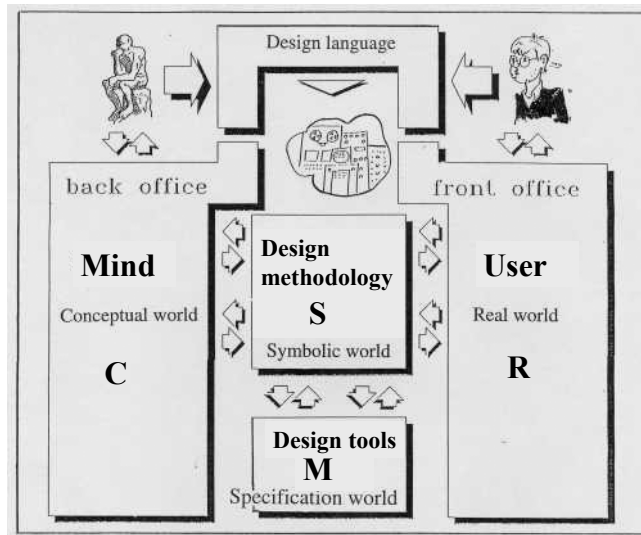


manageable size. Decomposition is based on building component functions. This functional decomposition is carried out hierarchically so that the structure is partitioned into sets of functional subsystems. Decomposition is carried out until simple building components remain whose design is a relatively easy task. Hierarchical abstraction implies the decomposition of information into levels of increasing detail, where each level is used to define the entities in the level above. In this sense each level forms the abstract primitives of the level above. These higher-level terms form condensed expressions of a given relational and/or operational combination of primitives from the level below. Sets of generic components are located at distinct levels of abstraction. The contents of the layers are based on the technical vocabularies in use, technology-based layers or levels. Each layer represents an abstraction of the levels below. For a more extensive description of the models that formed the basis for the notion of technology-based layers see (Alberts et al. 1992). Separation is made between:

- Information level, knowledge-oriented, representing the “conceptual world.”
- Process level, process oriented, representing the “symbolic world.”
- Component level, device orientation, representing the “real world.”

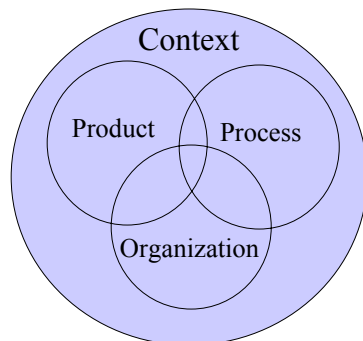
In addition, a new level is defined by us: part level, parametric orientation, representing “the specification world.” Thus, the four levels of aspect abstraction in the descriptive model of design are:

1. *Information Level.* This level deals with the knowledge of the systems by experts. One of the essential ideas behind this is that human intelligence has the capability of search and the possibility to redirect search. This information processing is based on prior design knowledge. One of the major problems in modelling design knowledge is in finding an appropriate set of concepts that the knowledge should refer to, or -in more fashionable terms- an ontology (Alberts 1993).
2. *Process Level.* This level deals with physical variables, parameters and processes. The set of processes collectively determines the functionality of the variables that represent the device properties. Modelling at the functional level involves the derivation of an abstract description of a product purely in terms of its functionality. This abstraction reduces the complexity of engineering design to the specification of the product’s desired functionality.
3. *Component Level.* This level describes the hierarchical decomposition of the model in terms of functional components and is domain dependent. Generic components represent behaviours that are known to be physically realisable. They are generic in the sense that each component stands for a range of alternative realisations. This also implies that the generic components still have to be given their actual shape.
4. *Part Level.* This level describes the actual shape and specific parameters of the parts of which the components exist. Relevant technical or physical limitations manifest themselves in the values of a specific set of parameters belonging to the generic components. These parameters are used to get a rough impression, at the current level of abstraction, of the consequences of certain design choices for the final result.



**Figure 5: Conceptual model of the four levels of aspect abstraction and the role of expert and other designers (Zeiler 2000).**

Designing takes place in an environment that influences the process, it is contextually situated (de Vries 1994, Dorst and Hendriks 2001). The context of the model of designing is defined by a “world view.” The model of de Vries consists of three worlds and is extended by us to four worlds: the real world R, the symbolic world S, the conceptual world C and the specification world M, see Figure 5. Communication between architect and building services consultants is based on abstraction, i.e. the exchange of abstract descriptions of a design; the transformation from the conceptual world to the real world.



**Figure 6: PPO model (Friedl 2002).**

The Product – Process – Organization model (the PPO model), developed by Friedl (Friedl et al. 2002) represents this “world view,” see Figure 6. Friedl’s PPO model applies and elaborates comparable concepts as introduced in the Building Design Process Model according to Domain Theory (Bax and Trum 2000). Friedl’s PPO model discerns four essential domains of concern in the design situation:

- ‘product domain,’
- ‘process domain,’
- ‘organization domain,’
- ‘context domain.’

The dynamics of these domains are the parts that form the life cycle of the design situation. Therefore there is a need to define the knowledge content and characteristics of the dynamics for these domains during the specific design phase (Ivashkov 2004). The relation between the extended model of de Vries and the PPO model is shown in Figure 7.

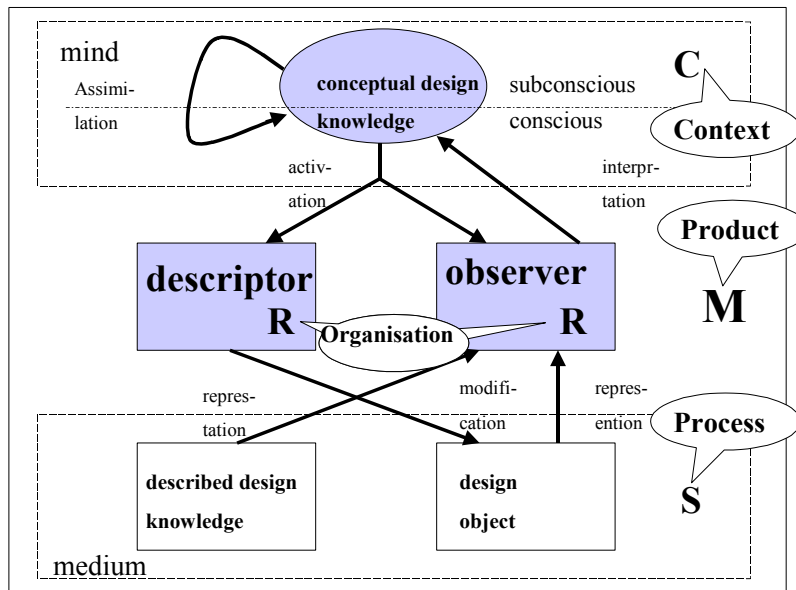


Figure 7: Extended model analytic schematic interaction model of designing.

To work effectively with methodology, practitioners should learn to work with, and understand, the role of methodology in the building design process. The building to be designed takes a central place in thinking of the design team, see Figure 8. Means and goal are mixed up. More and more the insight is growing that it is not the building to be designed that should be central but the needs of the humans for which the building is intended. This leads to a new approach in which the human needs are key aspects that have to be fulfilled, see Figure 9.

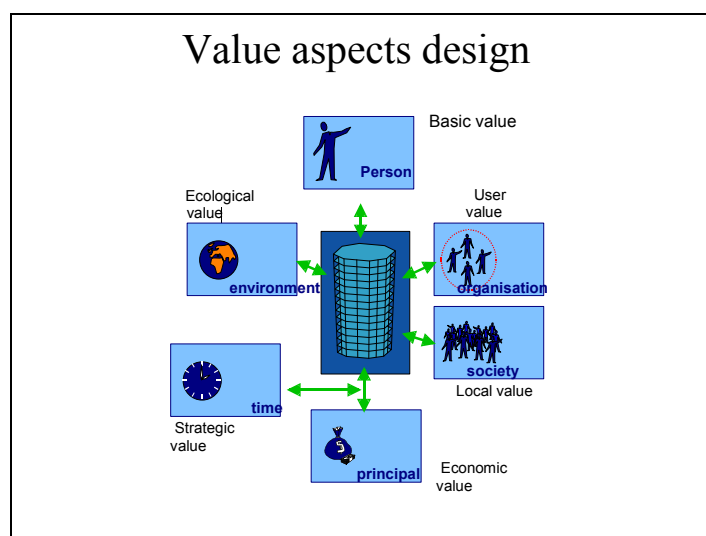


Figure 8: Strategic design, Paul Rutten (Hasselt et al. 1998).

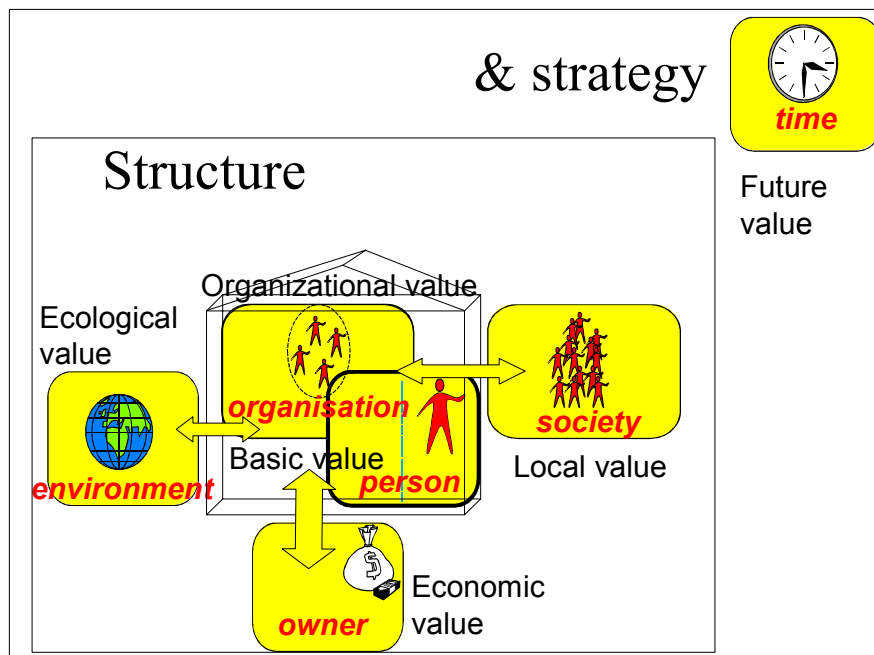


Figure 9: Integral design.

Problems emanate from a lack of integration between architectural design and design of indoor climate. Building Services consultants have difficulties adapting their methodical and arithmetical way of working to artistic and intuitive characteristics of architectural design. To a slightly lesser degree, the same applies to structural consultants. This notion of 'professional enmity' is not as insurmountable as it may seem (den Hartog 2003).

### 3. Integral design workshops

The integral design research project of TVVL-BNA-TUD consisted of a series of design workshops for architects and HVAC-consultants. Interactions during the design process were studied in different settings. During one session the designers, architect and consultants, changed roles in order to get a better understanding of one another's position in the design and construction process. Other forms of workshops were also tested in the Integral Design project. To that effect, a sufficiently complex and innovative design project was selected, and a series of different types of workshops with experienced professionals from the TVVL and BNA were organized. In the Integral Design project TVVL-BNA-TUD the following concepts of workshops were tested:

#### Workshop 1 (October 2001): expert multidiscipline participation

Within this workshop some of the leading Dutch architects and building service consultants participated and worked together in four groups of six people. After working for half an hour on the conceptual design the teams had to pass their results to another group, see Figure 10 (next page). This group had to continue working on the design. For each group, one observer had to write down the actions during the two sessions. The results were evaluated in a separate session with the participating experts.

Workshop 1 ; teams prepare conceptual design and get primarily design from another team

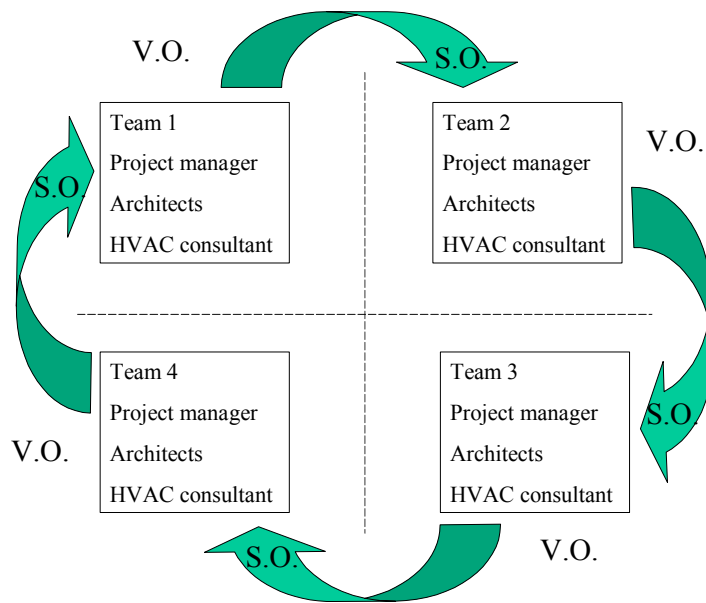


Figure 10: Scheme workshop 1.

### Workshop 2 (January 2002): mono disciplinary

In this workshop, 26 building service consultants were asked to think about different aspects of the design process, to give reactions and to offer ideas and suggestions for improvement of the current situation. Focus of this workshop was on interpretation, see Figure 11.

### Workshop 2 Building Services consultants

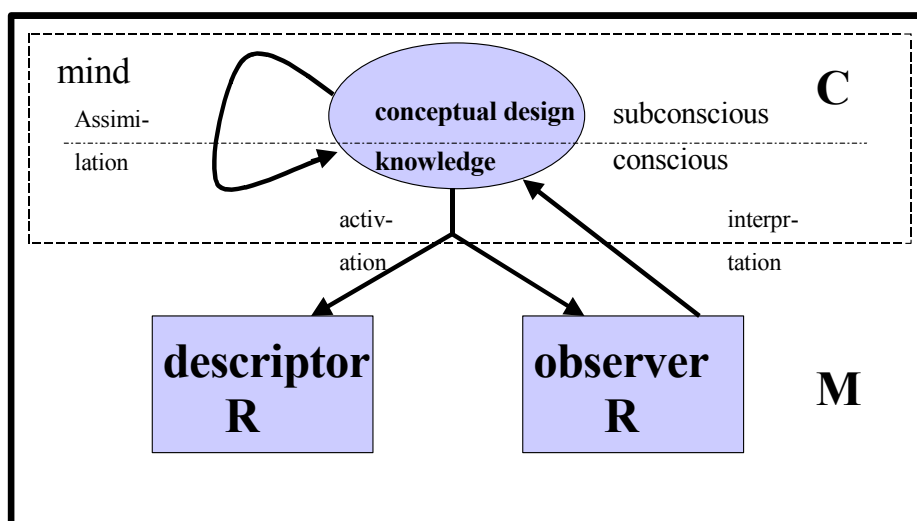


Figure 11: Scheme workshop 2.

### Workshop 3 (September/ October 2002): combined design teams BNA-TVVL

In this concept, the members of the different organisations participated and changed roles. The architect became building service consultant and vice versa, see Figure 12. Each group had two observers who wrote down the actions concerning certain aspects during the design sessions. The results of the workshops were evaluated on 9 criteria. Students evaluated the 31 designs, in which more than 120 architects and building service consultants participated.

#### Workshop 3; Change of role and position in the conceptual design phase

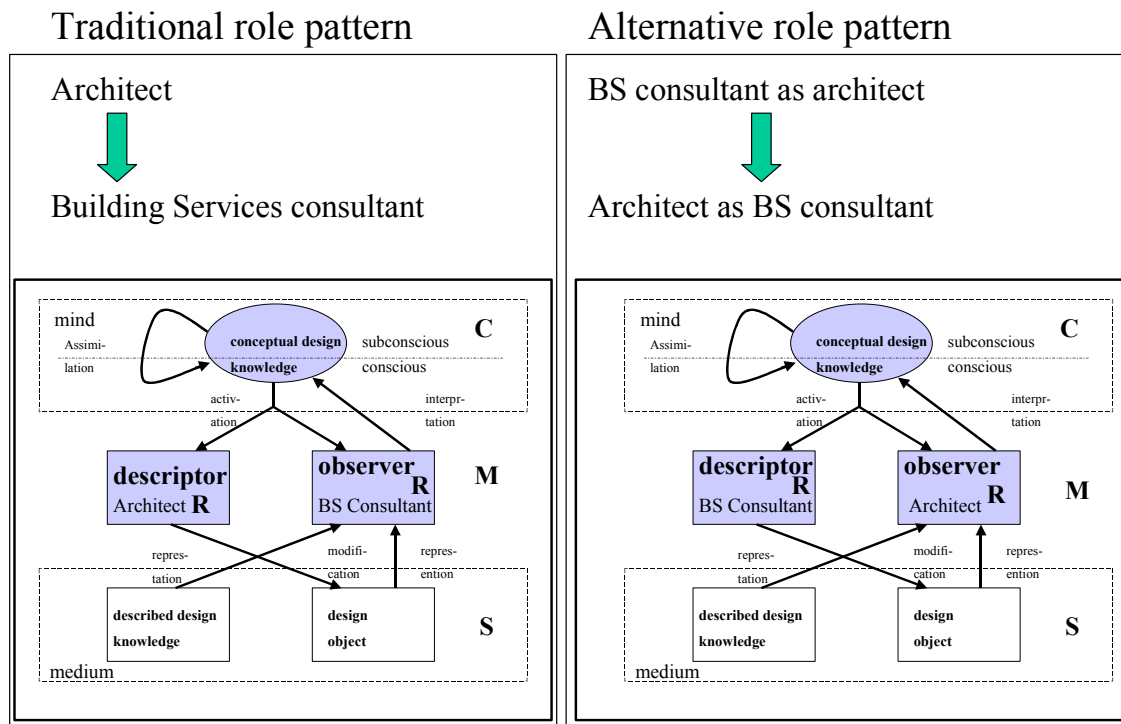


Figure 12: Scheme workshop 3.

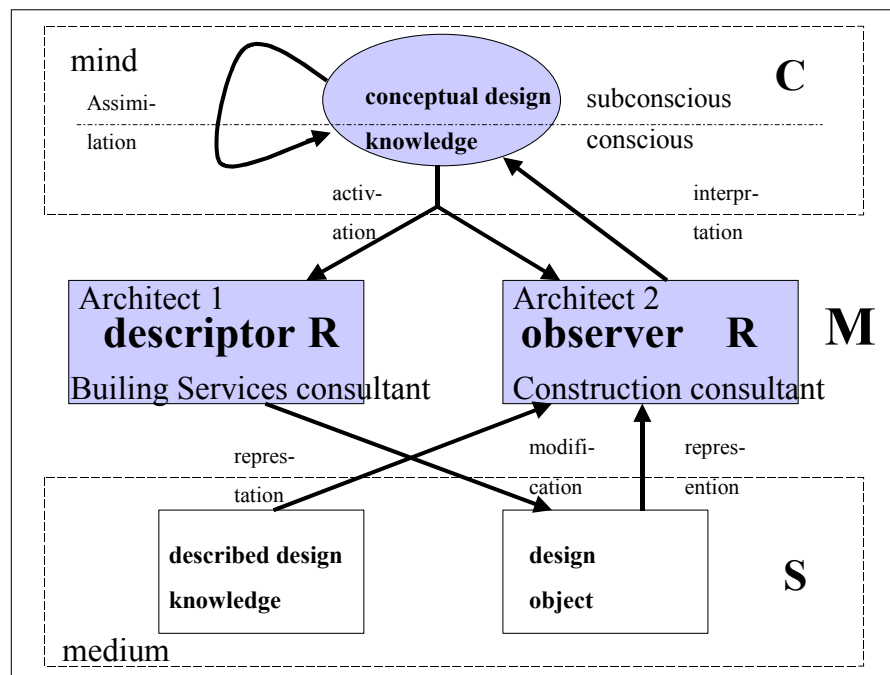
The workshops gave some insights into the design process. Workshops can bridge the gap between theory and practice. Workshops may enable, even force, participants to experience something of the commitment, attachment and pressure that are associated with taking part in real-world events.

#### 4. Follow-up

After these series of workshops, the project Integral Design ended and participants looked for a way to continue the research. Through cooperation the Knowledge Centre Buildings & Systems (KCBS), between TU/e and TNO Bouw, ideas were developed and a PhD proposal was written. This led to a new project in which BNA and ONRI are participating, apart from KCBS.

The new project is characterized by a new approach in which supportive methodological elements are added to the integral design process to stimulate multi-disciplinary project and product development. Especially in early conceptual phase of design the use of sustainable energy solutions is stimulated.

This approach was tried out in two KCBS workshops. In the first KCBS workshop, two architects had to work together with a structural consultant and a building services consultant. The fact that both architects cannot do the same task at the same moment, that as one architect acts as descriptor, the other architect has to act as observer and visa versa. It proved an interesting concept, which clearly showed the different roles of the participants, see Figure 13.



**Figure 13: Schematic interaction model of KCBS workshop 1, with two architects in one group.**

In the first workshop, a tool from methodical design was introduced: the morphological scheme. Sub functions and solutions are presented in a framework of columns and rows. Each combination of solutions chosen at the various levels of sub functions makes a structure that represents a solution for the overall function to be performed.

In the second KCBS workshop, a team consisting of architect, construction consultant and building services consultant had to work together, see Figure 14. In this process the use of the morphological scheme was also stimulated. The morphological scheme was aimed at the use of sustainable energy in the building design.

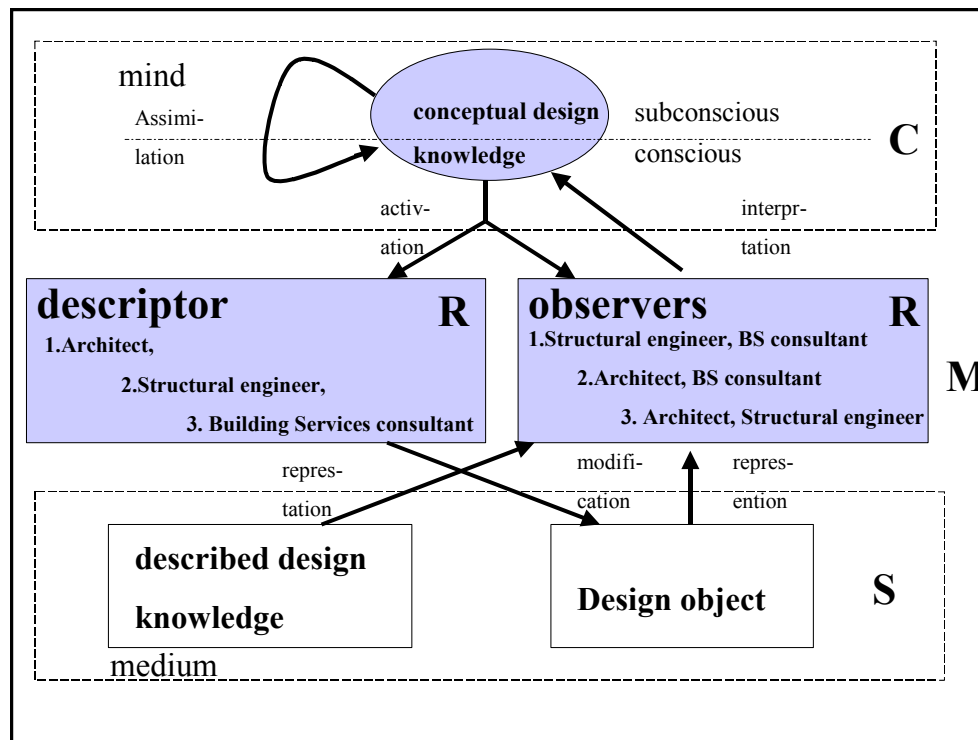


Figure 14: Schematic interaction model of KCBS workshop 2, with one architect in one group.

## 5. Conclusion

The need for an integral approach of the design of a building and its services systems, such as heating, ventilation and air-conditioning systems is strongly felt. Methodical design is proposed as a theoretical basis for design of the building and its building services systems. Design is viewed as a problem-solving activity in which functional reasoning is central.

In order to allow a stepwise approach in which each design decision has well defined implications, four different ontological levels are distinguished for designing energetic process:

- Information Model.
- Physical Process Model.
- Functional Components Model.
- Parametric Model.
- Conceptual World.
- Symbolic World.
- Real World.
- Specification World.

These levels provide a structured framework for morphological schemes. The benefits of methodical process design strongly depend on the experience of the design team members with the approach and its tools.

To support architects more effectively with their tasks, integral design methodology for conceptual design proves to be helpful. If used together with necessary feedback within a framework of building design workshops, it will increase consciousness of sustainable energy characteristics of conceptual design. This approach was tested favourably in various workshops with experts from the various disciplines.



When verifying a new methodological concept, it is not common to work with experienced designers from different disciplines. This is mostly done by experiments with student groups (Segers 2002) or with design groups within one company (Blessing 1994). However, the relevance of research for the daily design practice improves by using experienced designers, as there is a major difference in approach between novice and experienced designers (Ahmed et al. 2003, Kavakli et al. 2003).

Clearly, transferring a methodology from domain-independent design theory to a specific multi-domain approach will help to construct a bridge between architecture and building services. So if research for this methodology is carried out in close cooperation with the designers of the different domains, bridging the gap between design theory and daily practice will truly become reality.

In addition, it will be possible to supply information about sustainable energy applications at a much earlier stage in the design process. And, since this stage precedes the points where most decision-making takes place, these applications will have a much better chance of actually being implemented.

By doing this it is possible to supply information about sustainable energy applications much earlier in the design process. Chances for applying sustainable energy become bigger as most of the decisions still have to be taken.

### **Acknowledgements**

TVVL, BNA and TU Delft have supported the Integral Design project. KCBS, Kropman bv and the foundation “Stichting Promotie Installatietechniek (PIT)” support the new research.

# Energy and Comfort Advice for Consumers Designing Their Own House

## A connection between iBuild and IWCS

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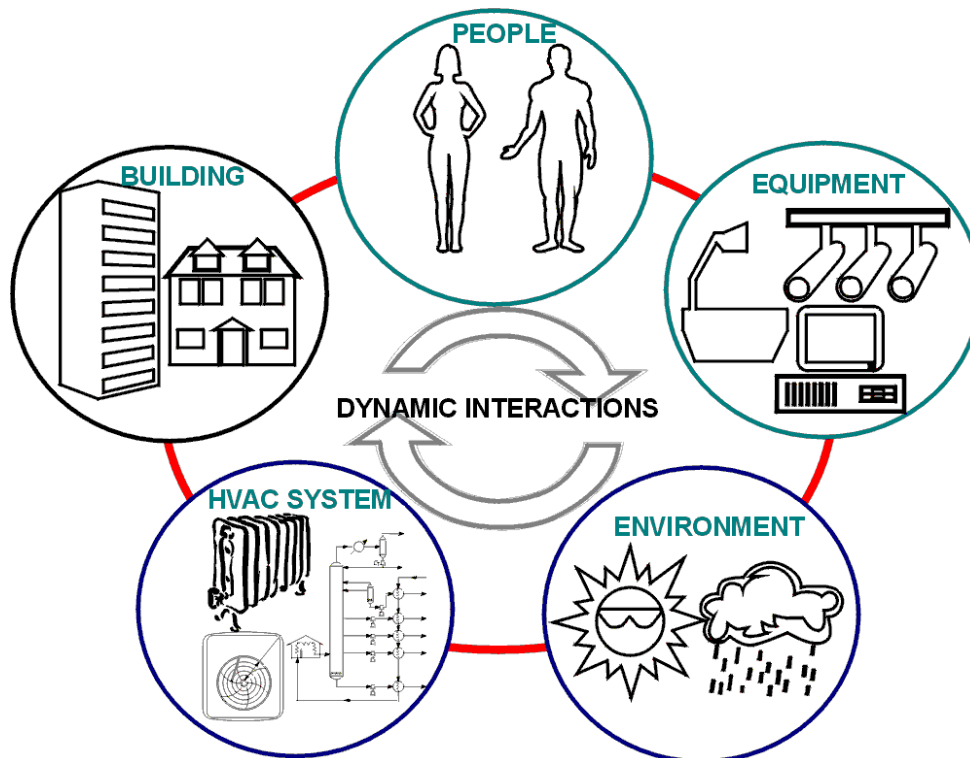
Delft

## 1. Introduction

In the (Dutch) construction industry relatively little attention is paid to low-energy and comfortable housing. It is often limited to prescribed rules by the government. For low-energy and comfortable solutions beyond the minimum legal requirements in one's own home, someone almost has to be an environmental 'enthusiast.' Many people don't realise that a sustainable building offers besides environmental benefits also other important qualities such as improved health and comfort. Especially the last aspects are important for consumers. Therefore people should be informed about these 'extra' benefits of low-energy and comfortable building during for example the designing or buying process. On the one hand people get a more comfortable house (and life) and on the other hand it is positive for the environment and the future population. This paper introduces a project which aims to develop a consumer design support system which is based on combining an architectural design support system with building performance prediction software.

### Building performance simulation

Computer modeling and simulation is a powerful technology for addressing interacting architectural, mechanical, and civil engineering issues in buildings. Building performance simulation can help in reducing emission of greenhouse gasses and in providing substantial improvements in fuel consumption and comfort levels, by treating buildings and the systems which service them as complete optimized entities and not as the sum of a number of separately designed and optimized sub-systems or components. It is only by taking into account dynamic interactions, as indicated in Figure 1, that a complete understanding of building behavior can be obtained.



**Figure 1: Dynamic interacting sub-systems in a building context.**

For more than a quarter of a century, building performance simulation programs have been developed to undertake non-trivial building (design) analysis and appraisals (Kusuda 2001). The techniques of building performance simulation are undergoing rapid change. Dramatic improvements in computing power, algorithms, and physical data make it possible to simulate physical processes at levels of detail and time scales that were not feasible only a few years ago. Although contemporary programs (for an overview see e.g. DOE 2003) are able to deliver an impressive array of performance assessments (see e.g. Augenbroe and Hensen 2004, Hensen and Nakahara 2001, Hong et al. 2000), there are many barriers to their routine application in practice, mainly, in the areas of quality assurance, task sharing in program development and program interoperability (see e.g. Augenbroe and Eastman 1998, Bazjanac and Crawley 1999, Blis 2002, Bloor and Owen 1995, Crawley and Lawrie 1997, Eastman 1999), and because the use is mainly restricted to the final stages of the overall building design process.

Although it is evident that the impact of design decisions is greatest in earlier design phases, building performance simulation is rarely used at all for supporting early design phase tasks such as feasibility studies and conceptual design evaluations. (De Wilde 2004). The main applications of building simulation in current building design projects are code compliance checking and thermal load calculations for sizing of heating and air-conditioning systems; in other words: analysis (of a single solution) rather than (multiple variant) design oriented (e.g. Altavilla et al. 2004).

Our research aims to address some of these issues. The ultimate goal is to provide integrated design and operation tools, knowledge and procedures which lead to innovative, elegant and simple building designs with (a) a balanced attention to the value systems of the building occupier, building owner and the environment, (b) a better quality, (c) a shorter design time, and (d) lower life-cycle costs.

## Consumer design support

The building market is slowly shifting from mass building to consumer based building. This means people have more influence in the shape and attributes of their future house. Consumer based building could appear in the form of participation in the design process or even making the design by themselves. Designing your own home sounds great, but is not an easy job for everyone. Especially the inexperienced consumer could use some support in the design process. For example virtual reality to give a good view of the future house, cost information and energy and comfort advice. Designing a large window may look great in virtual reality, but also has some consequences like a large energy loss. When people know this in advance, the design of the house would probably be different. Virtual reality, cost information and energy and comfort advice during the design process must help the consumer to make well-considered design decisions in order to prevent disappointment about the final result.

## Research objectives

The *iBuild* concept (developed by TNO Built Environment and Geosciences in association with European Design Centre and Willems van de Brink Architects) offers consumers the possibility to design their own house with a view of reducing construction costs. The software allows inexperienced consumers to design their future house. With the help of 2D- and 3D-views and virtual reality (to walk through the design), consumers get a good idea of how the future house will look like. The consumer designs the façades and interior of the future house just by dragging a certain building part like a window, door or interior wall into the façade (2D) or interior design (2D and 3D).

Besides giving a good idea of how the future house will look like, *iBuild* wants to offer energy and comfort advice during the design process. This could for example be a simulation to show the daylight impact or a calculation to show a score for energy use.

One of the solutions to support consumers during the design process is a connection between *iBuild* and an existing energy and comfort advice program. In the research, described in this paper, the possibilities of a connection between the existing advice program *IWCS* (also developed by TNO) and *iBuild* is analyzed. *IWCS* stands for 'Integrale WoonComfortScan' which loosely translated means integrated home comfort scan. Figure 2 is a visual presentation of the connection between *iBuild* and the *IWCS*.

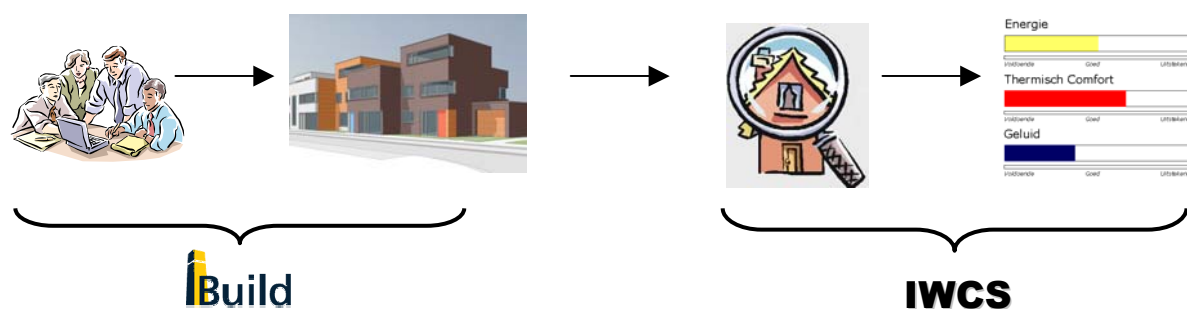


Figure 2: Connection between iBuild and IWCS.

## 2. Research methods

The research presented in this paper comprises a literature search and prototype implementation and testing as elaborated in the following.

### Literature search

A literature search was carried out to determine which calculations are needed to generate that kind of results which will support the consumers during the design process. This research occupies not all the possible energy and comfort aspects, but only the aspects energy, thermal comfort and air quality. The number of studied aspects is limited because of the short period of time available for this research. The aspects energy, thermal comfort and air quality are chosen due to own interest and the strong relationship between them. One of these three aspects couldn't be studied without the knowledge of the others. For example the energy use could be zero when the thermal comfort and air quality isn't taken into account.

The literature search was to find out what each of the three aspects mean (what is thermal comfort?), which parts of the aspects are important for the consumers to know and which building restrictions apply.

### Prototyping

The connection between *iBuild* and the *IWCS* is made with the knowledge of these existing (prototype) programs. An architect delivers a basic design for *iBuild* which the consumers can transform in their own 'perfect' house. This can be done within the guidelines of the architect and the building restrictions of the government and the local authority. To guarantee a reasonable price, *iBuild* has a direct connection with the product database of suppliers of building parts such as, windows, doors, kitchens and interior walls. When designing his house, a consumer can directly choose building components from the manufactures, guaranteeing that his design can actually be built. Such a connection improves the building processes and communication, eventually leading to lower costs.

On the technical part, *iBuild* consists of a model that describes how the design information is stored. Such a model is called an *Express* model and is in this case an IFC *Express* model. IFC stands for Industry Foundation Classes and is a standard for the storage of geometrical data, relations between spaces and properties of the building elements. This standard is supported by many CAD applications. This means that a house design made with *iBuild* can be opened (and edited) in those CAD applications. Therefore a connection between the *IWCS* and *iBuild* can in principle also be used by users of CAD applications to calculate energy and comfort scores of their designs.

The *IWCS* program supports advisors in evaluating the status of an existing house with respect to energy use, thermal comfort, indoor air quality, noise and moisture problems and giving an integral advice for improvement on these aspects. The calculations are at building level and are designed to have an advice available in a couple of hours. The *IWCS* also consists of an *Express* model which describes how the information is stored.

In order to make the connection between *iBuild* and the *IWCS* three aspects had to be dealt with. At first the calculations of the *IWCS* needed to be updated. The calculations behind the *IWCS* are based on building restrictions of the government for existing houses and are simplified with respect to input requirements, i.e. based on observation rather than detailed design information. Because with *iBuild*, new houses are designed, the building restrictions for

new houses need to be applied. And, since detailed design information is available, the simplified calculations could be made more accurate. Besides that, the original *IWCS* calculations are applied at building level whereas the geometrical data from *iBuild* are at room level. The question was whether the calculations behind the *IWCS* needed to be fitted to apply at room level or that the geometrical data from *iBuild* needed to be transformed to apply at building level to fit the *IWCS* calculations. Of course, this decision also depends on the required accuracy of the calculations.

Secondly the update of the calculations behind the *IWCS* caused a change in the kind and detail of data that's needed for the calculations. This also applies for the calculated output data. Because of the different data, the *IWCS* program needed to be updated. The earlier mentioned *Express* model of the *IWCS* is no longer valid and needs to be changed to make a connection between *iBuild* and the *IWCS* possible and to be applicable for new houses.

The last problem consisted of the actual connection between *iBuild* and the *IWCS* and the programming of the new calculations. The data from a final design in *iBuild* needs to serve as input for the calculations and, vice versa, the energy and comfort results need to serve as input for *iBuild*. Since both models do not have the same structure, the connection is made through a mapping between the *Express* models of both programs. This mapping tells which data from *iBuild* needs to be connected with the data needed for the *IWCS*. For example *iBuild* generates the length and height of a wall and these need to be connected with the area data of a wall in the *IWCS* (with the knowledge  $\text{area} = \text{length} * \text{height}$ ).

In many applications, connections between drawing programs and building physics calculations already exist. But the connection is generally made with the use of one model which describes how the data must be stored. And this often means that the drawing or the calculations model has been adapted to fit in the other. Both *iBuild* and the *IWCS* consist of such a describing model, called an *Express* model. In this research these models are kept separate, that way each model is made after fundamental research.

### 3. Results

#### Performance requirements

The information of the literature research leads to a list of calculations to determine values for a good advice. The list of calculations could be seen as a guideline. Some of the needed values are defined with simple calculations and others are defined with complex simulations to determine a right value. Thereby not all the defined calculations could be programmed. Some of them are replaced with other calculations to give a global value. In the future these simplified calculations could be exchanged with more accurate calculations or a complex simulation. In the following text the aspects energy, thermal comfort and air quality are explained and a table shows the concerned indicators and calculation methods.

Since the energy crisis in 1973, energy saving played an important role in the Dutch construction industry. In the beginning energy saving meant mainly preventing heat loss by raising the thermal resistance and the air tightness of the house. Nowadays the building restrictions of the government prescribe a certain energy performance which a house has to satisfy. Consumers could be interested in the energy performance of a house because energy saving also means money saving. Important aspects for the energy performance are thermal isolation, air tightness, design of installations and the use of sustainable energy sources. All these aspects are taken into account in the energy performance coefficient (EPC). Other values that

could give an indication of the energy performance are the Energy-Index (EI), which is comparable to the EPC but applicable for existing houses, and the energy use ( $Q_h$ ) for heating. The calculation of the energy use for heating takes a lot of important aspects not into account. Figure 3 shows a list of possible values and matching calculation methods for a good advice to the customers in the field of energy. After fundamental and scientific research, the conclusion is that the EPC value is preferred for a good advice. The calculation of the EPC value is simplified to make programming possible in the short time available for this research.

Energy Performance			
PI	Value presentation	Calculation method	Demanded/Aligned value
<i>EPC</i> [-]	Single value per house	<i>EPN 2001, NEN 5128</i>	<i>EPC ≤ 1,0</i>
<i>EI</i> [-]	Single value per house	<i>Rekenmodel EPA</i>	<i>n/a</i>
$Q_h/Q_{wh}$ [kWh]	Single value per heating season	<i>ISSO publicatie 16</i>	<i>n/a</i>

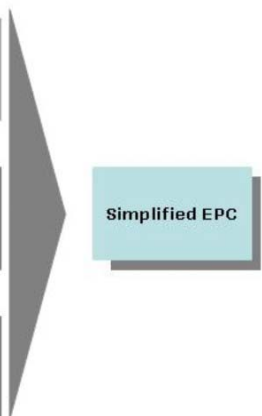


Figure 3: Indicators energy performance.

Thermal comfort is not an easy term to explain, a commonly used definition is: “That condition of mind which expresses satisfaction with the thermal environment.” A definition which many people agree with, but which is also difficult to translate into physical parameters. The experience of thermal comfort depends, in addition to the interior climate (temperature, draught, cold feet), on the activity level and the clothing a person is wearing. When the heat balance of a person and its environment is disrupted, he will feel uncomfortable. Thermal comfort can be divided in global and local comfort. Global comfort is related to the total environment of the user, but not directly related to the user, whereas local comfort deals with the direct influence on the user himself, for example draught near a window, asymmetrical radiation or a vertical temperature gradient. In the first place it is important for the consumers to know whether the global thermal interior environment is comfortable.

Values that could give an indication of the global comfort are operative temperature  $T_o$ , which is the average of the air- and radiance temperature, PMV and the PPD. The PMV describes the general opinion of a group of people about the thermal comfort. And the PPD, which is related to the PMV, describes the percentage of dissatisfied people about the thermal comfort. Figure 4 shows a list of the indicators and matching calculation methods in the field of global comfort. After fundamental and scientific research could be concluded that the PMV and PPD values are preferred. There has to be noted that the calculation of the PMV and PPD values are made with a couple of assumptions to make programming in a short time frame possible. In the future these assumptions, for example the clothing level, can be made more accurate. For the global comfort in the summer the indicator GTO (weighted exceeding hours of a certain temperature) is preferred.

**Global thermal comfort**

Aspect	PI	Value presentation	Calculation method	Demanded/Aligned value
Global TC	$T_{\theta}$ [°C]	Average per hour	n/a	n/a
Global TC	PMV [-]	% appearance PMV < -0,5 en PMV > +0,5	Fanger	Max. 10% of the time
Global TC	PPD [%]	% appearance PPD > 10%	Fanger	Max. 10% of the time
Summer TC	GTO [hours]	Hours per summer	Rgd	Max. 20 hours > 28 °C Max. 100 hours > 25 °C (offices!)

PMV and PPD (assumptions)  
GTO

**Figure 4: Indicators for global (whole body) thermal comfort.**

Besides global thermal comfort, local comfort is of concern. Research in the field of interior environment problems and health effects (Platform Binnenmilieu 2004) showed among other things that draught is one of the main complaints in houses and is therefore useful to take into account. Draught can arise near large windows with poor thermal insulation, because of radiance asymmetry or because of a large velocity of cold dropping air. A possible indicator for draught is the predicted percentage of dissatisfied due to draught (PD). Another local discomfort that could be relevant for the consumers to know is the vertical temperature gradient. This temperature difference appears in situations with a cold floor (poor thermal insulation) and/or a hot ceiling (heating installation). However, the relevance for new houses is limited, since building restrictions prescribe severe thermal floor insulation to prevent energy loss and heating installations in the ceiling are very rare. Figure 5 shows a list of the indicators and matching calculation methods in the field of local comfort. After fundamental and scientific research could be concluded that the PD value is preferred. To make programming possible in a short time frame, the single PD value is chosen.

**Local thermal comfort**

Aspect	PI	Value presentation	Calculation method	Demanded/Aligned value
Draught	PD [%]	% appearance PD > 15%	Fanger & Christensen (1986)	Max. 10% of the time
Draught	PD [%]	Single value	ISSO researchrapport 5	< 15%
Vert. $\Delta T$	$T_{r,floor}$ [°C]	Average per hour	n/a	19 – 26 °C

PD (single value)

**Figure 5: Indicators for local comfort.**



After the energy crisis in 1973, the indoor air quality became a problem. To prevent heat loss, the air tightness of houses increased, mainly by closing openings at cracks and joints. However, the ventilation of many houses took, besides the installed facilities, place through such cracks and joints. By closing these openings, the ventilation rate decreased. This caused poor ventilation and polluted indoor air. The indoor air quality is of high importance because we spend most of the time inside. Ventilation provides a building with fresh air (oxygen) and removes smell, combustion gases, smoke, dust and vapour. Therefore, the provisions for infiltration and ventilation are important to guarantee the required minimum level of fresh air.

Indicators for the quality of the indoor air could be the pollution intensity and ventilation rate. Other important aspects are the type of ventilation and the amount of possible adjustments. Figure 6 shows a list of the indicators and matching calculation methods in the field of indoor air quality. After fundamental and scientific research could be concluded that the air velocity in a room, the ventilation, infiltration and pollution rate are preferred. The air velocity is needed for other calculations like the local thermal comfort. In this stage the indicators can't be programmed and will be omitted. The infiltration and ventilation rate can be calculated, based on the available provisions in the house, however the pollution rate is more complicated. It depends on the material use in the building and the emission rate of volatile components from these materials, which is often difficult to quantify.

<b>Air quality</b>				
Aspect	PI	Value presentation	Calculation method	Demanded/Aligned value
Air velocity	$v$ [m/s]	Average per hour per zone/node	- Zone: AFN simulation - Node: CFD simulation	< 0,15 m/s
Ventilation rate	$V_c$ [dm <sup>3</sup> /s]	Average per hour	n/a	Function depending
Infiltration rate	$q_{v10}$ [dm <sup>3</sup> /s]	Average per hour	- Global - Richtlijnen NEN 5128 - Advanced	< 200 dm <sup>3</sup> /s
Polution	Concen- tration [mg/m <sup>3</sup> ]	per certain time period	n/a	Polution depending

Ventilation,  
infiltration  
rate

Figure 6: Indicators for indoor air quality.

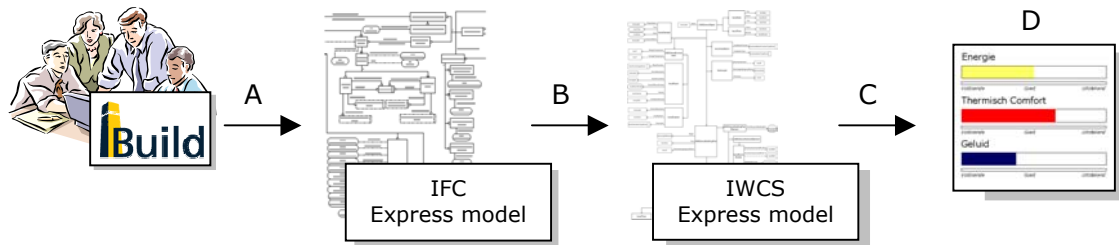
### Prototype design and implementation

This phase of the research project consists of several steps:

- Requirements of the evaluation tools, based on the literature review
- Redesign and adaptation of the *IWCS* to meet the requirements
- Coupling between *iBuild* and the adapted *IWCS*
- Programming of the new *IWCS* calculations

These steps are described below in more detail.

The connection between *iBuild* and the *IWCS* is made in a couple of steps. These steps are discussed in the following text. Figure 7 gives an impression of the technical consequence of this connection.



**Figure 7: Schematic of the connection.**

The first step (A) consists of the storage of the house design made by the consumer according to the IFC standard. This step is integrated in the *iBuild* program and implies that the house design of the consumer can be opened and/or edited in CAD applications which support IFC. Step A is not a part of this research.

Step B describes a mapping between the two *Express* models. As mentioned before, this mapping prescribes which data from *iBuild* needs to be connected with the data needed for the *IWCS*. For example *iBuild* generates the length and height of a wall and these need to be connected with the area data of a wall in the *IWCS* (with the knowledge  $\text{area} = \text{length} * \text{height}$ ). Vice versa, mapping prescribes how the results of the calculations in the *IWCS* are transferred to the *iBuild* model. Both mappings are part of the research and are made with the language (Express-X) specially made for the connection between *Express* models.

Step C is the mechanism to get the information from the *IWCS* model into the calculation modules of the *IWCS*. Since the *IWCS* does not have a native interface to read from and to write to Express models, such an interface is provided by the program EDM (2005) and the program language C. This language can be coupled easily to the *IWCS* modules, providing the data in the model to the internal algorithms of the modules. For example the model consists of a wall with a certain thermal resistance. This value is read from the model and used for the calculation of the thermal transmittance.

Step D consists of the programmed calculations. The calculations are programmed in the C language. The data needed for the calculations is, as mentioned before, picked from the *IWCS* model. The results of the calculations in the *IWCS* modules are transferred back to *iBuild* in the reversed way, using the same Express models.

#### 4. Discussion

Discussion of building performance simulation normally includes validation and verification. Validation concerns mostly whether “the model” is implemented correctly, whereas verification is about whether the correct model has been implemented. In the current case, the latter can be read to mean whether it is any good for the prospective users.

## Validation

In this stage of the research, the connection between iBuild and the IWCS is working. The first (simple) calculations can be made with the use of information from a drawing made in *iBuild*. But it is still very much work in progress. The connection could be seen as a thin line between *iBuild* and the *IWCS* which will be thickened with the extension of calculations. Eventually, all the calculations as mentioned before will be programmed. This extension will have effects on the programmed calculations, the *IWCS Express* model and the connection between the *Express* models. The (simple) calculations which are performed still need to be tested to find out if the results correspond with the reality.

## Utilization

The building physical calculations in the field of energy, thermal comfort and air quality can be made without the interference of the consumer, according to their house design. But the results of the calculations still have to be transformed in a score per analysis aspect. The presentation of the scores is highly important for a good understanding. More research is necessary to find a good visual presentation of these scores. Such a presentation can help the consumers during the design process. The question is in which stage the consumers need to be able to check the energy and comfort results, and how often such an analysis is required. Is it only once at the end of the design, in order to have a final check on the energy and comfort status, or repeatedly from the beginning? In the latter case, the results of the basic design are visible and these results change according to the design decisions made by the consumers. To make an active use of the advice possible, the advice should be available in the earliest stage of the design process.

The coupling as developed in this project is not only useful in the context of a design session with consumers. It can also be used by professionals, like architects, to get support from evaluation modules during the design. Designs made in 3D with a CAD application which supports IFC are suitable for a connection with the *IWCS* calculations. A designer is asked to insert just once certain values, for example the thermal transmittance, which are normally introduced by iBuild. This makes intermediate testing of a design possible. The final design of an architect is often sent to a consultant, which performs building physical calculations, to verify the design. This is quite expensive and can lead to suboptimal solutions, since the architect aims for a final design to be certain fulfilling the energy performance requirement without having feedback during his design. Intermediate testing of a design gives the architect more design freedom and more certainty of the final design fulfilling the energy performance requirement. When in the future the calculations are extended and more accurate, the connection is even more useful. The question arises in which phase of the design process it should be possible for the designers to generate energy and comfort results. Energy and comfort results should be available in the earliest stage of the design process. And it has to be distinct for the designer when enough information is available and the *IWCS* calculations can be executed.

*iBuild* generates all the information needed for the *IWCS* calculations. It enriches the IFC *Express* model with certain (material) properties which cannot be automatically be generated from the drawing, for example the thermal transmittance of a construction. When a designer uses the *iBuild – IWCS* connection, he has to enrich the IFC *Express* model by himself. The question is, whether the designer has the disposal of enough knowledge to insert this (technical) information. When a certain value is inserted wrong, will it be noticed by the designer with almost no experience in the field of building physical calculations?

## 5. Conclusion

The information generated from *iBuild* can be used to perform the (new) *IWCS* calculations to provide information of the design in the field of energy, thermal comfort and indoor air quality. The connection between *iBuild* and the *IWCS* makes it possible to generate these results without the interference of the consumers. The coupling is also applicable for professional designers like architects for intermediate testing of the design. A 3D-drawing of the design made in a CAD application which supports IFC can provide a large part of the information needed for the *IWCS* calculations.

Before the connection between *iBuild* and the *IWCS* is useful for the support of consumers, more research is needed. The results of the calculations need to be transformed in certain scores. And the visual presentation of these scores needs to be understandable for the consumers. A test among consumers designing their future house could show the actual usefulness of the offered energy and comfort advice. Also in the field of the support of designers, more research is needed. Especially in the field of enriching the IFC *Express* model. When a designer has almost no experience with building physics, a mistake in the inserted information stands little change of being noticed. Research can find out whether the support of the designer needs to be extended.

The results of the calculations have to be tested to find out if the results correspond with the reality. In the future the calculations can be extended or replaced with more advanced ones for more accurate results.



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# Artificial Design

## Automatic style generation

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### 1. Introduction

The Institute of Artificial Art Amsterdam (IAAA) works in the area where art & design intersects with computer science and artificial intelligence. The institute started in the 1980's as a primarily artistic endeavour, with a mission to explore the possibilities of computers and other machines for automatic art generation. In recent years, the IAAA has increasingly focussed its research and development efforts on design generators for architecture, information visualization and graphic design. Designs in these fields are to some extent constrained by functional requirements, but there is always considerable room for purely aesthetically motivated variation. We are particularly interested in computer-supported methods for exploring design-spaces of this sort. This paper gives an overview of our theoretical positions and our design-related projects (section 2 and section 3). Special attention is given to an ongoing project, sponsored by *Premisela* (the Dutch Design Foundation), which investigates the application of our approach to corporate identity (house style) design (section 4). This project also involves the development of new interface techniques for our design tools (section 5).

### 2. Meta-design

Our perspective on design may be called *meta-design*. In graphic design as well as in product design, there is an obvious need to design *styles* rather than individual products. The identity of companies, brands and even individuals is defined by their style: specific designs should be recognizable instances of such a style.

In our research we investigate computational methods which support the process of designing styles: automatic and semi-automatic style generation algorithms. Such algorithms presuppose that the notion of a “style” has been construed in a mathematically precise way - or, at least, that a suitable mathematical analogon of the “style” notion has been devised. How to do that is not immediately obvious, since styles are not natural objects whose structure can be directly observed. In the real world we only encounter *examples* of styles, and we may even feel that a style is *constituted* by its examples. The situation is rather analogous with the study of language, where the only “objective” data are concrete utterances (Saussure’s “parole”), while the science of linguistics is necessarily based on the assumption that different people make largely the same generalizations from these data (Saussure’s “langue”; cf. Saussure 1915).



In Chomskyan linguistics, a *language* is therefore defined as a (usually infinite) set of sentences, generated by a finite grammar which also specifies, for every sentence of the language, what its internal constituent structure is. In thinking about formal theories of visual form, the analogy with verbal language has turned out to be useful. Researchers in the “shape-grammar” tradition have followed Chomsky in defining “visual languages” by means of “shape grammars.” Just as a language can be concisely specified in terms of a grammar and a lexicon, we can specify an unlimited number of possible graphics by using a limited set of basic terms, plus a set of operators for constructing complex terms or categories out of the basic ones. Shape-grammars and similar formalisms have been used to define freely invented “meta-artworks,” as well as to simulate the specific historical styles of cultural communities or individual artists or designers (Stiny and Gips 1978).

In our turn, we follow the example of the shape-grammar tradition, and adopt the linguistic approach to the study of visual form. Especially useful for our purposes is the notion of a “sublanguage,” due to Chomsky’s teacher Zellig Harris (Harris 1991, chapter 10). A “language” need not be construed as one monolithic object; rather, it may consist of several “sublanguages,” characterized by grammars which “instantiate” the grammar of the “superlanguage.” That styles have sub-styles and super-styles is an important consideration if we want to think about exploring “spaces of possible styles,” because this property induces a particular, lattice-like structure on such spaces.

### 3. Research areas

Our visual design research ranges from random image generators for art exhibitions to formal theories of visual structure and their application to automatic information visualization, architecture or house style design. We first describe the scientific context of our research into formal models of Gestalt perception. Then we indicate some application areas in architecture and graphic design.

#### Perceptual structures

In the context of art and design, the most important property of an image is what structure the human perceptual processes will assign to it. This structure is needed to predict its similarity to other images or its likely interpretation. Therefore, the formalisms used to specify visual designs should have what linguists call “*strong* generative power.” They should not just generate all and only those forms belonging to a certain visual style, but they should also assign a structure to the form that reflects the visual structure perceived by a human observer of that form.

But what does it mean for a formal expression to reflect a visual structure? How do you test this requirement? Can we build on the results of the study of human perception?

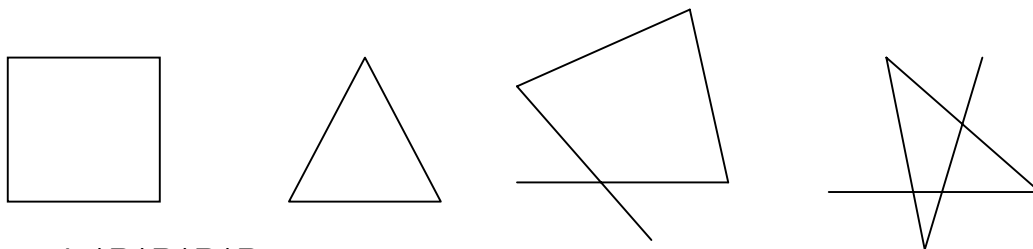
The theory of Gestalt perception tried to explain why people prefer particular structural interpretations of visual stimuli, even though these stimuli almost always allow multiple (perhaps even infinitely many) structural characterizations. Wertheimer (1923) identified a number of important organizing principles such as proximity, continuity and similarity. Many of these can be subsumed under one umbrella-principle, called *simplicity* or *Prägnanz*: human perception chooses the simplest analysis among all possible alternatives (Koffka 1935:171-174). The principle of *Prägnanz* was formalized by Leeuwenberg (1971) in a framework called *Structural Information Theory* (SIT). Leeuwenberg conjectures that perceiving an image consists in encoding it as an expression of a particular image-description language. Perception is thus a disambiguation

problem: an image can usually be described by many different expressions of the coding language, but our perceptual processes tend to choose only one of these. *Prägnanz* can now be turned into a formal disambiguation criterion: among all the expressions that encode an input image, our perception prefers the shortest one.

Structural Information Theory (SIT) is essentially a theory of the perception of linear patterns. Its empirical claim is that such patterns are perceived in terms of a limited number of regularities. In recent versions of the theory, these regularities are: symmetry, repetition, and alternation. In the coding language proposed by, primitive perceptual elements can thus be combined by simple concatenation and by three composition operators: *Repetition* (which repeats the same sequence a number of times), *Symmetry* (which repeats a sequence in the reverse order) and *Alternation* (which alternates the steps in a sequence with some other sequence).

To apply SIT to visual patterns, severe restrictions on the class of possible inputs are needed. The primitive elements in SIT are best seen as basic instructions for a “turtle graphics” program (*draw line*, *move pen*, *turn*). By using the earlier-mentioned structural operators, the sequence of basic turtle steps leading to a particular line drawing can be rewritten. For example, the sequence *ABABA* (with A and B standing for some basic turtle instruction) could be rewritten as *sym(AB, A)*, i.e. a symmetrical structure in which AA is mirrored around an A. Of course, any non-trivial sequence can be reproduced by many different SIT expressions: in this case for instance,  $2 * AB, A$  (i.e. two repeats of AB followed by an A), would lead to the same sequence of turtle steps, but to a different structural analysis. In SIT, the complexity of an expression (determined by its length) is taken as a measure of the complexity of the corresponding perceptual structure. Humans are claimed to prefer the interpretation corresponding to the least complex SIT expression.

The SIT analysis of various classes of visual input patterns has been successfully validated. (Cf. Buffart et al. 1981, Boselie 1988, Boselie and Wouterlood 1989, Van Leeuwen and Buffart 1989, Van Lier 1996). However, as a theory of visual perception, SIT is severely limited by its one-dimensional “turtle” perspective. Essentially a formalism for describing sequences, it cannot handle “proximity”, as it lacks a notion of distance, nor can it handle even simple 2-D elements such as crossings. A fourfold repetition of an angle A and a line B (ABABABAB) can lead to very different 2-D structures, depending on angle size: a square if A is 90 degrees, a triangle (with one line drawn twice) if A is 120 degrees, or a self-crossing polyline if A is greater than 90 degrees (excluding 120).



**Figure 1: ABABABAB patterns.**

In a Ph.D. project in cooperation with the University of Amsterdam, we have started to deal with some of these limitations. We envisage the design of a formal image description language for 2D-patterns which allows us to apply Leeuwenberg’s ideas about regularity and simplicity in Euclidean 2D-space, without first mapping it to a linear structure. (Cf. Dastani 1998; Dastani and Scha 2003.)

### Information visualization

Automatic systems for information visualization or information design presuppose principled and effective methods to reflect the *structural* properties of the information in *structural* properties of the graphics being designed. (Cf. Bertin 1983; Mackinlay 1986; Roth 1990; Roth et al. 1994; Kamps et al. 1996; Zhou and Feiner 1996; Engelhardt et al. 1996, 1998; de Bruin 1996; Tufte 1997; Dastani 1997; Wang et al. 1997.) An important first step is a systematic analysis of the meaning of the spatial structure of a picture or graph. We achieved significant progress in this area in a Ph.D. project with the University of Amsterdam (Engelhardt 2002).

### Architecture

For Archipel Ontwerpers (The Hague) we wrote an algorithm generating random buildings within certain stylistic constraints. The algorithm was geared towards generating penthouses to be realized by means of a steel construction method which allows considerable freedom in the angles of walls and roofs. Archipel Ontwerpers used our algorithm interactively and chose one of its designs for further elaboration. The resulting design is expected to be realized next year as a penthouse on top of an existing building in the Witte de Withstraat in Rotterdam (Cf. Melet and Vreedenburgh 2005).



**Figure 2: A penthouse design.**

### Corporate identity design

A good example of meta-design is corporate identity design. Corporate identity covers anything that might affect the public image of an organization, from the styling of its products to the architecture of its buildings, the decoration of its stores, the uniforms of its personnel or its association with certain sports or famous people. In a project funded by *Premsele*, the Dutch Design Foundation, and several large companies, we look at one small but important aspect, the design and management of the visual styles used in corporate communications: company brochures and flyers, reports, business cards, company websites, ads.

The design and management of a house style has become a complicated and costly affair, as media and communication channels multiply and desktop publishing makes it ever easier for departments as well as individual workers to generate their own formats. Corporate communication departments need to strike a balance between the need to control consistency, quality and costs (which seems to call for strict guidelines and predefined formats), and the need for sufficient diversity and local autonomy.

A house style is usually prescribed by a combination of fixed, template-based formats for certain types of documents (e.g. business cards), much more flexible design examples for e.g. company brochures, and purely anecdotal examples of the mood or emotion that e.g. pictures used in company ads would have to convey. Our project is aimed at the design of documents that cannot be given a frozen template-based format, because of the variation in content, but that still need to conform as much as possible to common layout guidelines. Because designers lack a powerful, formal language for specifying visual structures, style guide writers rely on a combination of examples and low-level formatting instructions, such as “always use *this* grid” or “always put the logo at precisely 4 mm from the left and bottom margin.” As a result, these style guides leave much to the imagination of the designers. If they take the examples and instructions literally, they will miss intended opportunities for variation, but if they take full advantage of the room left for generalizations, they may well come up with all sorts of unintended variations.

#### 4. Artificial Design project

The goals of the *Artificial Design* project are to develop a formalization of the visual style of company brochures, show how the specific styles of three participating companies (KPN, NS and Océ) can be specified as substyles of this general document design style, and build a prototype that enables the partners in the project to test the implications of our approach for their house style management.

##### House styles

Generally speaking, the visual style used for company brochures and flyers is rather uniform, with little room for variation. This is at least partly due to functional considerations. These documents often contain a fair amount of text and tables, so readability requirements severely constrain both the placement of items and their rendering. While readable text can still be formatted in different ways, using the same lay-out for different folders makes sense as it eases the search for particular information. There are also economical reasons: by using fixed formats, the cost of applying a style can be kept down. Last but not least is the desire to present a consistent image. Corporate communication managers like to see their folder racks filled with similar looking folders, for aesthetic reasons, but also to show that their organization is in control, knows what it is doing.

The challenge in this project is to show that given all these restrictions, there is still room for variation, that in order for individual items to be seen as variations on the same theme, it is not necessary for each of them to share the same properties. (Cf. Wittgenstein’s notion of family resemblance: styles are like natural categories, concepts that cannot be defined in terms of necessary and sufficient properties, even though there is a broad consensus on what objects would fall under their extension.)

## Content versus form

In data visualization, the data and their visualizations should (and can) be kept separate and treated distinctly. Automatic visualization techniques rely on this. They use rules to map the semantic properties of the data onto appropriate visual properties and layouts: e.g. a relation between two variables can be mapped to a line graph if the relation corresponds to a table listing two quantitative properties of a set of items; but if one of these variables is a category label and the other variable the number of items in that category, as in a frequency table, then a histogram would be more appropriate.

In document design this distinction between content and form is often harder to make. It can be made when dealing with table-based data, i.e. when formatting catalogues or similar highly structured documents, where the appearance and formatting of various elements can be inferred from their semantic properties. However, when dealing with magazines, books, flyers or advertisements this distinction between content and form is often impossible to make. Isolating the meaning of text from its actual wording is still mostly beyond reach for current technology. The title of a text cannot be automatically inferred from its contents in the same way that for instance a correlation coefficient can be computed for two numeric variables.

As a result, the semantics available for textual documents is mostly restricted to what could be called *presentational* semantics: structural (e.g. title, subtitle, author, footnote etc.) and pragmatical (e.g. *emphasize*) mark-up. While the actual appearance of the documents can thus be kept separate in formatting rules and/or style sheets, their basic structure and format is already presentational: the decision to represent the information contained in the document as a text, and how to structure that text, has already been made and is taken as the starting point for the design process.

For this reason, we treat graphic design not so much as the visualization of an idea or function, but primarily as a matter of reformatting, starting from a simple sequence or graph of textual and other graphical elements. In what is – somewhat confusingly in light of the above remarks – known as *content-based formatting*, i.e. the formatting of books or catalogues, this formatting is a sequential process in which text and other elements flow onto a sequence of pages, the number of which is determined by the amount of text to be formatted. While this may involve some clever computation to deal with widows, hyphenation etc., it is basically a matter of repeatedly filling in page templates. In *layout-based formatting* on the other hand, the overall layout and visual impact of the design is often more open, but the total amount of space available is fixed. This is true of e.g. flyers or posters. In this type of formatting, designers use a trial-and-error approach to achieve the desired impact, going back and forth between different formats and adding elements or suggesting changes to the elements to be included. The *Artificial Design* project is focussed on this type of formatting, which is clearly much harder to formalize.

## System architecture

The kernel of the system is a generator that takes a style grammar and an initial expression, and rewrites the non-terminals in this expression until only terminals are left. The resulting intermediate design consists of graphical elements of which the visual rendering has been filled in, but the layout may still be specified in relative terms (e.g. “align vertically with center of predecessor in parent structure, horizontally 5 mm to the left of the right border of the containing graphic”). In the next cycle, these lay-out instructions are applied to the current design, leading to a design in which the absolute size and position of all graphical elements has been determined. This design can be output as an XML document, which can then be rendered

by any lay-out program for which an appropriate script has been written. In the prototype systems, instantiated designs can either be rendered directly by a renderer written in Java, or by Adobe InDesign, using a simple Visual Basic script.

### Design representation

Non-terminals are like frames or classes (or complex types, in XML terminology), with attributes whose value restrictions are again specified as (subtypes of) non-terminals. The set of non-terminals will be open-ended, but any new types will have to be specified as subtypes of a small set of basic types. Fully instantiated designs are specified using only basic types, to ensure that they can be rendered using the scripts provided for various renderers. Some basic types are:

- *graphic*, any element to be placed somewhere in the design, with attributes such as color, size, alignment, scaling (examples of subtypes: paragraph, image);
- *structure*, a collection of graphic and/or structure elements (and itself a kind of graphic); in addition to providing a hierarchical nesting that provides context when evaluating the scaling and alignment instructions, structures may also come with their own layout (e.g. a grid);
- *alignment*, an instruction to align some graphic relative to some other graphic.

We use the XML Schema standard to specify these basic types. A second XML Schema specifies the formalism used to define the actual style grammar, for instance to declare a brochure as a kind of structure consisting of a cover spread (itself a structure consisting of pages) and several inner spreads etc. These complex type definitions restrict the value range and cardinality of attributes, including their probability distributions. Style definitions can thus be maintained as separate XML documents.

## 5. Interface

Traditionally design software is seen as a tool for a designer working on the visual layout and appearance of a particular product. Consequently, the user interfaces of these tools are stuck in the toolbox metaphor: Photoshop, InDesign, AutoCad or QuarkXpress, they all start with a blank sheet and a rather overwhelming array of menus and dialogs. However appropriate this approach may be for expert designers who know what they want to achieve (and how to achieve it), it is not the most efficient way to interface with style generators, neither for users of such generators nor for their developers.

Style definitions can only be developed by looking at significant and representative samples of the sort of designs they would give rise to. When applying the style definitions, users should be able to get a good impression of the variation allowed by the style before committing to a particular design. Most users will lack the expertise needed to infer the implications of a style definition, let alone of changes to such a definition, without being able to look at concrete examples.

A simple approach would be to generate a large number of example designs in some random order. This is the approach followed in our artificial image generation programs. For artificial art this is an effective way to give an overall impression of a style, but when users are looking for a good design for a particular document, this is not very efficient. Design is often described as the search for a fitting solution to a set of constraints. Using automatic generation this becomes literally true. The solutions are all there, the problem is knowing where to look for likely candidates.

To be able to quickly zoom in on the right area, we are exploring a technique we call flashing. Flashing is like automatic browsing (as in a slide show), but with a more flexible method of selecting the items to be shown, providing a better sense of the space of possibilities of which the item shown is just one instance. Direct manipulation of, and navigation through, some visual representation of information spaces is a standard tactic in data visualization. New in our approach is that we show the actual items, instead of just a few visual indicators of some of their attributes. When visualizing collections of non-visual information such non-iconic indicators are unavoidable, but here we are dealing with data whose visual appearance is their main, if not their only point of interest. To convey the impact of a particular style, certainly to non-experts and in most likelihood also to experts, it will be more effective to show the samples themselves, and not try to abstract away from their actual appearance. Designers communicate almost exclusively by example, not just to their clients but also among colleagues.

Flasher was originally developed as an alternative way to browse the internet for non-textual, graphical items. Searching for such items with current tools is rather cumbersome and inefficient, not only because these searches are mostly severely restricted by the limited number of available keywords, but also because only a limited number of results of such searches are shown, ordered on a single relevance measure.

Flasher assumes a more active approach, continually collecting items, ordering them in a multi-dimensional space and actively displaying a random slide show of the items falling within the area of the search space currently selected by the user. Items are ordered in a limited number of categories on each selected dimension. Two of these are used to subdivide the presentation panel in an  $n$ -by- $m$  cross-tabulation, each sub panel showing a selection of items that fall within that particular subgroup. Users move through a search space by switching perspective, i.e. by choosing different 2-D slices through the  $n$ -dimensional space, and by zooming in and out of the sub-divisions. When zooming in, the items in that particular cell are again distributed over an  $n$ -by- $m$  cross tabulation that further divides the attribute ranges zoomed into.

## 6. Discussion

The overall aim of our research is to come to grips with the elusive notion of visual style, using a formal, algorithmic approach, centred on the development of automatic generators of visual designs and taking human perception of visual structure as pour inspiration. The *Artificial Design* project attempts to make the step from specialized, hand-tuned generators for specific designs, i.e. generators with a built-in style, to a more general generator that uses declarative style specifications to guide its designs. Later this summer we expect to demonstrate a prototype written in Java and consisting of a generator, a Flasher-based interface, a specification of three different house styles for the design of brochures and, in addition to the bundled Java renderer, an option to render documents in InDesign.

Focussing on corporate styles greatly restricts the variation in visual designs to be handled. Corporate styles tend to be simple, uniform and rather similar, ruled by the regular grid of modernistic design. However, this lack of variability is momentary: corporate styles change over time, mostly in sync with general fashions regarding preferences for straight versus curved lines or the use of decorative elements. An adequate style specification needs to handle not only the ostensibly restricted styles occurring at a specific moment in time, but also at least some of their variations over time.

As indicated in section 3, the search for perceptually relevant structure-building operators is on-going. A major challenge is satisfying the constraints imposed by top-down generated hierarchical structures with the constraints imposed by the elements to be positioned in these structures. In terms of the linguistic metaphor used earlier: if visual structures are seen as expressions of a visual grammar, generation is not just a matter of finding a sequence of words that expresses the intended meaning, but also of using pre-determined words and phrases as part of that expression, and of making sure that the length of the total expression stays within a particular range.

The usefulness of the proposed Flasher interface depends on the availability of useful dimensions to categorize the items to be flashed. In this automatic design system, information about these dimensions is available from the style definition file. The main issue in this type of application is whether users can actually use these dimensions effectively to zoom in on the desired designs. This will depend both on the structure of the overall space (i.e. can designs that are similar in terms of what the user is looking for, actually be found together in the space used) and on the ability of users to infer a sense of direction towards such groups in this space.

Artificial graphic design is conceivable because graphic design is a matter of reformatting. Such design-as-repackaging is not restricted to graphic design. It occurs whenever design is not determined solely by function, but also by considerations of taste, fashion or aesthetics. We are convinced that designers will increasingly use automatic design tools to explore this “room for aesthetic maneuver,” formulating the rules once instead of repeatedly creating new samples.





# Representing Computational Change in Design

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## 1. Introduction

There will always be a need for different representations of the same entity; this is particularly true in the building domain, whether it be a building in its entirety that is under consideration, or a part of a building, albeit a shape, or some other complex collection of properties. The building domain, at all stages, is multi-disciplinary, involving participants, knowledge and information from various specializations. Problems in building design require a multiplicity of viewpoints, each distinguished by particular interests and emphases. In the main, the architect is concerned with aesthetic and configurational aspects of a design, the structural engineer is engaged by structural members and their relationships, and the performance engineer is interested in the thermal, lighting, or acoustical performance(s) of an eventual design. Each has views – derived from an understanding of current problem solution techniques in their respective domain – that requires a different representation of the same (abstract) entity. Even within the same task, or by the same person, various representations may serve different purposes defined within the problem context and selected approach. This is especially the case in architectural design, where the design process, by its exploratory and dynamic nature, invites a variety of approaches and representations (see, for example, Kolarevic 2000).

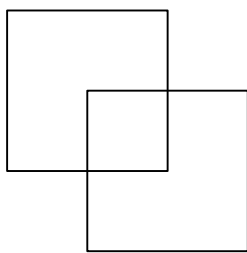
Integrated data models span multiple disciplines, and support different views. Such models allow for a variety of representations in support of different disciplines or methodologies, and enable information exchange between representations and collaboration across disciplines; examples include the ISO STEP standard for the definition of product models (ISO 1994), and the Industry Foundation Classes (IFCs) of the International Alliance for Interoperability (IAI), an object-oriented data model for product information sharing (Liebich 2004). These efforts characterize a, primarily, a priori top-down approach: an attempt is made at establishing an agreement on concepts and relationships, which offer a complete and uniform description of the project data, independent of any project specifics (Stouffs and Krishnamurti 2001a).

As such, these models do not support the creative aspects of the building design process, especially, in the early design phases. Creativity, in design, relies on a restructuring of information that is not yet captured in a current information structure – that is, emergent information – for example, when the design provides new insights that lead to a new interpretation of constituent design elements. The standard object-oriented approach (in CAAD) requires a specification of design elements as objects (with properties) that is maintained at all times, unless explicitly altered. Any reinterpretation of design elements, then, requires the specification of a change – in this case, computational – that not only fixes beforehand the source and destination object types, but also their numbers as well as the mapping between properties. It has been shown that continuity of computational change requires anticipation of the particular structures that are to be

changed (Krishnamurti and Stouffs 1997). Creativity, on the other hand, is without such anticipation.

Computationally, recognizing emergent information structures requires determining a transformation under which a specified structure is similar to a part of the original (Krishnamurti and Earl 1992). It requires the definition of a part relationship that governs when one information structure is considered a part of another. This part relationship may be freely defined, as long as it constitutes a partial order. The algebraic model for shapes (Stiny 1991; Stouffs 1994) is based on such a part relationship. In this model, a shape is specified as an element of an algebra, ordered by a part relation, and closed under the operations of algebraic sum, difference and product, and the affine transformations. Moreover, under the part relation, any part of a shape is a shape. Whence, each shape specifies an infinite set of (sub-)shapes, each a part of the original shape; in this way, users can deal with shape in indeterminate ways. As such, shapes emerge.

The maximal element representation (Krishnamurti 1992; Stouffs 1994) captures this notion precisely. Consider Figure 1, which shows a combination of two squares. In the object-oriented approach, each square may define an object as made up of four line segments. Visually, however, the composition in Figure 1 contains not two, but three squares. In order to recognize this third square, each square object needs to be reinterpreted as a collection of six line segments, such that two can be taken from each to define the middle square object. However, the transformation of a square object into such a collection of six line segments is specific to this particular context, and not generally relevant. Under the maximal element representation, each object is, in a minimal way, made up of maximal line segments, and each such maximal line segment specifies an infinite set of (sub-)segments that are each part of the original segment. Thus, the four line segments defining the middle square object can always be found in the representation of the original two squares, each a collection of four maximal line segments. Furthermore, although an indefinite number of other collections of line segments can be determined and represented, none is of any higher importance, except by designer choice. This provides the designer with the freedom to reinterpret a design in any way, and have this interpretation supported by the system.



**Figure 1: A composition of two or three squares.**

Both the algebraic model for shapes and the maximal element representation have their origin in shape grammar research (Stiny 1980; 1991). They were initially developed for shapes, made up of points and line segments, in one and two dimensions, later extended to three dimensions and to planar and volume segments (Stouffs 1994). Each type of spatial element specifies its own algebra, e.g.,  $U_{12}$  for line segments in two dimensions,  $U_{23}$  for plane segments in three dimensions. The notation  $U_{ij}$  refers to linear shapes made up of  $i$ -dimensional elements in a  $j$ -dimensional Euclidean space, with  $U_i$  as shorthand, when the dimensionality of the space is

known (Stiny 1991). When a shape is made up of more than one type of spatial element, it belongs to the algebra given by the Cartesian product of the algebras of its spatial element types, e.g., a shape of points and line segments belongs to  $U_0 \times U_1$ . The algebraic model has also been applied to shapes augmented with non-geometric properties, such as labels, weights (e.g., line thickness; Stiny 1992), and colours (Knight 1989). The notation  $V_i$  refers to linear shapes made up of  $i$ -dimensional elements augmented with labels and  $W_i$  to linear shapes made up of  $i$ -dimensional elements augmented with weights (Stiny 1991). Both  $V_i$  and  $W_i$  can be defined as the Cartesian product of the algebras of the spatial element type and, respectively, an algebra for labels and weights.

By extending the algebraic model for shapes, a framework for representational flexibility, named *sorts*, can be defined that supports, computationally, the recognition of emergent information. In this framework, each *sort* defines its own algebra: a *sort* of points corresponds to  $U_0$ , a *sort* of line segments to  $U_1$ , a *sort* of plane segments to  $U_2$  and a *sort* of volume segments to  $U_3$ . Corresponding to the Cartesian product of algebras, we can define a conjunctive operation on *sorts* such that a *sort* of labelled points can be defined corresponding to  $V_0$ , given a *sort* of points and a *sort* of labels. Likewise, we can define a *sort* of weighted line segments corresponding to  $W_1$ , or a *sort* of linear shapes corresponding to  $U_0 \times U_1 \times U_2 \times U_3$ .

Two remarks are in order with respect to the conjunctive operation on *sorts*, and its similarity to the Cartesian product. Firstly, the operation is not commutative, thus a *sort* of labelled points is not identical to a *sort* of ‘pointed’ labels. The former *sort* consists of points with associated labels; the latter consists of labels with associated points. This distinction derives from the fact that each *sort*, or algebra, defines its own algebraic operations, based on its own part relationship, and the resulting algebraic operations for the two conjunctive *sorts* may behave differently (see below). Secondly, an element belonging to a conjunctive *sort* necessarily contains elements from each constituent *sort*. For example, a shape belonging to a Cartesian product of algebras, e.g.,  $U_0 \times U_1 \times U_2 \times U_3$ , must contain (spatial) elements from each algebra, otherwise it necessarily belongs to the algebra given by the actual Cartesian product of the algebras of its specific element types.

In order to define a disjunctive *sort* — where neither the ordering of the component *sorts* is important, nor is the explicit presence of elements from the different component *sorts* necessary — we can define a disjunctive operation on *sorts*. Under this disjunctive operation, any element of the resulting *sort* is necessarily an element of a constituent *sort*. The disjunctive operation on *sorts* consequently defines a subsumption relationship on *sorts*: a disjunctive *sort* subsumes each constituent *sort*, because each element of a constituent *sort* is also an element of the disjunctive *sort*.

Subsumption is a powerful mechanism for comparing alternative representations of the same entity. When a representation is subsumed by another, the entities represented by the former can also be represented by the latter representation, without any data loss. There are many representational formalisms that consider the subsumption relationship in order to achieve partially ordered type structures; most are based on first-order logic. Applied to building design, a good example is Woodbury et al. (1999), who adopt typed feature structures as the model for design space exploration. Like many other formalisms, typed feature structures consider a record-like data structure for representing data types. Record-like data structures facilitate the encapsulation of property information in (a variation of) attribute/value pairs (Ait-Kaci 1984). Furthermore, the properties may themselves be typed by type structures, i.e., expressed in terms of record-like data structures, containing (sub-)properties. Then, the subsumption relationship

defines a partial ordering on type structures. Furthermore, the algebraic operations of intersection and union (or others similar) may be defined on type structures so that the intersection of two type structures is subsumed by either type structure, and the union of two type structures subsumes either type structure.

*Sorts* can be similarly conceived, with at least one exception: the association of properties to a *sort* occurs through the conjunctive operation on *sorts* — that is, each property of a *sort* is itself a *sort*. Primitive *sorts* are the exception to this rule. Like primitive data types, primitive *sorts* are the smallest building blocks for building *sortal* representational structures. A primitive *sort* defines the domain of possible values that elements from this *sort* may hold, e.g., a primitive *sort* of weights specifies the domain of positive real numbers, and a primitive *sort* of line segments specifies the domain of intervals on linear carriers. Primitive *sorts* may be constrained over the extent of their domain, for example, limiting weights to values between 0 and 1. Then, the subsumption relationship between *sorts* derives from the disjunctive operation on *sorts* (similar to a union of two or more type structures) and the expression of constraints on primitive *sorts*. The specification of an intersection-like operation on *sorts* adds no further value because the intersection of two *sorts* can always be reduced, through distributive and associative rules, to the intersection of primitive *sorts*; the intersection is non-empty only when the primitive *sorts* are identical, except for possible constraints (Stouffs and Krishnamurti 2002).

Another important distinction is the fact that first order logic-based representations generally consider an open world assumption — that is, nothing can be excluded unless it is explicitly excluded. For example, consider polygon objects that may have a colour assigned. When looking for a yellow square, a square without any colour specified is considered a potential solution — unless, it has another colour explicitly specified, or it is otherwise known not to have the yellow colour. The fact that a colour is not specified does not exclude an object from potentially being yellow. *Sorts*, on the other hand, hold to a closed world assumption. A polygon only has a colour if one is explicitly assigned: when looking for a yellow square, any square will not do, unless it has the yellow colour assigned. This restriction is commonly used in shape grammars to constrain emergence. More specifically, labelled points commonly serve to constrain the applicability of shape rules, which encapsulate both shape recognition (emergence) and shape transformation (computational change). *Sorts* provide a component-based approach to developing grammar systems, utilizing a uniform characterization of grammars (Stouffs and Krishnamurti 2001b). Another way of looking at this distinction between adopting the open or closed world assumption is to consider their applicability for knowledge representation. Logic-based representations are developed essentially for representing knowledge. *Sorts* are intended only to represent data and information — any reasoning (computational change) is based purely on present (or emergent) information.

## 2. A constructive approach to *sorts*

A *sort* constitutes the basic entity for our formalism. Conceptually, a *sort* defines a set of similar data elements, e.g., a class of objects, or a set of tuples solving a system of equations. For example, points and lines are each a *sort*, and so are plane and volume segments. *Sorts* are not limited to geometrical objects, colours are a *sort*; other data types too define *sorts*. Elementary data types define the basic building blocks for the construction of *sorts*; these building blocks are denoted as *primitive sorts*. Primitive *sorts* combine to form *composite sorts* under compositional operators over *sorts*.

The *attribute* operator (corresponding to the operation of Cartesian product), specifies a conjunctively subordinate composition of *sorts*. The resulting representational structure is a combination of both operand structures under the familiar object-attribute relationship. For example, a *sort* of labelled points is specified as a *sort* of points, with one or more labels assigned to each point in the data collection. The attribute operator is non-commutative.

The *disjunctive* operator allows for disjunctively co-ordinate compositions of *sorts*: the resulting data collection combines the different types of data elements from its operand *sorts*, without imposing any hierarchical relationships. The resulting representational structure distinguishes all operand structures such that each data element belongs explicitly to one of the operand *sorts*. For example, a *sort* of points and lines distinguishes each data element as either a point or a line. The disjunctive operator is commutative.

The algebraic model implies the specification of a part relationship on the elements within a *sort*. This part relationship not only governs when one element is a part of another but, as a result, also how elements combine and intersect, and what the result is of subtracting one element from another or from a collection of elements from the same *sort*. Since this part relationship may be freely defined, as long as it constitutes a partial order, different part relationships may be applied to different *sorts*, reflecting on a desired behaviour for the *sorts'* elements. For example, points and labels adhere to a discrete (or set-like) behaviour, with the part relationship corresponding to the subset relationship on mathematical sets; weights (e.g., line thickness or surface tones) adhere to an ordinal behaviour, with the part relation on weights corresponding to the less-than-or-equal relation on numeric values; and line segments and other one-dimensional quantities, such as time, adhere to an interval behaviour (Stouffs and Krishnamurti 2002).

Behaviours also apply to composite *sorts*, that is, a part relationship can be defined for data elements belonging to a *sort* defined under the attribute or disjunctive operator. Specifically, a composite *sort* inherits its behaviour from its component *sorts* in a manner that depends on the compositional relationship.

Under the attribute operator, the composite behaviour is that of the first component *sort*. The attribute operator specifies a dependency relation on component *sorts*, where each component, except for the first, defines a *sort* of attribute data to the previous component. The corresponding data collection consists of data elements of the first component *sort*; each element then has, as attribute, a data collection corresponding to the *sort* as a composition of all but the first component, in a recursive manner. Thus, a data element is part of a data collection, composed under the attribute operator, if it is a part of the data elements of the first component *sort*, and if it has an attribute collection that is a part of the respective attribute collection of the data element(s) of the first component *sort* it is a part of. When data collections of the same composite *sort* (under the attribute operator) are pairwise summed (differenced or intersected), identical data elements merge, and their attribute collections combine, under this operation. All elements with empty attributes are, necessarily, removed.

Under the disjunctive operator, the behaviour is that of the component *sort* for each component — a data element is part of a disjunctive data collection if it is a part of the partial data collection of elements from the same primitive *sort*. In other words, data collections from different component *sorts*, under the disjunctive operator, never interact; the resulting data collection is the set of collections from all component *sorts*. When the operation of addition, subtraction or product is applied to two data collections of the same disjunctive *sort*, the operation instead applies to the respective component collections.

Behaviours play an important role when assessing data loss in data exchange between different *sorts*. When reorganizing the composition of components *sorts* under the attribute operator, the corresponding behaviour may be altered in such a way as to trigger data loss. Consider a *sort* of weighted points, i.e., a *sort* of points with attribute weights, and a *sort* of pointed weights, i.e., a *sort* of weights with attribute points. A collection of weighted points defines a set of non-coincident points, each having a single weight assigned (possibly the maximum value of various weights assigned to the same point). These weights may be different for different points. The behaviour of the collection is discrete. On the other hand, a collection of pointed weights, which is defined as a single weight (which is the maximum of all weights considered) with an attribute collection of points, has an ordinal behaviour. In both cases, points are associated with weights. However, in the first case, different points may be associated with different weights, whereas, in the second case, all points are associated with the same weight. In a conversion from the first to the second *sort*, data loss is inevitable.

A behavioural specification is also a prerequisite for a uniform handling of different and a priori unknown data structures. Consider the association of building performance data to design geometries. The behaviour of these data, as a result of an alteration to the geometry, can be expressed through a number of operations chosen to match the expected behaviour. When an application receives the data together with its behavioural specification, the application can correctly interpret, manipulate, and represent this information without unexpected data loss.

### 3. Computationally recognizing emergent information

Recognizing emergent information requires matching a specified information pattern onto a similar part of the original information. This match is determined under an allowable transformation. The kinds of transformations that are allowed depend on the kind of information that is being recognized. For example, for spatial recognition, this transformation is geometric, commonly, a Euclidean transformation: a square must be computationally recognized as a square irrespective of scale, orientation or location. Similar transformations can be considered for other kinds of information. For example, search-and-replace functionalities in text editors allow case transformations of the constituent letters. The part relationship underlying the behavioural specifications for *sorts* enables the matching problem to be implemented for each primitive *sort*. Composite *sorts* inherit their behaviour and part relationship from their component *sorts* — thus, any technical difficulties in implementing matching apply just once, for each primitive *sort*.

Recognizing emergent information is useful if the emergent information is subsequently the subject of an operation or manipulation. This is particularly true of design, where creativity relies on a restructuring of emergent information. Data recognition and subsequent manipulation can be considered part of a single computation  $s - f(a) + f(b)$ , where  $s$  is a data collection,  $a$  is a representation of the data pattern,  $f$  is a transformation under which  $a$  is a part of  $s$ , and  $f(b)$  is the data replacing  $f(a)$  in  $s$ . See, for example, Krishnamurti and Stouffs (1997) for a discussion on spatial change.  $s - f(a) + f(b)$  is an expression of computational change and can also be written as a design rule:  $a \rightarrow b$ . Rule application, then, consists of replacing the emergent data corresponding to  $a$ , under some allowable transformation, by  $b$ , under the same transformation.

Rules can be grouped (into grammars). A grammar is a formal device for the specification of a certain language, which is the set of all designs generated by the grammar. Each generation of a design in the language starts with an initial design, and employs the rules to achieve a design that contains only elements from a given terminal vocabulary. In spatial design, the specification of (spatial) rules and grammars leads naturally to the generation and exploration of possible

spatial designs. According to some (Mitchell 1993; Stiny 1993; 1994; and more recently, Woodbury and Burrow 2004), spatial elements or shapes emerging under a part relation is highly enticing to design search.

The concept of search is much more fundamental than any generational form alone might imply. Any mutation of a data collection into another, or parts of others, constitutes an action of search. As such, a rule may be considered to specify a particular composition of operations and/or transformations that is recognized as a new, single, operation and applied as such. Rules can serve to facilitate common operations, e.g., for changing one data collection into another or for creating new design information based on existing information in combination with a rule. Similarly, a grammar is more than a framework for generation; it is a tool that permits a structuring of a collection of rules or operations that have proven their applicability to the creation of a certain set (or language) of designs or the derivation of certain information. Stouffs and Krishnamurti (2001b) present a few examples of design grammar formalisms that can be expressed using *sorts*.

#### 4. Future work

The research described here is part of the Informatics research programme at the Faculty of Architecture, Delft University of Technology. This research programme focuses on the use of various aspects of Information, Communication and Knowledge Technology (ICKT) to support collaboration and communication in the building sector.

The research described here is also partly the result of a collaboration with researchers at Carnegie Mellon University. Park and Krishnamurti (2004) investigate the application of *sorts* to a case study from the construction domain considering the comparison of as-designed and as-built building models. In this case study, the as-designed model is a 3D design model obtained from a commercial parametric design software in the form of an IFC file, and the as-built model is a 3D geometric model derived from laser scanning results. The particular focus in this project is on the integration of different models into an integrated project model, that allows for both models to be compared in order to look for discrepancies outside of allowable tolerances described in the construction specifications, and that is designed to capture both changes in the drawings (as-designed) and changes on a given construction site (as-built).

Future work at Delft concerns the specification of a query language through the embedding of numeric functions into the representational structure that supports the derivation of new information. It is our intention to apply this query language to Industrial, Flexible and Demountable (IFD) building models for the extraction of such information as quantities and distances for various purposes.

#### 5. Acknowledgments

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# Development of Design and Engineering Engines to Support Multidisciplinary Design and Analysis of Aircraft

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## 1. Introduction

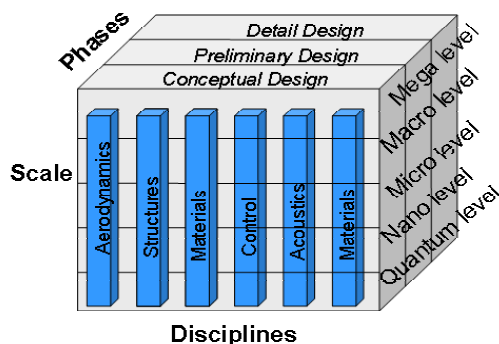
In 2002, NASA and the Advisory Council for Aeronautics Research in Europe produced two relevant documents, the Aeronautic Blueprint and the Strategic Research Agenda, where the first century of aviation is briefly analysed and the technological challenges for the next 20 years are set. In a couple of decades the aeronautic systems will differ from today's systems at least as much as the actual systems differ from those of 1930. The aeronautic community will have to face such a challenge in a problematic socio-economic scenario, where the availability of economical and intellectual resources is shrinking upfront the increasing complexity of demanded products. A fundamental paradigm shift is required to pass to a new knowledge based vision of business, where knowledge needs to be engineered and managed as a key business asset. Knowledge Management (KM) and Knowledge Based Engineering (KBE) represent two organizational and technical disciplines that can support this knowledge paradigm shift and help companies to retain their competitive advantage in the engineering market. KM can provide the vision and the strategy to make the best use of the people involved in products development, and freeing more time for creativity and innovation at expense of repetitive and non-adding value activities. Knowledge Based Engineering can provide a technological solution to implement this vision in the field of design and engineering. A critical analysis of designers needs during the evolutionary phases of the aircraft design process reveals the need of more advance tools able to support the conceptual stage of design, as well as enable a smooth transition to the following design phases, without creating discontinuities in the knowledge generation flow.

In this paper the KBE design approach is introduced and its impact on the design process is discussed in perspective with the traditional design methodology. This high potential design technology has been exploited to develop a complex knowledge based modeling environment, the Multi Model Generator (MMG), able to support designer in the conceptual and preliminary phase of aircraft design. The development of a set of high level primitives (HLPs), which constitute the fundamental components of the MMG, is discussed with particular emphasis on their capability to capture the view of designers on the aircraft product and automate part of the design and analysis process. The paradigm of a new modular design and engineering environment, referred as the Design and Engineering Engine (DEE), is introduced as a viable solution to attack complex multidisciplinary problems, exploiting engineering skills and analysis tools from many different design experts, eventually dispersed outside the boundary of the single company walls. In particular, the role of the MMG within the DEE and its key role to provide customized models for the different disciplines tools connected in the federated design and analysis environment are discussed. A prototype of the software framework now under development, to link the various DEE components and control the design process activities, is described as introduction into a new research direction.

## 2. The impact of knowledge based engineering on the design process

In the design process of a product, such as an aircraft, a car, or a generic mechanical component for example, a diverging and a converging phase can be generally distinguished (La Rocca, Krakkers, van Tooren 2002; van Tooren 2003). During the first conceptual phase, many potential solutions are synthesized to comply with the list of requirements provided by the market/customer. The broader is the amount of proposed solutions, the higher the chance to have enclosed the most appropriate or the closest to the best. These solutions can be either variants of one product concept, or completely different product configurations, which, in any case, must be analysed and eventually optimized in order to perform a fair trade-off. This will initiate the converging phase of the design process, where the best solutions are selected for the next design level. This diverging-converging process is actually strongly iterative and requires a continuous adaptation and modification of each proposed configuration during the design loops. Large amount of data and information are continuously generated and exchanged across the various involved disciplines operative with a large suite of design and analysis tools. Many different models need to be (re)generated and adapted for the different process stakeholders. Generated outputs from one design and analysis tool often need to be re-processed in order to be transformed in usable inputs to others.

As illustrated by the design cube, in Figure 1, a thoroughly exploration of the 3D design space requires the capability to move along the three directions. There are not only the typical time-defined conceptual, preliminary and detailed design phases, but the product has to be continuously examined from the point of view of the various discipline stakeholders. The capability to change the focus on the product needs also to be supported, which implies the capability to get simplified models of the global aircraft as well as detailed models of isolated sub-systems or components. An exhaustive exploration of this multidimensional space calls for an organised and integrated involvement of many different experts, together with many analysis tools, which need to be agilely plugged-in and out during the evolutionary design process.



**Figure 1: The design cube. Multi-phase, Multi-disciplinary, multi-scale.**

The traditional design approach shows some inherent limitation in handling such complexity with efficiency and effectiveness. The various models required by the discipline involved in the design and analysis process are generally very different by nature, because they have to reflect the very different views that different discipline expert have on the same product. Since the design/drafting and analysis stages are generally carried by different persons using different software tools, the whole design scenario results populated by a lot of non-synchronized non-relational models, leading to a high risk of analysis inconsistencies. Due to the large extent of

manual processing and data acquisition, the set-up of all these models results very time expensive: a critical bottleneck for the whole design process. Whenever major changes are required in the product configuration, because dictated by the need to improve the product behavior or add extra functionalities, all the models available at the moment become immediately obsolete, as well as many of the analysis results. New models that reflect the design change must be generated and analysis performed again. The experts get frustrated by all the time consuming and repetitive activities, without considering the fact that, for each manual iteration there are possibilities to generate new errors. As a result, the inertia of the design process is such that less design iterations can be performed than those actually necessary, less *what-ifs* can be investigated, and many possible product configurations and variants must be discarded a priori. Mature in-house knowledge very often prevails over unproven and risky innovation, which, in many cases, leads to the elimination of promising ideas before any fair assessment. Quality and innovation are the first victims; a real multidisciplinary design is almost impractical.

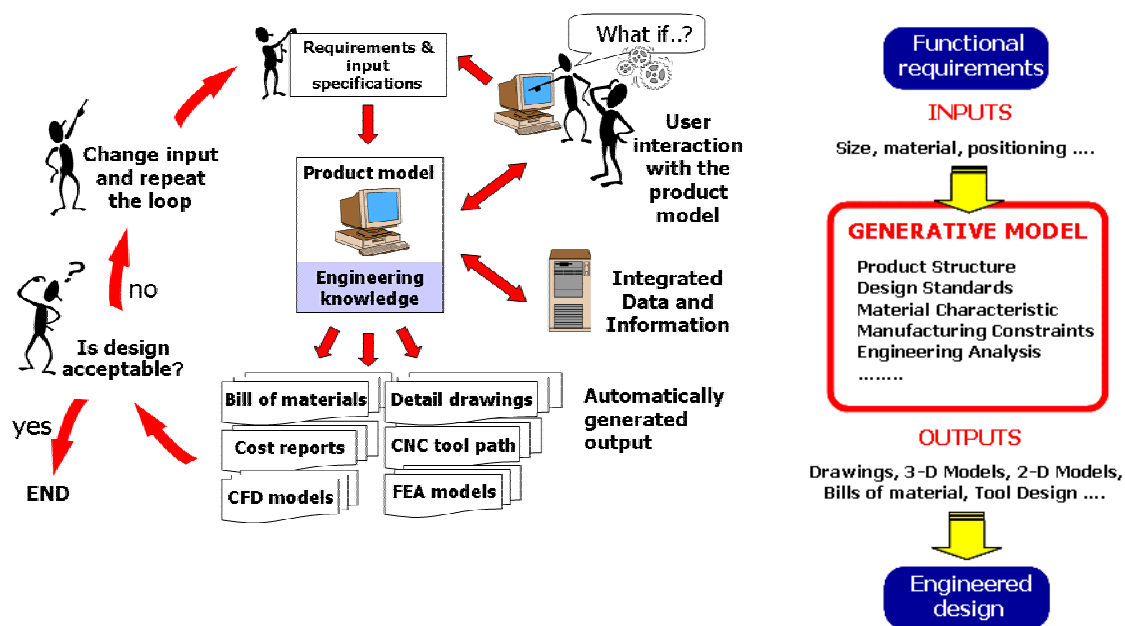


Figure 2 (left): The Knowledge-Based engineering design process. Figure 3 (right): The product (or generative) model.

The schema of Figure 2 represents a possible design paradigm through the implementation of KBE. The main difference, respect to the traditional design schema discussed above, consists in the new pivotal role assigned to the *product model*, which represents the central repository of the design knowledge within the process. This implies that the relevant knowledge of the design team and of the experts involved in the various disciplinary analysis activities has first to be captured and then opportunely translated into that set of engineering rules that actually makes up the product model. The product model is actually a computerized application that KBE developers code using a high level programming language, which has been enriched with sets of commands and methods to drive an integrated parametric CAD kernel. This integrated environment where Artificial Intelligence meets CAD represents the most relevant feature of KBE systems. The functionality of the product model can be described by the simplified representation of Figure 3 a set of input values is provided to the parameters used in the rules-base, the KBE system applies the rules which process the input values and the engineered design is automatically generated as

output (Cooper, Fan and Li 2001). With little or no human interaction, the product-model is able to generate geometry, or some other models, eventually not including any geometrical entity. The designer actively interacts with the design process through the editing of the product model input values. The bottleneck at the interface between the design/drafting and the analysis phase can be resolved by capturing in the product model the rules to generate automatically the various discipline specific models. *Separate but fully relational* models can be generated to guarantee the consistency of analysis results. The benefits of this integrated and largely automated approach are huge: since the expert is not asked anymore to manually assemble new analysis models when changes occur in the product configuration, the design process results accelerated and many more iterations can be performed in the same time normally required by a single manual iteration. The designer should feel the confidence that everything can be easily changed; the impact of every design choice on the final properties of the output product can be faster evaluated and eventually withdrawn.

### 3. The Aircraft Design Process and Designers' Needs

Among the available tools nowadays employed to support designers during conceptual design of aircraft, CAD systems are far the most common and widely used. Current generation CAD systems are mainly feature-based, which means that they have a standard set of parameterized primitives (points, lines, solid volumes, holes, chamfers etc.) that can be adjusted and combined together to represent a design. As a matter of fact, CAD primitives have very poor knowledge recording and learning capabilities, thus they provide conceptual designer a rather inadequate mean to support the knowledge work and the level of design abstraction typical for this early phase of the design process. For a CAD program an aircraft wing will always be a set of surfaces and solids, never, for instance, a lift generating object compiled of different wing sections with leading and trailing edge devices and an internal generic structural concept. However, if we consider the way a conceptual designer thinks and the way he looks at design problem, we find that actually it is this global modeling approach that is required. What the designer needs is an efficient way to virtually manipulate ideas and create many different design solutions. Then an efficient way is needed in order to assess and compare these possible solutions in a fair trade-off. Hence designers should not be hampered by the manipulation of infinite sets of lines and points, but provided with a limited set of *high level primitives*, easy to adjust and link together, with inherent functionalities and knowledge capability (that is the capability to autonomously act and react to the occurrence of certain events). These primitives should be able to fulfill functionalities such as generate lift, provide control and thrust, carry loads, store payload et cetera (van Tooren et al. 2003). Furthermore they should be able also to automate (part of) the activities required for the aircraft assessment, such as the generation of models for structural and aerodynamic analysis, or cost estimation, or tooling for manufacturability study and so forth.

A solution is needed to gain more knowledge about the product already in the early stage of the design process, which implies the need to fill the gaps and discontinuities between the various design phases (namely conceptual, preliminary and detail phases). If a design tool is developed to target just one specific phase of the design process, discontinuities in the flow of data, information generated during design might occur. For example geometry models generated by purely conceptual design tools are typically suitable just and only for visualization purposes. When advanced analysis tools such as CFD or FEM are required for a proper assessment of the concept, new models with the appropriate level of refinement have to be generated from scratch, in separated design environments. It should be considered that nowadays in order to handle the

complexity of the design process, aircraft configurations are generated largely based on semi empirical models and statistic methods rather than first-principle. About the 80% of the total life cycle costs of the final product turns out to be determined by the use of low fidelity models (Staubach 2003). The reliability of the obtained results is often arguable and, as soon as new and non-conventional aircraft concepts need to be evaluated such methods result inadequate, because of the lack of any previous reference and statistical data.

On the other side, there are continuous attempts by industry and academia to develop comprehensive integrated design tools able to handle all the modeling, analysis and optimisation phases, at a relatively high level of detail. This ambitious approach has often led to an irresolvable level of integration between design and analysis components, with significant drawbacks concerning the possibility to further develop and maintain such complex system. Furthermore the exploitation of such complex tools within broader collaborative design environments results always very problematic. Experience has shown the difficulty to substitute one of the analysis functionality integrated in such design system with a different analysis tool provided by another party; or to use only some of the tool functionalities, spilling data streams directly from the internal flow or by-pass some modules.

#### 4. Use of KBE Technology to Define New High Level Primitives

Given a set of top level requirements, a good designer would like to investigate more aircraft concepts and see which one has the best potential to fulfill them, for example a traditional airliner and a blended wing body aircraft configuration might be good candidates. These apparently very different design solutions are actually linked by several elements of similarity: they all feature some components, with the common purpose to fulfill certain functions (generate lift, supply thrust, provide control and stability, accommodate payload et cetera). Even if these components have different shapes and are recombined in different topological configurations, an object oriented analysis of the aircraft model shows that is possible to abstract a certain amount of *classes*, which can be instantiated in wing, fuselage, engines and connection *objects* (see Figure 4). These classes of objects, able to capture the similarity element linking the different aircraft components, are actually what we addressed in the previous section as the *High Level Primitives* (HLPs): generic entities with a similar functionality, shape and behavior.

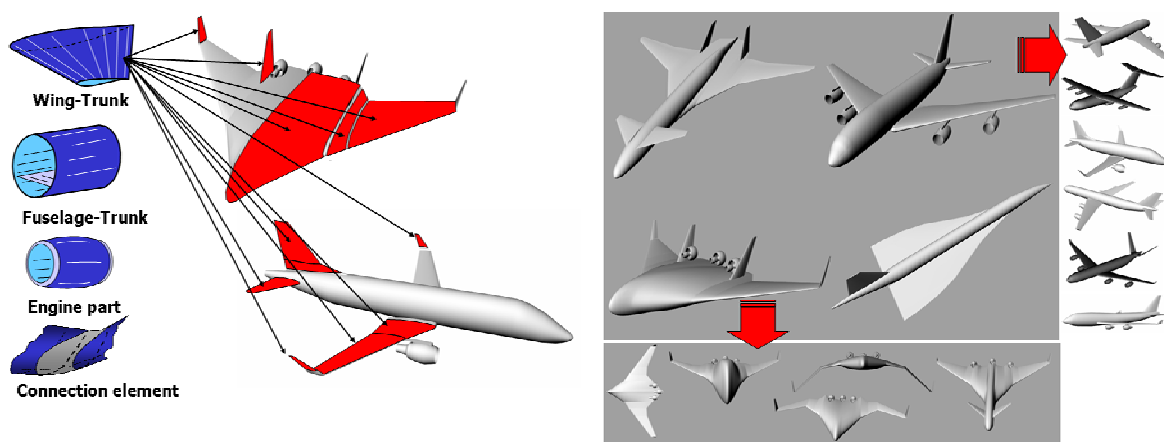


Figure 4 (left): High Level Primitives modeling approach. Figure 5 (right): Aircraft configurations with HLP's.

The HLPs can be interpreted as special bricks, kind of rubber LEGO blocks, which can be individually morphed thanks to their *full parametric definition*, and combined together in order to generate a potentially infinite amount of different aircraft configurations. KBE, which fully supports object-oriented modeling, has been used to develop a computerized modeling environment where the conceptual designer can define and combine these primitives to agilely build a virtual representation of the aircraft concept he has in mind. In Figure 5 it is shown that, just using four of these HLPs, namely the *wing-trunk*, *fuselage-trunk*, *engine parts* and *connection element* primitives (La Rocca and van Tooren 2002a, Koopmans 2005), it is possible to generate a broad range of aircraft configurations and almost infinite variants of each configurations.

The flexibility of the HLP, here intended as the capability to represent objects within a large range of *typicality*, is directly related to the choice (and number of course) of parameters used to define the corresponding class. In order to design a wing, for example, the designer can use multiple instantiations of the wing-trunk and connection HLPs, and define the shape and topology of the wing, just adjusting the values of parameters such as span, chord length, sweep and twist angles, number, location and type of airfoils and many others.

The definition of the HLPs is not just limited to the parametric description of aerodynamic surfaces, but includes also some advanced generative capabilities to model internal structure configurations. Through a specific set of parameters, the designer has the possibility to modify the position of the internal structural elements (ribs, spars etc.) as well as to change the topology of the structure configuration (i.e. change the number of spars, ribs etc.). Since the definition of the internal structure is associated to the shape of the outer surface, it will automatically adapt when the latter is modified for example by a different wing design (La Rocca and van Tooren 2002b).

This capability to strongly affect the topology of a model configuration sets a big difference between classic parametric CAD and KBE HLPs based models. Indeed the HLPs definition via a high level programming language offers the possibility “to teach” the HLPs how *autonomously handle constraints* during any topological variation. Furthermore the ruled-based approach used to define the primitives offers also the possibility to handle some known native CAD kernel limitations and bugs. Typically, when an experienced CAD operator realizes that a given geometric operation often fails he knows how to implement a different approach to work around the problem. This very approach can be directly programmed in the body of the HLPs, such that workaround procedures can be automatically triggered, either proactively or after a failed operation has been diagnosed.

There is another fundamental element of similarity that links the design of very different aircraft configurations, such as the two of Figure 4, the KBE technique can capture and harness through the HLPs definition. Indeed, the *assessment process* of very different aircraft configurations calls for very similar analysis methods and relative procedures. KBE can be used to capture and manage also *process knowledge*, not only the what, but the how as well. For example specific models will have to be generated for CFD analysis in order to evaluate the aerodynamic characteristics, or for FEM analysis to validate the soundness of the structural design, or for weight and balance module to assess the stability margin and so on (more details are provided in next section). A very large deal of these preprocessing procedures consists of repetitive activities that can be captured and formalized into explicit rules, such that the various HLPs can reapply them systematically and autonomously. In this way the designer can be relieved from the burden of time consuming routine activities and the conditions for extensive engineering automation are created. This represents a valuable use of Artificial Intelligence in aircraft design, because

addressed at capturing and automating the *non creative* part of designers' work, where designers actually need the most support, rather than in the creative process of thinking about a feasible aircraft concept.

## 5. A flexible multi model generator to support aircraft multidisciplinary analysis

As anticipated in the previous sections, in order to perform a multidisciplinary design of aircraft, a number of sub models have to be generated for the disciplines involved in the analysis and optimization processes. These sub-models represent the specific viewpoints the various design process stakeholders have on the aircraft. For example the aerodynamicist's view on the aircraft mainly consists of the outer aerodynamic surfaces, without any direct interest in the internal structure configuration, neither in the location of the various aircraft systems. By the way, the *consistency* of these sub-models is as much important as their *tailoring*. For example, if the wing planform design is changed, updated structural models suitable for stress analysis and wet-surface models for aero analysis needs to be promptly generated. If the aerodynamicist changes the thickness of the wing, such modification must be reflected also in the model of the structure used by the stress engineers, or in the mould line model used for tooling design. These two requirements call for the development of advanced and smart modeling tools, which are able to discern and distill the various disciplinary aspects of a product, and deliver them as sets of *separate but fully relational* sub-models.

In the development of an effective multidisciplinary design and analysis strategy, there are other important issues, apparently of non technical nature, which in the end turn out to have a significant impact on technological implementations. It has been proven, how crucial is the capability to give discipline experts the possibility to participate in the design process with their *own* analysis instruments (Morris 2002; Morris et al. 2004). The experts should not only be welcomed with their tools, but also put in condition to exploit them at best. This imposes demands both on the *format* to be used for data exchange between analysis and modeling tools, and on the *level of maturity* of the data exchanged, that relates to the level of pre-processing required on the exchanged data and information, to make them directly "edible" to the recipient analysis tools.

On the base of the issues discussed so far, a highly flexible and modular aircraft modeling tool, based on the High Level Primitives concept, has been developed with the ICAD KBE system and qualified as the Multi Model Generator (MMG). In synthesis the MMG defines an aircraft *super class* that, on the base of a large set of input parameters, can be instantiated into a specific aircraft design, which is again the result of the automatic multiple instantiations of other component-classes, namely the HLPs. Methods and rules are programmed in the body of the generic aircraft product model, such that for different input values, different amount and type of HLPs are selected, instantiated and assembled together to shape the desired aircraft configuration. As discussed above, the various HLPs contain the knowledge about how to generate their shape and perform some other tasks. When multiple HLPs are instantiated together to generate a complete aircraft model, the latter inherits as a whole the characteristics and the capability of the single HLPs/components. For example, if a given wing-trunk primitive is able to generate from its outer surface a specific model for a given aerodynamic analysis tool, then the whole wing (built up as an assembly of several wing-trunk primitives) will be able to generate from its complete surface a model for the abovementioned analysis.



## 6. Structure and functionality of the multi model generator

Structure and functionality of the MMG can be discussed referring at the oversimplified representation of Figure 6. Two main functional blocks can be pointed out, namely:

1. The product model, which is the main body of the MMG and contains the definition of the various HLPs and the rules to bring them together to build-up different aircraft configurations.
2. The reports writer, which is the set of utilities in charge to extract from the whole aircraft product model the data and information needed to build the specific sub-models (called *reports* in the technical implementation of the MMG), for the various analysis tools.

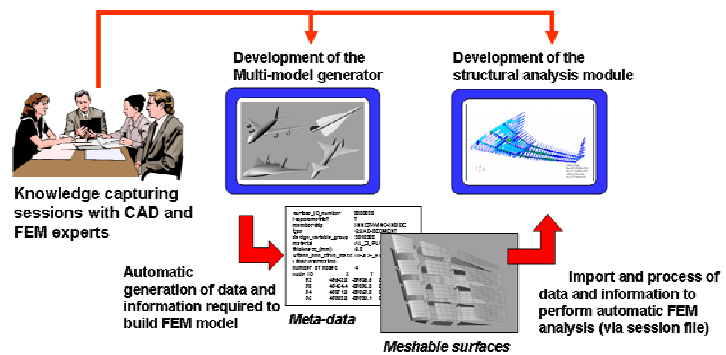
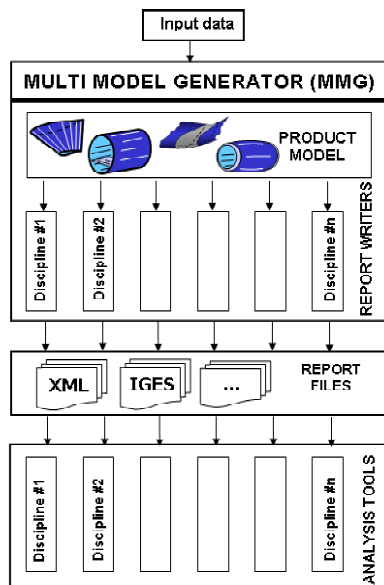


Figure 6 (left): MMG structure and analysis tools. Figure 7 (right): Knowledge capturing.

Prior to launch the MMG, the user has to fill the input file containing the list of all the parameters used to define the aircraft super class instantiation. The MMG is connected to an amount of external libraries and data repositories (containing airfoil data, fuselage cross section definition et cetera), whose contents are automatically retrieved when required for a specific instantiation. The user, still via the input file, can indicate which specific reports he is interested to get generated by MMG. The KBE platform used to define the MMG support an interesting feature, called *Demand-driven instantiation*, which has a large impact on the efficiency and computational time required for model computation: when the generation of specific reports is requested to the MMG, not the entire aircraft product model is computed, but just the branches which are strictly required to match the specific user request.. For example, when a user asks for the generation of the aircraft wet-surfaces report, the MMG will not perform any operation concerning the generation of internal structure, or the distribution of the various aircraft systems and so on.

As shown in Figure 6, the reports-writer block represents the actual link between the modeling environment and the analysis disciplines. It is here that the processing capabilities coded inside the HLPs are invoked and data and information are generated and collected in such a way to create input models for specific analysis tools. In particular the links between the MMG

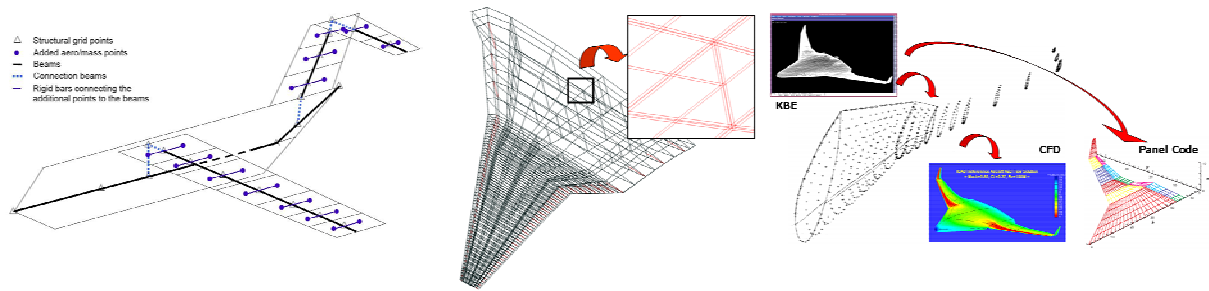
and the structure and aerodynamic disciplines are discussed, as examples of a methodology to integrate the KBE modeling engine with external analysis services, without any attempt to duplicate or incorporate any of those analysis capabilities directly inside the MMG. The way the MMG has been developed guarantees several advantages:

- The MMG can be operated interactively, editing the input file via keyboard and evaluating the changes in aircraft model directly in the MMG graphical browser.
- The MMG can be operated remotely. A complete input file can be edited by a remote user (N.B. this operation can be also automatically performed by an optimization tool, when the MMG is operative within an interconnected analysis and optimization environment) and then submitted to the MMG for a *batch run*. The output reports can be retrieved via web, after the MMG has signaled his ready status.
- As a consequence of the above, many *non-geographically collocated* users can use the MMG submitting their customized version of the input file and their list of required reports.
- For a given version of the product model (stored with an appropriate file revision system), each input file defines univocally one aircraft configuration/variant. It might be very efficient to store just one copy of the given input file version (and re-submit it to the MMG whenever required) rather than store a multitude of large output models/reports, generated with that given input file.
- The MMG code, even if featuring several hundred of thousands of code lines, has been developed with a modular approach. Each HLP for example is a module, which again features a surface-generator-module and a structure-generator-model. Again these modules are composed by various “capability modules” (such as split-in meshable-surfaces and create-cloud-of-points described in the next subsections) of which some are shared by different HLPs. In this way maintenance and further development of the application is facilitated. When a single module is improved it can be simply plugged-in to replace the old version, provided that the *interface* remains the same. Relying on a correct use of the interfaces system, new modules can be generated, to create new report writers for example, and bolted onto others to add extra functionalities to the MMG.

### Link with Structural Analysis

Efforts have been made to create a seamless link between the geometry modelling and the FEM analysis environment, via a complete automation of the pre-processing and analysis phases, hence passing from the MMG native geometry definition directly to the post-processing phase of the FEM analysis results. The way this process is typically performed requires combined efforts and good communication between draftsmen and FEM experts. A lot of manual, lengthy and repetitive operations are required to assemble a FE model, starting from a CAD geometry model. One of the most time consuming, accordingly with the complexity of the geometry model, concerns splitting the model surfaces in *meshable* surface elements, that is surfaces with adequate aspect ratio and skeweness, no more than four edges, each edge matching with just one edge of the neighbor surfaces (La Rocca and van Tooren 2002b). Several interviews and other contrive knowledge capturing techniques (Stokes 2001; Shreiber et al. 2000) have been used to capture into sets of explicit rules and logical mechanisms the *modus operandi* of FEM experts in different situations with diverse levels of geometry complexity. These rules and mechanism have been implemented in the HLPs (in the capability module mentioned above) in such a way, every time a new input model for FEM analysis is required, the surfaces cutting routine can automatically take action and create as report a consistent set of meshable surfaces, no matter

how the current aircraft configuration might have been changed in shape and topology. The IGES format is used to transfer this purely geometry information, whereas a complementary data and information stream has been activated to bring outside the MMG the other *meta-data* required to automate the generation of FEM models (see Figure 7). A set of XML files (addressed here as *FEM-tables*) is automatically generated by the MMG, in parallel with the IGES files, to transfer to the FEM environment all the relevant (non-geometric) information generated by the MMG. A smart PATRAN session file has been programmed in the PATRAN Command Language to complete the automated generation process of the FEM model and finally run a structural analysis and/or optimization, using one of the supported solvers.



**Figure 8 (left): Two structural models. Figure 9 (right): Generation of consistent models.**

Other report writers have been generated to link the MMG to other kind of structural analysis tools requiring for example a *lumped masses and beams* representation of the aircraft (see Figure 8 on the left from Koopmans (2005)) or a solid elements discretization of the entire structure to exploit advanced FE formulation based on solid p-elements. See Figure 9 on the right from Lisandrin and van Tooren (2004). This diversity of model demonstrates how different the same product can appear to the eye of different experts, operating with different tools, in different location in the design space.

### Link with Aerodynamic Analysis

Similarly to the structural analysis case, the goal here was to create a seamless integration between the MMG modeling environment and external aerodynamic analysis tools, either commercial off the shelf (COTS) and proprietary codes. The easiest form of link is based on the direct exchange of the MMG native geometry via IGES or STEP files. Eventually it is possible to preprocess the surfaces in order to match some specific requirements from the aerodynamic customer, such as split the surfaces in more patches and so on. This approach actually is feasible whenever the analysis tool to be linked with the MMG is able to accept standard file format such STEP or IGES. For other cases a special capability module has been generated in the HLPs to “translate” the aircraft surfaces into a *cloud of points* (see La Rocca and van Tooren 2002c), whose Cartesian coordinates are automatically evaluated by the MMG with respect to a reference datum and then written into an ASCII file, formatted to be readable by the given aerodynamic tool. This strategy has offered the possibility to deliver high quality surface model to powerful in house developed aerodynamic tools which were not provided with own adequate modeling capability. The MMG user has the possibility to adjust the amount and distribution of these points via a specific set of control parameter in the input file, to affect also locally the density of the cloud of points. Thanks to this flexible approach the points stored in the cloud can be used directly as mesh seeds for a grid (Qin et al. 2002), or as corner points for a panel discretization, or just as constraints to re-

spline a surface (Laban et al. 2002). Some functionalities have been included in the MMG to generate other kind of simplified aircraft model, and then write directly compile sets of NASTRAN cards for the vortex lattices model solution (Koopmans 2005). A high level of automation for the modeling-analyzing process has been reached also for high fidelity CFD analysis, where the MMG has been used to create an accurate 3D-aircraft model, inclusive of the surrounding computation control volumes and grid information. In the specific case FLUENT was the selected CFD package, and its preprocessor GAMBIT, driven by a case-specific journal-file automatically generated by the MMG, could perform all the needed preprocessing activities and launch the computation run (Sterkman 2002).

As indicated by the list of references mentioned here, the development of the High Level primitives and their capability modules is a continuous process at the DAR group of the Technical University of Delft. The object oriented definition of the HLPs allow an extensive reuse of coding and software modules in such a way to re-apply and the knowledge gained in one project to the specific need of new study cases.

## 7. Development of design and engineering engines

In this section the paradigm of a design and analysis environment, addressed as Design and Engineering Engine (DEE), is discussed to show the ideal framework where the capability of the MMG can be exploited at best. The basic structure of a DEE is shown in Figure 10: it consists of a set of properly interconnected toolboxes, which are either COTS or proprietary software modules, such that, as far as possible, automated multi-disciplinary design, analysis and optimisation becomes feasible. The MMG constitutes the core unit of the DEE. The *bi-directional interfaces* system, which links the MMG with the various toolboxes, as well as the *Initiator* and the *Converger* modules form the other key components in the structure of the DEE. The Initiator box is in charge to generate the initial values for the parameters contained in the MMG input file. It should be noted that Initiator might consists of a computational module, eventually including some optimization capability, as well as another KBE module which are separated from the MMG. The Evaluator/Converger boxes provide the functionality to judge if the set of input generated for the MMG yields to an aircraft whose performances match the initial requirements, and if the convergence of a FEM analysis is reached on the base of forced changes in the mesh configuration.

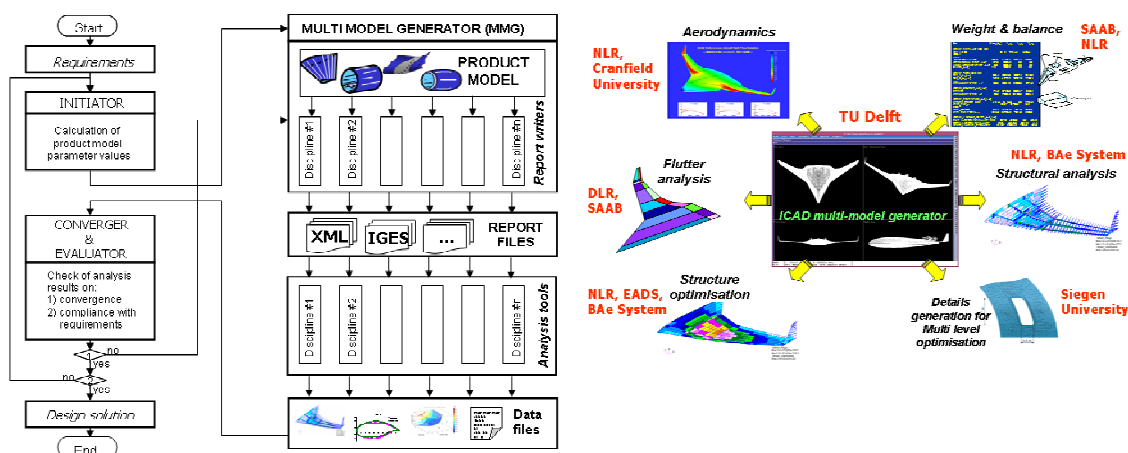


Figure 10 (left): Design and Engineering paradigm. Figure 11 (right): Role of the MMG in the MOB project design engine.

In order to participate to DEE the various toolboxes should all be able to operate as stand-alone modules, and be accessible via a clear input/output interface. In this way they can be easily plugged in and out of the DEE, keeping high the level of flexibility and maintainability of the whole design and analysis system. According to an object-oriented (O-O) perspective on the DEE, the various toolboxes can be interpreted as sets of different *methods* that can be applied to perform conceptual and preliminary aircraft design. A successful prototype version of a DEE was represented by the outcome of the EC sponsored project MOB (Multidisciplinary Design and Optimization of Blended-Wing-Body Aircraft Configurations). In that project it has been shown how KBE can impact the design process and turn MDO from a great potential to a real working business. In Figure 11 the position of the MMG within the MOB DEE is represented. The MMG, starting from a unique definition of a BWB aircraft configuration, was in charge to extract a set of different, yet coherent sub-models tailored to the various analysis tools provided by a broad group of partners from the industry and academic world: low and high fidelity models for aerodynamic analysis, 2-D planform models inclusive of movables surfaces for aeroelastic analysis, structure models for FEM analysis and optimization, fuel tanks and systems masses distribution for weigh and balance assessment. The MMG provided also the capability to focus on a specific detail of the aircraft, a door cutout in this case, and provide the base to apply a multi-level analysis and optimization strategy.

In van Tooren (2004) other examples of DEEs developed at the DAR group of the Technical University of Delft are discussed. The experienced gained so far has shown how this approach can be effectively used for many different study cases, ranging from the investigation of the ground effect of sport cars (Adriansen 2004), to the design of fuselage panels including piezo-elements for active sound damping (Krakers et al. 2003); from loads calculations for large commercial airliner (Cerulli, Mejer and van Tooren 2004), to manufacturing studies and costs estimation of aircraft components (van der Laan 2004).

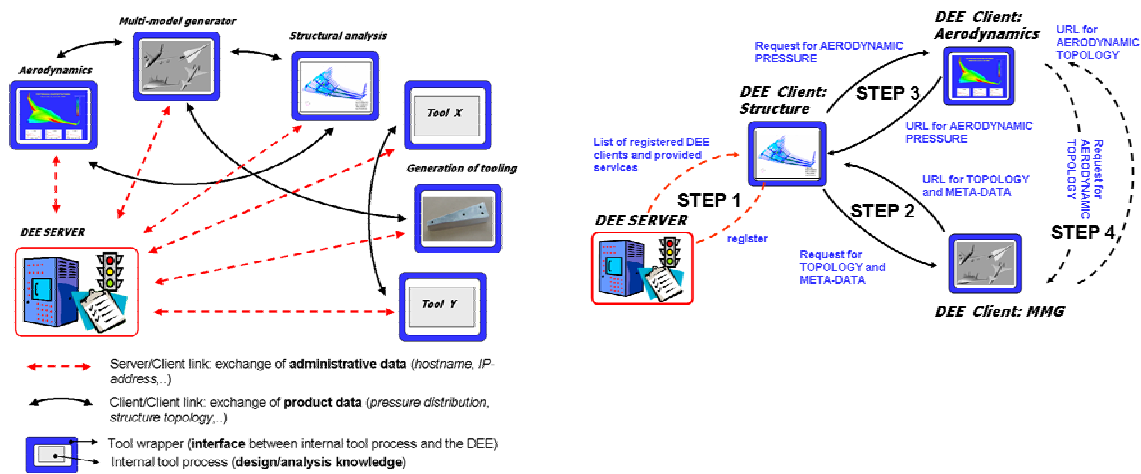
The experience gained at DAR has shown that, every time the design process of a product involves an amount of different stakeholders, in terms of different experts and different design and analysis tools which must interconnect and exchange data and information, the set up of a customized DEE gives not only the possibility to speed up the process cutting the time wasted by repetitive activity, but provides the possibility as well to introduce and test new technologies, e.g. advanced analytical FE formulation, implementation of smart materials etc.

## 8. Towards an implementation of a DEE software framework

We have discussed in this paper how the use of KBE techniques can be used to automate large parts of designers work, capturing best practice and routine activities in computerized application. Tools such as the MMG (and the PATRAN and GAMBIT session files briefly introduced above) represent anyway *islands of automation*, which need to be connected within a smart framework able to create physical links between the various DEE modules, manage the exchange of data and information and control the execution of the various design and analysis tools. The DEE framework, in principle, must be able to let a multi-disciplinary design team operate with a heterogeneous set of design and computational tools running on different computers, mounting different operating systems and belonging to separate networks, eventually geographically not collocated.

An *agent-based client/server* architecture is now under development at DAR to provide a *software framework* for the DEE (see Figure 12). The core of the framework has been implemented in the high-level scripting language Python, because of its platform independency; its capability to

supports object-oriented programming and the large set of available library modules. As illustrated in Figure 12, the main components of the system are the *DEE server* and the various disciplines involved in the design process (represented in this case by their specific tools), which represent the *DEE clients*.



**Figure 12 (left): Client/server architecture of DEE software. Figure 13 (right): Automation of wing structural analysis case.**

Every DEE client is embedded in a *wrapper*, which provides the access *interface* each tool needs to *wear*, in order to be allowed joining the DEE environment. The role of this interface is fundamental in view of the flexibility level we want to reach in the DEE assembly process. In order to create a real plug-and-play design and analysis environment, it is essential that each tool can be easily substituted by a new one (or an upgraded version of the same tool), and that is achievable only if the tool interface is kept consistent. This wrapper actually consists in an XML configuration file which contains information about how to trigger the tool, about the list of required inputs to operate the tool and the list of data (or models) to be expected as output.

Server and clients exchange *administrative data*: any DEE client that participates in the DEE must register to the DEE server, which in return provides the client with the list of all the other registered clients in the DEE and the kind of services they provide. Typical administrative data are hostname, IP-address, port-number for communication and others. The DEE server is responsible for checking that all clients in the list of registered clients are running and accepting connections. Once a client is registered, it is allowed to send a request (to produce some kind of data or model) to any of the other clients in the list of the registered clients. If the request can be satisfied by the requested client, a peer-to-peer connection between the two clients will be instantiated; the required data or model (the *product data*) will be generated and their storage location will be communicate to the requesting client in the form of a Uniform Resource Locator (URL). This URL is then used to retrieve the requested product data.

An advantage offered by this approach is that every client in the DEE is actually able to initiate the design process, because it is informed by the DEE server about which of the available clients in the DEE is able to provide the required inputs and how to connect it. The design process turns out highly dynamic and able to *self-configure*, without the need for a static, predefined process flow, as typical with most of the commercially available process integration software. The example described below will better illustrate the concept.

### Example of a design scenario: structural analysis of a wing

In the diagram of Figure 13, the various steps of an automated process for the FE structural analysis of a wing are represented, to show how such a process can be automated through the implementation of the DEE framework described above. In Step 1, the structure analysis tools registers to the DEE server. The DEE server returns a list of all available DEE clients (in this case the MMG and aerodynamic tool), their address and the services they provide. Once the registration has finished, clients are allowed to have peer-to-peer connections. In Step 2 the structures client connects to the MMG and sends messages to request the wing structural topology and the meta-data to generate the FEM model. In Step 3, the structure client also sends a request to the aerodynamics client for the aerodynamic pressure distribution on the wing, such to generate a load case for the structural analysis.

At this point the aerodynamic tool needs a model of the wing surface to compute the pressure distribution, hence in Step 4 an implicit request for aerodynamic topology is sent to the MMG. When the MMG and the aerodynamic tool have satisfied the requests of the structure client, the latter is informed where it can retrieve topology, meta-data and pressure distribution, as originally requested and finally the wing structural analysis can take place.

## 9. Conclusions

In order to meet the technical challenges set for the next future of air transport, the aeronautic community should put more focus on the development of new design strategies and advanced tools aiming at a more efficient exploitation of designer knowledge. Better aircraft design depends on the availability of more product knowledge since earlier phases of the design process, which is a critical condition that available tools and the current design approach struggle to succeed. Designers need more flexible and powerful tools to virtually access ideas, create solid conditions to implement multidisciplinary design, free time for creativity via automation of all the repetitive activities that enormously hamper the design process. KBE can provide the tools to capture and reuse product and process multidisciplinary knowledge in an integrated way, in order to reduce time and cost for engineering applications via the automation of repetitive design tasks and a systematic application of design best practices.

The interdisciplinary DAR group of the Aerospace Faculty of the Technical University of Delft has started since few years to commit to a new program of research and development activities aiming at the development of new integrated but flexible design tools able to capture and automate the design and analysis process of complex products from the aeronautic and automotive world.

The development of a new set of so called *high level primitives* represents part of the output of the last years of research in the object oriented analysis and modeling of complex products. These high level primitives provide a way to support designers shaping and assessing concepts they have in mind in a faster and more reliable way. KBE applications have been created and grown in a modular approach, which implement and exploit the concept of theses primitives.

The experience gained by DAR during the involvement in complex multidisciplinary design and analysis programs has led to the formalization and development of the Design and Engineering Engine. DEEs represent a possible answer to the need of industrial community of open and modular design and analysis systems able to take advantage of experts and design/analysis tools, which are not always to be found within the factory walls, but are often distributed on a world wide scale. The flexible and not monolithic nature of the DEE structure is

the key to guarantee a prompt integration of new and different analysis capabilities and methodologies, in order to adapt to the different nature of design cases, and give the possibility to maintain the system and upgrade it during time.

In this paper several references have been provided to a number of works of PhD and MSc students of DAR, to give readers the idea of the large involvement in this research topic and the variety of study cases where the use of KBE techniques and the development of a DEE have been successful.

We acknowledge that financial support to the research topics discussed in this paper has been provided partially by the European Commission, under the GROWTH Programme, for the research project “MOB - A Computational Design Engine Incorporating Multi-Disciplinary Design and Optimisation for Blended Wing Body Configuration” (Contract Number G4RD-CT1999-0172), and by the Dutch Technology Foundation STW for the research project “Parametric Modelling and Meshless Discretisation Methods for Knowledge Based Engineering Applications” (Contract Number DLR.6054).





# Research on Design Support at TNO

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## 1. Introduction

This paper gives an overview of research in the area of design support at TNO. It describes work from around 2000 until now, but also looks back a little further to work done in the eighties and nineties, and looks forward into the near future.

The overview focuses on activities carried out at TNO Building and Construction Research until 2004. As TNO is currently being reorganized, most activities are continued in a new organizational unit: the core area “Bouw en Ondergrond” (Built Environment and Geosciences), see *www.tno.nl*.

## 2. History

### Start of TNO Bouwinformatica

The work reported in this paper goes back to the mid eighties, when a small group called Bouwinformatica was established at TNO, by then led by Frits Tolman. This team was first interested in Computer Aided Design (CAD) and Computer Aided Engineering (CAE) applications, but soon developed a strong interest in standardized data exchange and integration issues.

At that time, international work was being done on the standard IGES (Initial Graphics Exchange Standard), a large specification standard for exchange between CAD-systems. However, a new initiative was started called STEP (Standard for the Exchange of Product Model Data) (ISO, 1993). STEP was (and still is) an ISO-development aiming at standardized data exchange based on semantic models of the products at hand, i.e. *product models*, instead of exchange based on geometric entities (such as points, lines and surfaces). The scope of STEP was wider than just building and included mechanical engineering, the automotive industry, the process industry and so on.

### STEP and GARM

In 1988, TNO submitted a proposal to the STEP community called the General AEC Reference Model (GARM) (Gielingh, 1988). This model presented a holistic view on the conceptual modelling of AEC (Architecture, Engineering and Construction) information, with concepts for modelling decomposition, specialization and life cycle information, etc. The GARM became a very influential model in building modelling literature.

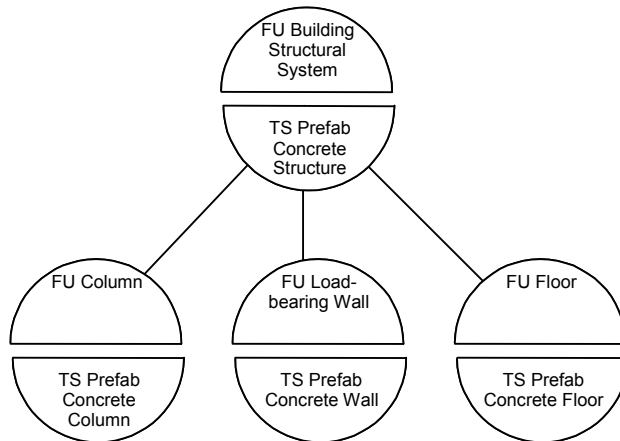
Perhaps the most appealing part of the GARM is the way requirements and solutions are modelled as Function Units (FUs) and Technical Solutions (TSes), in conjunction with decomposition:

- Functional Units describe objects “as required” and have Required Characteristics.
- Technical solutions describe objects “as designed” and have Expected Characteristics.

This approach makes it possible to *evaluate* a design by comparing the expected characteristics of Technical Solutions with the required characteristics of the associated Functional Units.

The GARM also proposes a decomposition tree in which:

- TSes decompose into lower level FUs,
- These FUs may have TSes,
- These TSes decompose again into lower level FUs; etcetera, see Figure 1.



**Figure 1: FU/TS-decomposition (GARM).**

### EU-projects in the nineties

In the early nineties, TNO Bouwinformatica (or Computer Integrated Construction, or CIC, as we started to call ourselves) was quite successful in the acquisition of research projects: first for Rijkswaterstaat, and soon after that in a number of European projects: IMPACT (1990-1992), followed by ATLAS, COMBINE, PISA and MARITIME (all approximately from 1992 to 1995, see [cic.vtt.fi/links/euproj/index.html](http://cic.vtt.fi/links/euproj/index.html)).

The scope of these projects was different each time (building, architecture, construction, process plants, energy in building, shipbuilding), but the TNO-contribution was always based on a STEP-GARM-approach that had become a common approach of the TNO-CIC-team. This approach was characterized by product modelling according to STEP and GARM, using methods and languages such as NIAM and EXPRESS, and process modelling using IDEF0.

This was all supported by grants from TNO, TU Delft, STW and others for a professorship and 7 PhD-projects. In these projects, scientific foundations could be developed for reference models for industrial automation (Böhms 1991), computer aided conformance checking (De Waard 1992), computer aided design for construction (Luiten 1994), building robotics (Krom 1997), conceptual models of shape (Willems 1998), and view models (Bakkeren 1997) and (Van Nederveen 2000).

Anyway, the early nineties was the most successful period of the TNO Bouwinformatica group. By that time the group (then 15-20 members) was internationally leading in the field. Around 1995, things started to change: TNO-CIC was less successful in the next round of EU-projects, we did not succeed to establish a follow up in terms of commercial projects, and some key people left TNO. However, EU-work was still continued on a smaller scale with VEGA (1995-1998) and later CONCUR (1998-2000) and eConstruct (2000-2002). Meanwhile, two members of TNO-CIC were hired on a fulltime basis to the Project Organization HSL, where they got involved in collaborative design issues in a large organization.

### 3. Organisation, mission, scope

#### Organisation

In 2001, the CIC-group (approx 10 members) merged into a larger department called Bouwprocesinnovatie (Building Process Innovation, BPI, approx 35 members). Within this department, teams were formed to deal with specific areas within the field.

One of these teams became the Design Support team (8-10 members). Most members of the Design Support were former CIC members, i.e. ICT-minded researchers, while others had a background in Open Building research, design processes etc. At the same time, some of the “ICT-people” joined other teams. In fact, there have been scope discussions between the teams from the beginning until today, for many (ICT) projects can be seen as a “Design Support” project, but as easy as a “Chain Integration” project (for which there was another team).

Anyway, in the next sections we will discuss recent work of the Design Support team members, but we will also discuss related ICT-projects that “formally” (for administration) belong to other teams. Also, while the Design Support team only operated from 2001 to 2004, we will also look at projects that started earlier as well as projects that are still running.

#### Mission

As Design Support team we have formulated the following *mission statement*: “to further develop knowledge and insight in multi-disciplinary design processes, methods and tools in order to help clients and other parties in realizing designs that are optimized on life-cycle value.”

That is quite a long statement and it may require twice or three times reading to fully understand it. Nevertheless it reveals some key characteristics of our team:

1. Focus on multi-disciplinary design,
2. Focus on design processes, methods and software tools,
3. Focus on solutions for “real-life” clients with “real-life” problems.

The focus on multi-disciplinary design means that we are particularly interested in communication and collaboration between designers; it also means that we are interested in information exchange and integration issues, rather than support of individual design processes/development of stand-alone solutions.

Regarding processes, we can say that we pay more attention to multi-disciplinary processes than to e.g. design theories; on the other hand we strongly believe that better support of early design (pre-design) can greatly improve the overall effectivity of design. Regarding methods and tools we are still quite ICT-oriented, so methods and tools are in most cases software development methods (i.e. conceptual modelling) and software tools.

Finally we focus on solutions for “real-life” clients with “real-life” problems. This is of course motivated by the organization we are in: TNO, which calls itself in English “Netherlands Organization for Applied Scientific Research,” has a mission of bringing research to practice, etc. However, to really get the research results successfully working in practice is not that easy, as we will discuss later on in this paper.

#### Scope and themes

As can be concluded from above, our scope can roughly be described as design (both in architecture and in civil engineering), with a focus on multi-disciplinary issues and ICT-oriented approaches.

But what we really do, is best explained by giving examples. Therefore we will discuss a number of projects in the next section. For now, we will indicate a few common themes in our work:

- *Multi-disciplinary design and life-cycle integration*: collaborative design, group design sessions, specification (“PvE”) approaches based on systems engineering, design information management, object trees, integration of design and construction (e.g. 4D CAD), life-cycle oriented design;
- *Model-based design*: based on the conceptual modelling/product model approach, use of IFC-technology, focus on information integration, parametric design, and recent developments such as ontologies and semantic web;
- *Early design*: early design support/demand support, designing with stakeholders, multi-criteria analysis models.

These themes come back in the next sessions when we discuss a number of projects.

### **Positioning in the field of “Design Research”**

As discussed in 2, many projects and activities have been carried out over the years, and a certain “TNO approach” could be recognized in these. However, there has never been put much effort in the positioning of the work in the field of design research. In fact the group did not really consider their work as design research. For example, now and then questions were raised (at conferences, for example), whether the GARM was assuming a particular design approach, but such questions were normally countered with the statement that the GARM is aimed to support any design approach (top down or bottom up, you can start at any point in a FU/TS decomposition tree).

However, looking back one can say that the TNO-approach has at least characteristics of design as a rational problem solving process, with an important role for functional decomposition. This is more or less in the tradition of the design methodology approaches that became popular in the sixties (e.g. Alexander 1964), as well as systems engineering approaches, and also for example Eekels et al. (1986). Themes as irrational aspects of design, creativity, cognitive aspects etc. are not really dealt with. On the other hand, there is clearly a link with design research, as there are enough examples of other research where the use of product models is combined with reasoning in design, see for example the EDM-work by Eastman et al. (1991), the work by Haymaker et al. (2004), and work by CSIRO and University of Sydney (Ding et al. 2004).

## **4. Main projects**

In this paragraph four important projects of our team are discussed: eConstruct, ICCI, ROADCON, and iBuild. The first three are EU-projects, which means they are relatively large, relatively theoretical and strategically important to us, as they indicate directions for future work.

The fourth project, iBuild, is also quite large and strategically important, but different in the way it is organised; it is in fact a joint venture with an architectural firm and a consultancy firm. As such, it functions as a framework for several research activities that must support this joint venture, see further the iBuild project discussed below.

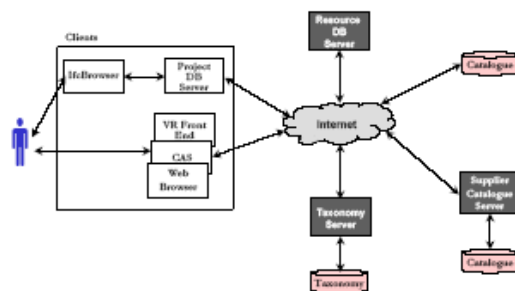
## eConstruct

*Researchers: Michel Böhms and Peter Bonsma, 2000-2002, with Taylor Woodrow Construction Ltd (UK), Betanet (EL), STABU (NL), TU Delft (NL), CSTB (F), Nemetschek AG (D), EPM Technology AS (NO), Thomas Liebich Consulting (D), and BuildingPlaza (NL).*

The EU-project eConstruct was an early attempt to explore the possibilities of e-commerce and e-business in building and construction. At the time of the project proposal, e-commerce and e-business were new and promising phenomena in business and ICT. At the same time, new Internet technologies were launched under the flag of Next Generation Internet. An important part of this was the by-then new language XML. XML was more powerful than HTML, mainly because structure and content were separated, and it was much simpler than SGML, the well-structured but very complex markup language developed by US Defense.

The goal of the eConstruct project was to develop a new communication technology for the building industry based on the Next Generation Internet and XML. An important part of this new technology has been the language bcXML, an extension of the XML language that was specifically developed to meet the needs of the building industry. The bcXML language and supporting technology (e.g. IFCs) is particularly intended to support e-commerce and e-business in building.

Based on this technology, scenarios have been specified and a proposed system architecture is elaborated, see Figure 2.



**Figure 2: eConstruct proposed system architecture (overview).**

The main result of the project was a demonstration system based on the architecture shown above. In this demonstration it was possible to electronically order a door by matching design requirements with catalogue data of door vendors. In addition, the eConstruct project contributed to the further development of IFCs, and to a CEN-standard on eConstruction. More information on eConstruct can be found on the project website, [www.econstruct.org](http://www.econstruct.org), and in (Tolman et al. 2001).

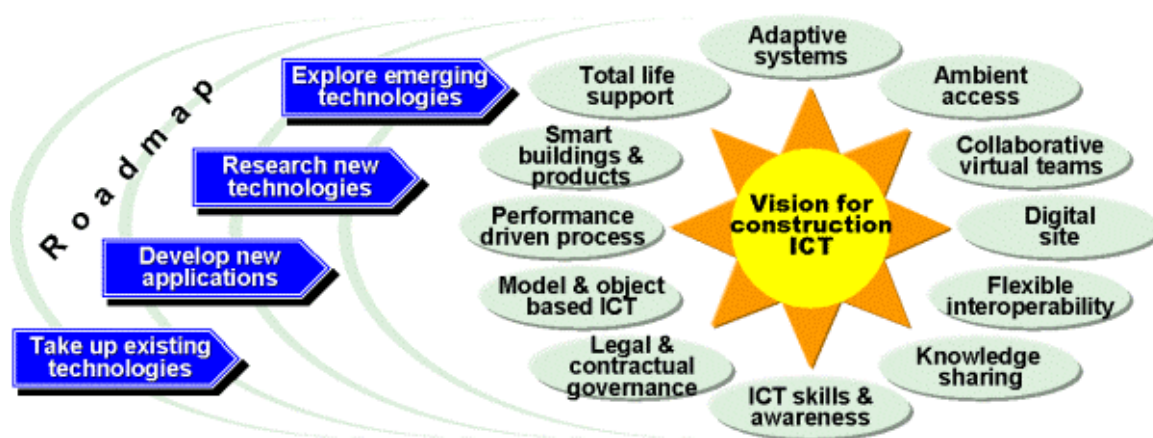
## ICCI and ROADCON

*Researchers: Michel Böhms, Sander van Nederveen, 2001-2004, with CSTB (F), VTT (Fi), University of Salford (UK), Loughborough University (UK), University of Ljubljana (Slo), AEC-3 (UK/D), Dresden University (D), TU Delft (NL).*

ICCI and ROADCON were two EU-projects with some common characteristics. They ran more or less at the same time with more or less the same partners. Also, both projects were late (EU R&D) Fifth Framework projects in which no software was developed, but rather consolidation of results of the Fifth Framework (ICCI) and road mapping for the Sixth Framework (ROADCON)

was aimed. The ICCI-project was structured around six existing EU-project that dealt with ICT for construction. The aim of ICCI was to consolidate the results of these projects, to stimulate co-operation between the participants of these projects and to enable joint dissemination, for example through conferences and publications.

TNO acted in ICCI as Work Package leader of WP 6 “Integration, strategy and future plans for ICT in construction,” a rather strategic, future oriented work package with a strong link to the road mapping activities of ROADCON. The work for ICCI addressed issues such as themes for the future, barriers and enablers for innovation, leading to recommendations for research policy. The ROADCON project aimed at the development of a roadmap for ICT in building and construction. Of course the main end result is such a roadmap, see [cic.vtt.fi/projects/roadcon/docs/roadcon\\_d52.pdf](http://cic.vtt.fi/projects/roadcon/docs/roadcon_d52.pdf). An overview of the key elements of this roadmap is shown in Figure 3.



**Figure 3: ROADCON vision on ICT for Building and Construction.**

TNO acted in ROADCON as Work Package leader of WP 3 “Trends and Opportunities for ICT in Construction,” but also significantly contributed to the final roadmap.

More information on ICCI and ROADCON on their respective websites: [cic.vtt.fi/projects/icci](http://cic.vtt.fi/projects/icci) and [www.roadcon.org](http://www.roadcon.org).

### **iBuild**

*Researchers: Roland van der Klaauw, Peter Bonsma, Peter Willems, 2004-current, with Architectenburo Willems van den Brink and EDC.*

iBuild is a joint initiative with Architectenburo Willems van den Brink and consultant EDC. It is a system in which the acquisition of a house by the future owner is supported by ICT. The envisaged iBuild process is roughly as follows: a customer who wants to buy a house gets in contact with a “woonadviseur,” a residential consultant that assist the customer in the specification of his requirements and in the acquisition of a house that meets his requirements. At this stage, the first information or knowledge about the planned house is already generated, and this is stored into the iBuild system. The iBuild system can already respond to this knowledge with design suggestions, reference designs (“cases”) and reference figures (e.g. on building costs).

Then, when the first design ideas are developed, iBuild can respond with visualizations, and calculated consequences regarding comfort, building physics, and costs. And after a first design session, the client can take home a scale model of his future house, based on the knowledge in the iBuild system.

From here on, the design and manufacturing processes are highly automated. Different software modules assist in building performance analysis and checking of building regulations. And the final design is translated into machine instructions for industrial building, etc.

An overview of the iBuild architecture is shown in Figure 4. A typical screenshot is shown in Figure 5.

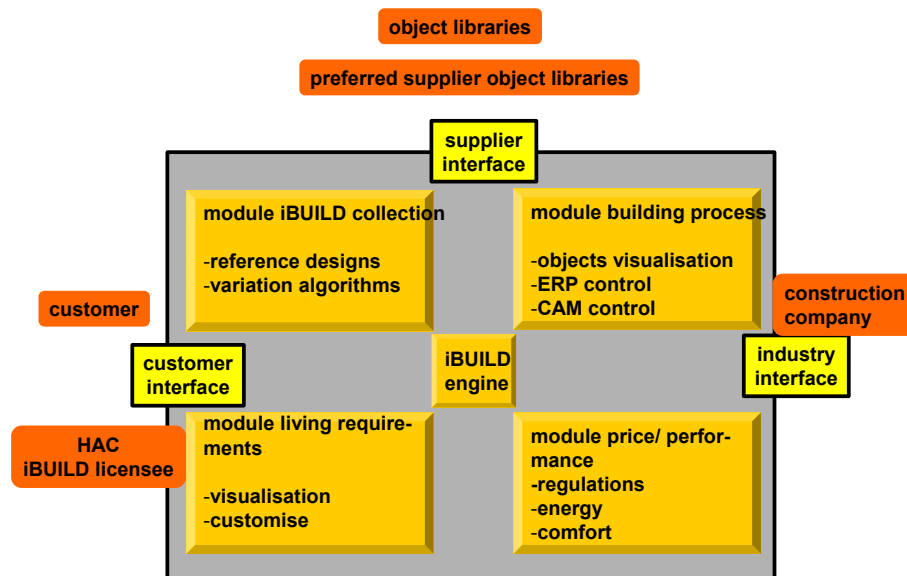


Figure 4: iBuild architecture.

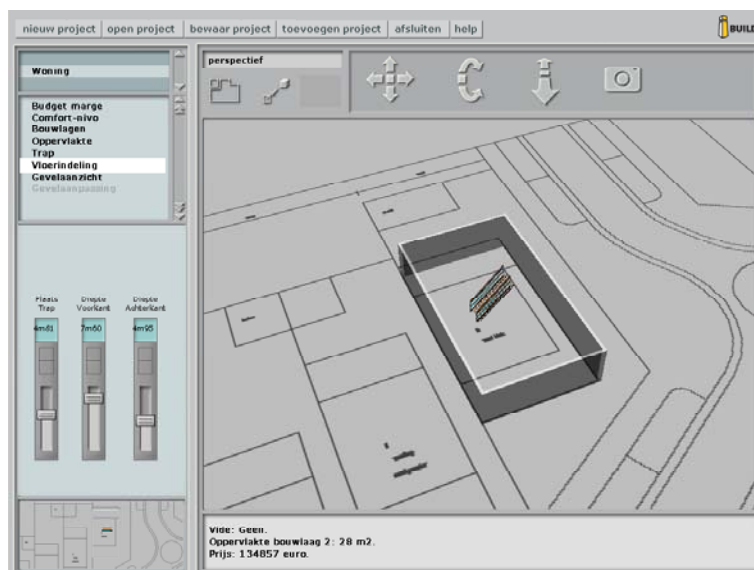


Figure 5: iBuild screenshot - as stairs are placed, consequences are displayed at the bottom of the screen.



The concept of iBuild covers virtually all research themes we are interested in, and even more: building product modelling, demand support in early stages, integration of processes and disciplines, e-commerce in building, parametric design, visualizations and simulation, industrial building (IFD), etc. etc.

The main problem (or challenge if you wish), is that the iBuild concept is being sold at the same time (or earlier), as it is developed. While we are still working on for example parametric design modules, an iBuild User Group is already established, pilot projects have been carried out (e.g. with the Eindhoven housing corporation SWS, see Figure 6).



Figure 6: iBuild pilot project.

Needless to say that this has put serious pressure on the research activities, and that it is sometimes hard to stick to the good principles of open standards and semantic modelling, and not go for quick and dirty solutions.

## 5. Other projects and activities

### Object Tree for the Amsterdam-Utrecht railway project

*Researchers: Johan Neuteboom, 2000-2001, with ProRail, Arcadis, Holland Rail Consult and Infostrait.*

In this project an Object Tree was developed for the Amsterdam-Utrecht railway project. The project was developed for the project client ProRail, in co-operation with engineering firms Arcadis and Holland Rail Consult, and software vendor Infostrait, using the PDM-package SmarTeam. The work was based on the HSL Object Tree, that was developed in 1997-1999, and the thesis by van Nederveen (2000) on Object Trees, (see also van Nederveen and Tolman 2001). The role of TNO was a consultant's role, while Infostrait took care of the software development.

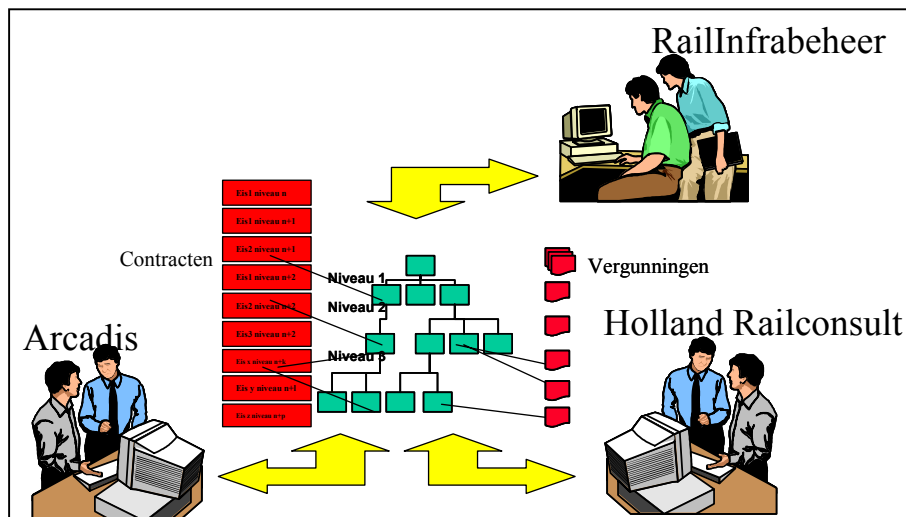


Figure 7: Object Tree developed for HSL and the Amsterdam-Utrecht railway projects.

In essence, an Object Tree is a hierarchically structured list of physical objects that are planned to be the outcome of the construction project. This Object Tree is implemented as project data base and serves as a placeholder for project information, including documents, CAD drawings, and links to cost calculations, planning, specifications and so on. An overview is shown in Figure 7.

Apart from this project, a few other projects have been carried out that were also based on the earlier experiences with systems engineering and object trees at the HSL. These smaller projects aimed at requirements specification and tendering approaches. Currently we are trying to continue work in this area within the research programme PSI Bouw (see [www.psib.nl](http://www.psib.nl)).

## VISI

*Researchers: Peter Bonsma, Sander van Nederveen, Michel Böhms, 2000-2003, with Gobar, CUR and the VISI-consortium.*

The VISI-project aimed at a communication standard for civil engineering projects based on transactions and messages. For this, VISI has developed standard formats for transactions and messages. These formats define the “envelope” of transactions and messages, the structure of the content was out of scope. TNO contributed to VISI in different ways: we did an analysis of object oriented approaches for VISI, developed a low-cost VISI-compliant message editor based on Outlook, and we provided a conceptual framework for VISI compliant software. Based on the last, we are still involved in compliancy checking activities for VISI.

## ASVB

*Researchers: Michel Böhms, Peter Bonsma, 2001-2003, with ASVB.*

Related to the eConstruct-project, our group became involved in a sequence of consultancy projects for the construction company Aan de Stegge Verenigde Bedrijven (ASVB), see [www.asvb.nl](http://www.asvb.nl). ASVB is a construction company with the ambition to realize significant innovations through ICT. In their search for promising technologies ASVB came across developments such as STEP, IAI/IFC, the STABU LexiCon and eConstruct’s bcXML. This resulted in subsequent projects in which TNO gave advise on the use of IFCs, on an information architecture for ASVB’s project information system, on 4D CAD, on document management and project management software etc.

## Demand Support by Virtual Experts

*Researcher: Hans Schevers, 1999-2004.*

“Demand Support by Virtual Experts” is the title of the dissertation by Hans Schevers, that concluded his PhD-study on this subject. This study aimed at improved support of clients in the earliest stages of a project. A demand support system is proposed in which virtual experts (software equivalents of human experts) collaboratively provide the client access to the body of construction knowledge starting from the inception phase of a building project. For example, clients can be supported by promptly providing adequate information on consequences of design decisions, such as cost information, consequences for adjacent buildings, parking needs, etc. etc.

TNO has supported the study by Schevers because it had special interest in early design. In fact we still believe that projects can be carried out in a much more effective and efficient way, when they would be better supported in the early stages. A screenshot from the research by Schevers is shown in Figure 8.

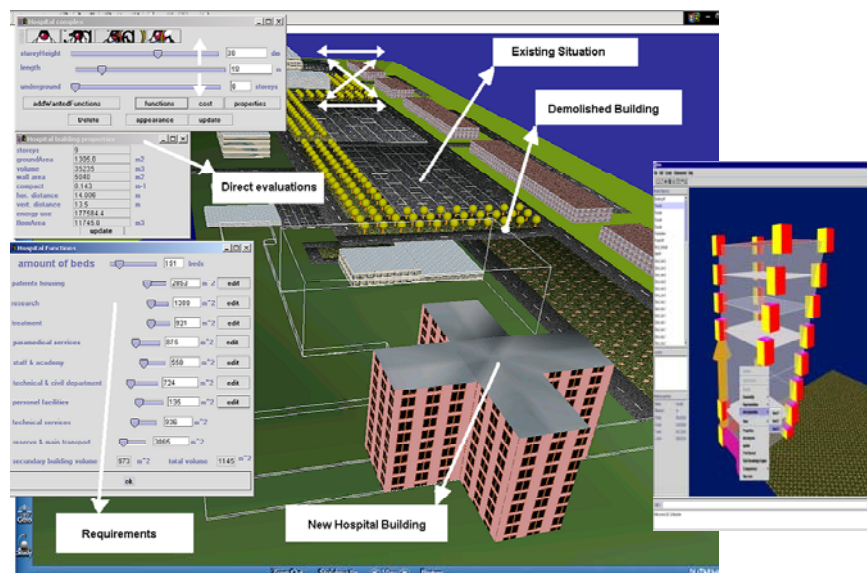


Figure 8: Screenshot of the “Demand Support by Virtual Experts” project.

## Strategic Design (Center for Buildings and Systems)

*Researchers: Maurits Dekker, Bart Luiten, 2001-2004, with TU Eindhoven.*

The Center for Buildings and Systems is a joint initiative of TU Eindhoven and TNO in which a number of mainly PhD research projects are brought together. Whilst most of the projects are concentrating on various issues in building physics and installations (building simulation, acoustics, heat and moisture, lighting, health comfort and productivity, and renewable energy systems), one programme of the Center is devoted to design processes: “Strategic Design.”

“Strategic Design” is based on ideas of Prof Paul Rutten of TU Eindhoven and focuses on integration of multiple aspects of multiple stakeholders in a design process. Later on a slight shift towards ICT took place when Prof Bauke de Vries of TU Eindhoven and Dr Bart Luiten of TNO became coordinators of the “Strategic Design” programme. Nevertheless, in 2004 TNO decided to reduce their involvement in “Strategic Design” significantly and there is not much activity at TNO at the moment.

The (all Eindhoven-based) PhD-studies in “Strategic Design” show a common interest in multidisciplinary design issues. Fayez Al-Hassan worked on a rather holistic theory for Strategic Briefing (this book: pp. 71-84), Gebhard Friedl worked on an innovative model of the conceptual phase of the building design process and on group design rooms, Frans van Gassel (this book: pp. 63-70) worked on multidisciplinary architectural design sessions (in group design rooms) and a method called “handstorming” (based on the idea that “design is thinking by hands”), and Nishchal Deshpande focuses on the ICT and knowledge engineering methods needed for collaborative design.

## IFCs, Ontologies and Semantic Web

*Researchers: Michel Böhms, Peter Bonsma, Peter Willems.*

As discussed earlier in this paper, TNO has a long tradition in building product modelling and STEP technology. In the second half of the nineties, the international platform for building product modelling moved from the ISO group STEP to IAI, an alliance of software vendors. Within IAI the basic technologies of STEP, including the EXPRESS language, were maintained, but the data models now were developed in a bottom up fashion, using the concept of Industry Foundation Classes (IFCs): standardized CAD objects for building elements defined in EXPRESS.

TNO has had the opportunity to participate in the development of IAI and IFCs through their involvement in the EU-projects CONCUR and eConstruct. In these projects TNO gained experience in the development of IFC-based software, mostly demos in which product data was exchanged based on IFCs. In addition, TNO developed IFC-based tools, most notably the IFC Browser and the IFC Engine. The IFC Browser can read IFC models and present them in 3D, see Figure 5; the IFC Engine is its successor with additional functionality and can be used to further develop dedicated IFC-based software. IFC Engine software can be downloaded from [www.ifcbrowser.com](http://www.ifcbrowser.com).

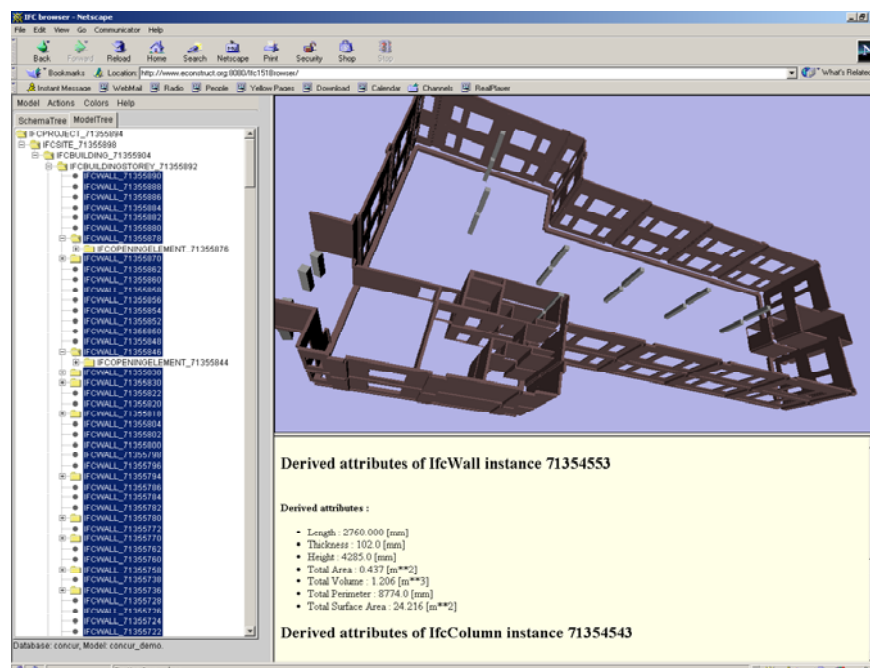


Figure 9: IFC Browser.

As a next step in semantic modeling, our group is at the moment particularly interested in the latest developments around ontologies and the Semantic Web. The Semantic Web is a new development that aims at a “more intelligent” World Wide Web. For example, the current Web can help you to find what you are looking for with search engines such as Google - if you give exact names or words. It does not help you with synonyms, contextual information, etc.

For example: if you try to plan a journey, you will clearly notice: the computer does not understand that you will need accommodation on the day of your arrival, if you rent a car, you will be asked where you want pick it up, even if you have just booked a hotel room in the same session, etc. So while such booking requests have several common characteristics and relationships, current technology does not recognizes them. Of course many other examples can be thought of, including examples for building design.

The goal of the Semantic Web is to enhance the functionality of the Web by adding such intelligence: by adding context awareness, by generating information structures, etc. An important concept in this context is “ontology”. An often cited definition of ontology is: “an explicit specification of a conceptualisation of a domain” (Gruber 1993). In the context of the Semantic Web, ontologies are used to define the universe of discourse of such a domain in a web-compatible manner. For that purpose, a Web Ontology Language (OWL) has been developed. More information on the Semantic Web and OWL can be found on the site of the World Wide Web Consortium, [www.w3.org](http://www.w3.org).

At TNO, we have explored these technologies and developed experimental software for a “Semantic Web-based” alternative for the eConstruct demo for ordering doors. Furthermore, we have developed an OWL-IFC-interface, between the new Ontology Web Language and IFC.

## 6. “Bringing research into practice”

Bringing research into practice is an important aim for TNO. TNO’s full name in English is “Netherlands Organization for Applied Scientific Research”. Hence this section is about the application of our research in practice.

In section 5 we have discussed some 10 research projects. These can be classified as follows:

- 3 European projects.
- 2 R&D projects with mixed funding (Center for Buildings and Systems, VISI).
- A few small projects with internal funding (IFC, Semantic Web).
- 1 PhD research.
- 2 commercial projects for specific clients (ProRail and ASVB).
- 1 commercial project with the purpose to sell to many clients (iBuild).

Now without getting into financial details, it is fair to say that the commercial projects are not well represented; in fact iBuild is the only one at the moment. For some reason, we do not succeed to find an enduring transition mechanism from research to practice. Why? That is a complex issue that we do not have a simple answer to.

## 7. Conclusions and future work

The near future of design research at TNO is closely related to the current reorganization of TNO. Because of poor financial performance it was decided in 2004 to restructure the department of Building Process Innovation, to discontinue the Design Support team as an organizational entity, and to reduce staff.



Regarding the future of projects: TNO has invested considerably in iBuild. For the time being, iBuild will be continued, but soon enough iBuild will need more commercial success stories. TNO has also invested considerably in the PSI Bouw research program, but until today this has not resulted in a large stream of research projects. However, we hope to start soon with an ICT-demonstration project called ProClient, and we see opportunities in the COINS-project. Meanwhile, we are about to start with a new European project called MANUBUILD, and we are trying to acquire more European work.

Regarding themes and topics for the future: with the discontinuation of our team, we also lost the forum to discuss these themes and to make explicit choices regarding themes for the future. Implicitly however, we did make choices into the following directions:

- We will continue with iBuild.
- We will continue with the broad theme of multi-disciplinary design, probably using IFC technology.
- We plan to build upon the developments in ontologies, semantic web and the OWL language.
- We might extend our design research in the direction of value engineering, using the value-price-cost model by De Ridder (2004), for example in a PSI Bouw-project.

So, although our Design Research team formally does not exist anymore and while the current workload is still less than we would like it to be, we have good hopes that our research activities on design support at TNO will soon be back on the same level.

## Websites

<http://cic.vtt.fi/links/euproj/index.html>, a comprehensive list of current and past EU-projects maintained by VTT, including ATLAS, COMBINE, VEGA etc.

<http://cic.vtt.fi/projects>, a list of projects in which VTT is involved, including ICCI, ROADCON, MANUBUILD and even PSIB.

<http://icci.vtt.fi>

<http://roadcon.vtt.fi>

<http://www.asrb.nl>

<http://www.econstruct.org>

<http://www.iai-international.org>

<http://www.ibuild-online.com>

<http://www.ifcbrowser.com>

<http://www.kcbs.nl>

<http://www.psib.nl>

<http://www.tno.nl>, the site of TNO

<http://www.visi.nl>

<http://www.w3c.org>



# The Chair for Computational Design in 2000-2005

## Five reflective years

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### 1. Introduction: end of an era?

2000, the year of the last symposium on Design Research in The Netherlands, was a turning point for the Chair for Computational Design (*Bouwinformatica*) at the Faculty of Architecture, Delft University of Technology. Administrative changes in the Faculty gave us the opportunity to modify the character and orientation of the Chair. These modifications were not merely the effect of the administrative changes but a conscious response to ongoing socio-technological developments. The democratization and popularization of the computer that characterized the last years of the previous century had a profound effect on the purpose and role of specializations such as computer-aided architectural design (CAAD), i.e. specializations that link computer science and technology with a particular application area. As an academic and technological elite CAAD has been the custodian of the rare, expensive and poorly understood computer technology in architecture and building. When computers became affordable and widely available CAAD was no longer required to provide computer literacy in teaching or to develop applications on behalf other architectural specializations, which could select from a wider range of available applications or even do their own customization and development.

Unfortunately the democratization and popularization of the computer were poorly understood in CAAD. In a climate of light panic many CAAD specialists approached the computer as a media machine or attempted hybrid solutions involving analogue media. Others concentrated on CAAD literacy and accepted a support role in the background of other specializations. Digital studios became less a tour de force of design computing and more a conventional studio with computers used for presentations and visualizations, frequently with little reference to the theoretical and methodical underpinnings of techniques used. Even efficiency could suffer, as the use of the computer became more cosmetic, unfocused and chaotic, paying lip-service to vague ideas and irrelevant principles.

By doing so many CAAD specialists focused on the technological side of their field and ignored the other, probably more significant side that developed theory and methods through a combination of domain analyses with general computational principles. In the genealogy of CAAD (Figure 1) the theoretical / methodical side is firmly based on late modernist design thinking and predates the introduction of the computer. Similarly to other areas the computer was arguably brought in to serve the analytical thinking and the complex, information-intensive methods that were developed in order to achieve rationalization, transparency and efficiency in architecture and building.



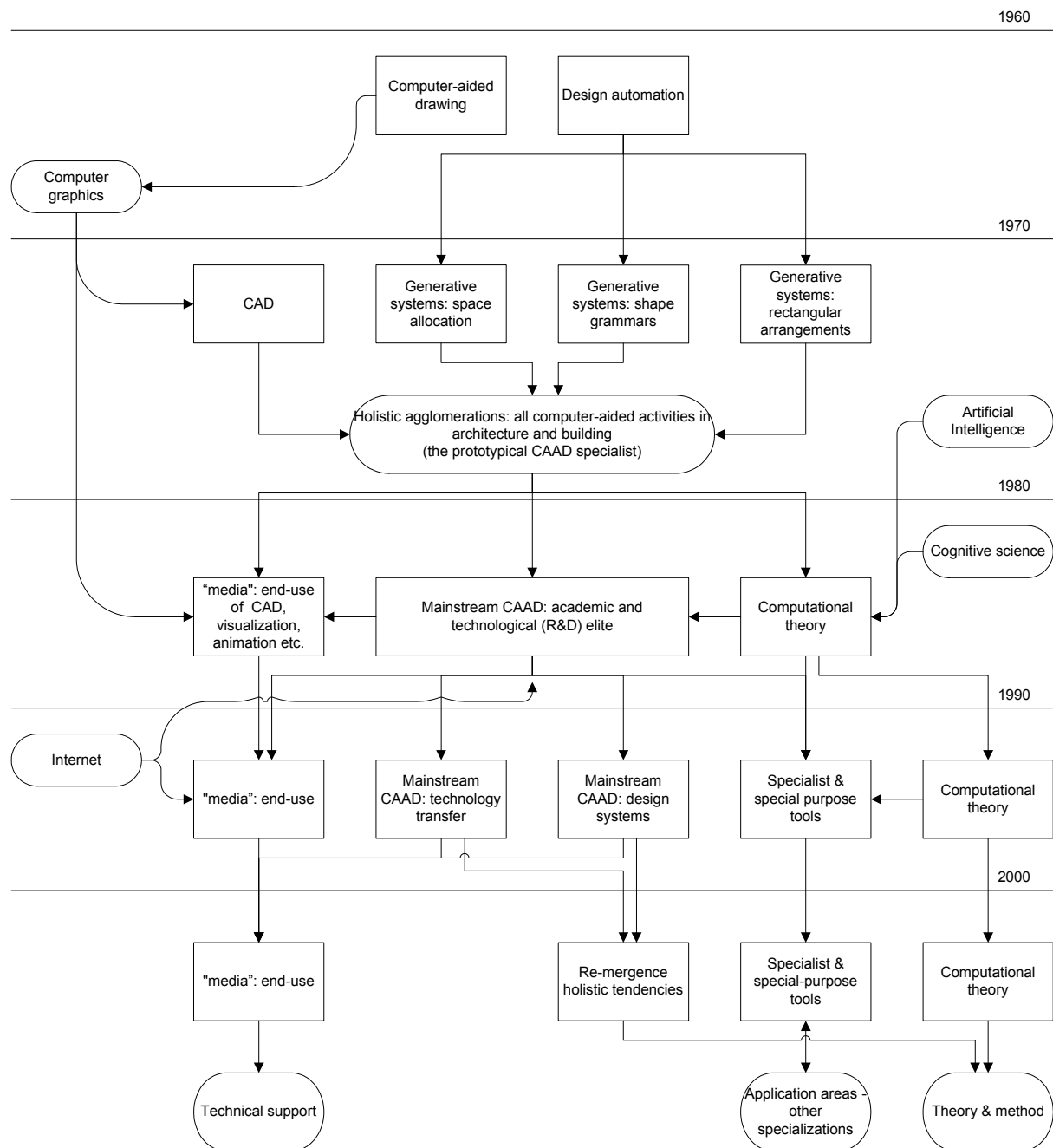
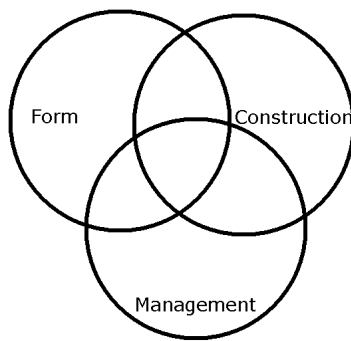


Figure 1: A genealogy of CAAD.

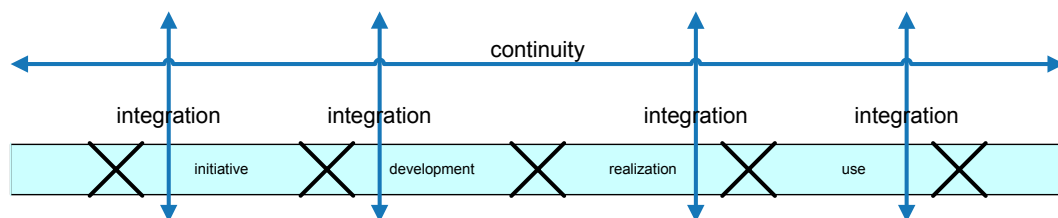
## 2. Changes at the Faculty of Architecture, Delft University of Technology

The main change that took place at the Faculty of Architecture, Delft University of Technology, in 2000 was the dissolution of the Computing Group (administrative unit *Vakgroep Informatica*) and the reallocation of the two chairs comprising the group to other administrative units. The Chair for Computational Design moved to the Group Building Management and Real Estate Management, which (following further administrative changes) later became the Department of Real Estate & Housing (RE&H). RE&H is one of the four departments of the Faculty (together with Architecture, Urbanism and Building Technology) and focuses on the management of products and processes.



**Figure 2: The domain and subdomains of architecture and building.**

As Figure 2 illustrates, the four departments represent different, complementary views on the domain of architecture and building. The role of RE&H is arguably unique within this framework, as it not only covers the entire lifecycle of the built environment but also provides integration of aspects in every stage and continuity between stages (Figure 3).

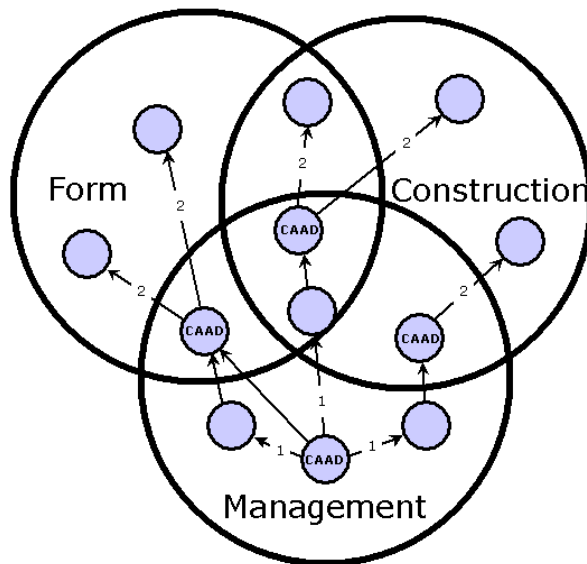


**Figure 3: The lifecycle of the built environment.**

The advantage of RE&H as the immediate context of the Chair for Computational Design lies in its broad, generalist character that allows for retaining the extensive profile of CAAD. In fact, most approaches to integration and continuity are closely related to or firmly based on computing and automation as a means of ensuring a consistent yet unobtrusive infrastructure for information management and communication. This also means a significant reduction of work in the areas of computer and CAAD literacy, in favour of more focused research and teaching. This does not necessarily imply that the other specializations in RE&H have already achieved a higher level with respect to design and building automation. It simply denotes different priorities, which have to do more with the utility and propagation of information and less with the actual production of information. This is also a fundamental weakness of most management approaches: the production of information is largely left to the designer who is left to his own devices, conventions and representations and yet expected to cater not only for the majority of information in a project but also for the integration of information. However, the designer has only indirect benefits from such tasks, while the manager who should be responsible for at least coordinating production and dissemination of information is generally restricted to issuing guidelines and directives. New specializations and subjects like design management and information management attempt to redress this conflict of interests and priorities but with variable results.

In general, the contribution of computational design to RE&H is dual (Figure 4):

- Methodical analysis of domain problems – methodical development of solutions (indicated by links marked “1”).
- Propagation of solutions to other areas and activities (links marked “2”).



**Figure 4: Contributions of computational design.**

This duality makes computational design an exception within RE&H but is consistent with the character of CAAD and the wider reasoning behind automation in professional areas. In practical terms it allows for influence on the theoretical and methodical levels, as well as for control of practical aspects (primarily information management, including representation, communication and constraint propagation).

### 3. Research foci

Shortly after 2000 the research of the Chair for Computational Design was reorganized in accordance with its new position and corresponding roles /priorities. It became structured around three main projects:

1. *Design technology*: technology transfer from computer science and other disciplines. The technologies are selected on the basis of general potential (e.g. judging from outside architecture and building) or applicability to specific domain problems. Technology transfer invariably involves adaptation to the purposes and frameworks of the domain (from customization to prototyping). The subjects and goals of technology transfer tend to vary in time. This is the result of technological innovation as well as of adoption of earlier technologies by the application area. An important observation is that adoption does not necessarily mean that the technologies have been applied to the advantage of the area. On the contrary, quite a few technologies return higher costs and no significant improvement of performance. Design automation in practice is characterized by a number of such failures. One of the reasons (which also exonerates CAAD) is that the influence of general socio-technological patterns and developments in related areas can

be much greater than that of academic research and development. For example, the democratization of the computer has had a deeper and more lasting influence on the computerization of architectural practices than CAAD education.

2. *Design methods*: the application of general computational principles and methods may be preceded or followed by a thorough analysis of domain phenomena and problems. In either case the correlation of the two makes it possible to reformulate domain knowledge in ways that offer deeper insights or operational advantages. The subjects of design methods research also evolve with time but a large share of the basic principles and general theory has remained largely unchanged. This makes us assume that despite the constant irritation of vagues computational design methods are reaching maturity.
3. *Design information management*: this project is not on the same level as the previous two, which represent the two basic components of computational design. It was conceived as a way of making the correlation and application of these two components explicit and relevant to the management of architectural products and processes. Our expectation is that in the near future attention will shift from the production of digital information to its utility and dissemination. This does not preclude that the digital information produced fails to meet structural and semantic requirements – on the contrary, uncertainty or vagueness concerning its utility and value conspire to reduce the specificity and coherence of such requirements. As a result, we expect that the consumption of information will not only occupy a higher place on the priority list of the domain but also provide significant insights into the nature and structure of design information (the users' point of view).

The demarcation between these projects could be considered purely academic and conceptual. Activities clustered under different projects can be closely related, even causally. For example, technology transfer in the first project depends on theoretical and methodical underpinnings, structured analyses and reformulation of domain knowledge – subjects that fall under the second project. Nevertheless, the projects indicate differences in the departure, goals and means of related activities. Scientific thinking requires cohesive and consistent networks, common methods and sound reasoning but, as Terry Pratchett has suggested in *Pyramids*, one of his *Discworld* parodies, “*either the universe is more full of wonders than we can hope to understand or, more probably, ... scientists make things up as they go along.*” In our case, even though we tend to (post)rationalize our choices, directions and findings, it is not uncommon that a research starts because of mere fascination with a problem, a viewpoint or a technology. Obviously one needs a few more substantial arguments in order to go ahead with a research beyond the early stages but the fact remains that departures can be more intuitive and more opaque than research proposals suggest.

#### 4. Design technology

Initially research into design technology continued along the lines of earlier research, including the application of automated recognition and multilevel hierarchical representations to analyses of complex aspects and complex building types (Koutamanis 2001b). Of particular interest in this line has been the interaction between people and the built environment, as in pedestrian circulation and fire safety (Koutamanis, van Leusen and Mitossi 2001).

Another line involves the application and adaptation of simulation techniques to architectural situations. In this line we worked with computational fluid dynamics in order to make explicit air quality and air flow (Den Hartog, Koutamanis and Luscuere 2001; Den Hartog 2004). Two significant conclusions from this research are:

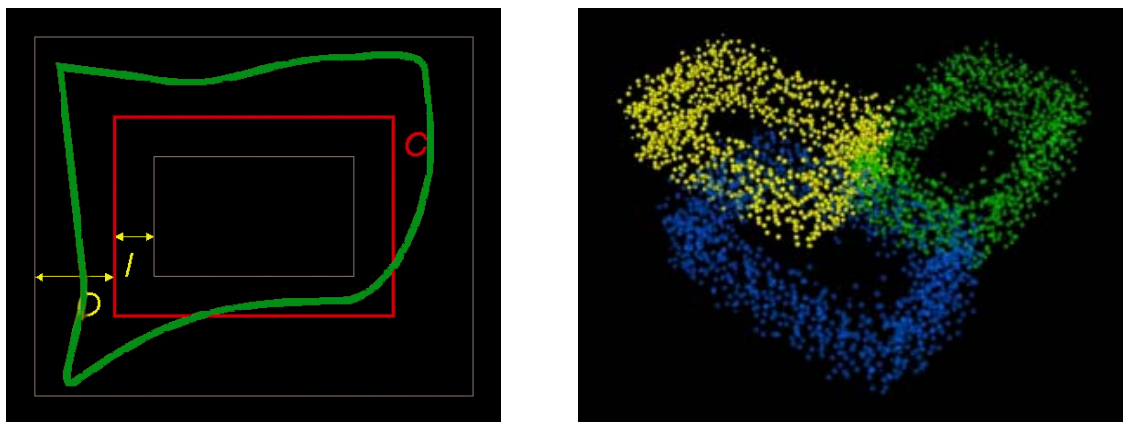
- Simulation and scientific visualization are capable of making explicit not only complex phenomena but also specialist domain knowledge.
- Communication and interaction between different aspects benefits more from analysis and focused queries than from information exchange.

Experimental applications of the results of the research in teaching were encouraging. Students seemed to appreciate the challenge and learning potential of such technologies and invested significantly more time in them than in more common tasks such as the production of photorealistic imagery. The two main limitations were that the technology is still computationally time-consuming and that effective feedback to the design decisions may require extensive consultation with specialists.

A third line relates to the exploration of the potential of autonomous mechanisms in analysis, synthesis and communication. This exploration ranges from the use of virtual users in simulations of pedestrian circulation to quality control in design representations to information retrieval (Koutamanis 2001e, 2002a). Under the principle of local autonomy quite a few design problems can be resolved automatically through knowledgeable autonomous mechanisms with a restricted scope but extensive understanding of both local and global constraints.

Closely related to issues of autonomy is the representation of complex and irregular forms. In many cases local variations and modifications can be delegated to autonomous local structures that cooperate in order to establish global consistency and coherence (Koutamanis 2001d, 2004a). Probably the most significant development in this respect is the notion of fuzzy modeling (Koutamanis 2001c).

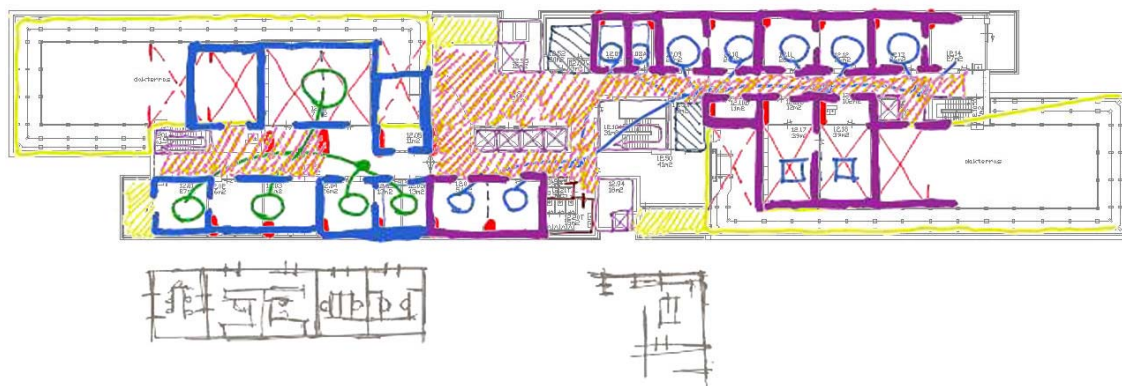
Fuzzy modelling emerged from a comparison between architectural sketching on paper and computer modelling. The vagueness of sketching offers possibilities for e.g. introducing tolerances, expressing relationships and deferring decision to later stages that are practically prohibited by the crispness of most computer modelling systems. More ambitious systems involve advanced techniques such as parameterization (almost always geometric; topological parameterization is severely neglected) to achieve a higher degree of precision and flexibility. However, the costs of developing and maintaining such models can be too high for the performance and support they offer. Fuzzy modelling has a much lower overhead, especially in combination with autonomous mechanisms that regulate object behaviour within the local constraints of fuzziness.



**Figure 5 (left): Adaptation of a fuzzy form. Figure 6 (right): Fuzzy forms as particle clouds.**

More recently we have started concentrating on mobile tools as a simple, unobtrusive means of achieving our goals. Such tools are often dismissed as mere gadgets but this simply reflects the way technologies are marketed. In terms of connectivity mobile tools offer significant advantages through the proliferation of GPRS, Wi-Fi and Bluetooth, while their portability and ergonomics have become acceptable for most practical purposes. Moreover, they are widely, affordable, familiar and available also for professional applications. Our research focuses primarily on:

- Mobile information processing with palmtops and smartphones: this has significant advantages for physically distributed processes of architecture and building, especially on construction sites and site visits.
- Digital sketching on analogue media: as most design documentation is produced with computers but presented, communicated and discussed on analogue reproductions, this technology presents possibilities for feedback from the analogue to the digital world (Koutamanis 2005).



**Figure 7: Digital sketch on analogue drawing (computer print).**

## 5. Design methods

Our research into design methods, their principles and applicability, related primarily to two issues that could be considered permanent and dominant preoccupations. The first is design representation and has been the target or carrier of many projects, from fuzzy modelling to route analysis. In the period 2000-2005 much of the work in representation has been subsumed by other projects, primarily in the areas of design technology and design information management. The second issue is decision support, especially in multi-actor contexts. Extensive attention to group processes and their significance for management and coordination has been a logical consequence of the integration into RE&H. The main characteristics of the approach developed under the name “open design” have been optimization, process and product innovation, collaboration between stakeholders, and correlation of management with decision-taking (Van Gunsteren 2003, 2004; Van Gunsteren and Van Loon 2002; Van Loon 2001).

In earlier research case-based reasoning and the use of design precedents have been closely related to representation. More recently these subjects have been linked to empirical knowledge and architectural typologies as means of encapsulating and ordering formal and functional patterns that support design analysis and guidance (Koutamanis and Steijns 2003).

Another consequence of the new position of the chair has been the tendency to look back the historical and conceptual development of CAAD as a scientific area (Figure 1). The absence of real historical analyses and overviews of the area encourages our amateur musings, which nevertheless help with the refinement of our viewpoints (Koutamanis 2004b).

## 6. Design information management

The main thrust of our research into design information management has been integration: on the one hand integration of the chair in its new context and on the other integration of design computing into the wider framework of architectural and building processes (Figure 2). In many cases this amounts to an extension of established approaches and techniques to managerial tasks (Koutamanis 2002c, 2003). Through this extension we have attempted to make management approaches more operational and practical, better attuned to information production and dissemination. This leads to a clear preference for descriptive rather than proscriptive or prescriptive approaches which may be more appealing at too high strategic levels (Koutamanis 2001a).

The practical challenge of design information management is the development of systems specific to particular types of problems or activities, such as school buildings and real-estate management (Martens and Koutamanis 2003; Steijns and Koutamanis 2004, 2004). These systems give a good measure of the applicability and efficiency of the proposed methods and techniques. They also provide valuable feedback concerning the structure of existing processes, the usability of domain knowledge and possibilities for innovation. This feedback has reinforced our belief in the necessity for transition from design information management to virtual design prototyping: an integral environment for the representation, analysis and communication of form, function, behaviour and performance (Koutamanis 2002b).

## 7. Future plans

The main characteristic of the period 2000-2005 is reflection. The combination of local administrative changes and wider socio-technological developments led to a reconsideration of the roles and targets of computational design. The main conclusion is that simple computer use (even when it concerns design tools) is currently beyond the scope of the specialist. While effectiveness, reliability and performance in computer-aided design practice may be well below the envisaged level, there is no practical possibility for academic research to compete with commercial development. There are fundamental differences that work against academic research. For example, scientific publication is a slow, controlled and time-consuming process, while commercial products appear at a rapid pace and frequently in a very early version so as to claim a market share early. Quite a few commercial products rely on user feedback for final testing and further development.

This allows us to concentrate on theoretical and methodical aspects. It should be stressed, however, that practice makes little use of academic understanding of these aspects. User dissatisfaction with the current performance of computerization in practice is rising but attempts to improve performance by changing tools and approaches usually rely on introspection and empirical arguments. Academic achievements in the analysis and reformulation of domain knowledge are unknown, misunderstood or mistrusted. It turns out that considerable effort, thorough understanding of new problems and good timing are required in order to propagate computational knowledge in practice. It is also important that we try to comprehend the various dimensions of the problem, including the viewpoints of different actors: architects, managers, engineers, clients and users.

In this framework our research in 2000-2005 aimed consciously at the augmentation of theoretical foundations, the exploration of new technologies and the analysis of current computerization solutions. In particular we enjoyed the challenge of new decision-taking

approaches and techniques, the still rapid development of cognitive science, the attention paid to computerization in the social sciences and the occasional innovations in related design and engineering fields. The proliferation of mobile technologies is also refreshing, as it requires a deep reconsideration of human interaction with information and information-processing devices. Less enthralling have been the results of analyses of current computerization in architecture and building. We are still lagging behind other industries to a worrying degree. The combination of poor industrial structure and over-reliance on prescriptive and proscriptive approaches has detrimental effects on performance and domain knowledge. Moreover, the role of the designer is frequently underrated in favour of new specializations (mostly managerial), despite the central function of designing in decision-taking and information processing.

In the coming years we see little reason to change our research subjects and approach. The only exception is our hope that our analyses of computerization might lead to synthesis, i.e. redesign of existing instruments and patterns of use. We expect however that any synthesis will be local and sharply focused on specific tough problems. In general lines the planning retains the three main projects as general clusters and departures. In design technology the focus remains on technologies outside the CAAD mainstream and in particular on mobile information processing and robotics. In design methods the emphasis is on fundamental development through the exploration of cognitive subjects such as affordances and figural goodness. Group processes remain a central issue, as does representation. Dynamic aspects such as continuity and abstraction take priority, as well as computational reformulations of domain knowledge (e.g. typology).

Design information management continues to form the convergence of our research. In practice it is already in danger of becoming a superficial technology race, characterized by the usual attempts to establish an early market share with preliminary versions and a limited integration of domain knowledge. This makes integration of knowledge from as many subdomains as possible a clear research priority. The evolution of virtual design prototyping should also take into account the emerging building information standards, not from a technical viewpoint but with respect to information supply and demand from every aspect in a design process. The context of such analyses and exploration is the Group Design Room (GDR) that is currently under development. In the GDR group process support is complemented with virtual design prototyping and background domain information systems towards an integrated environment for brainstorming, communicating and benchmarking.





# Analysis and Guidance in New Design Problems

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## 1. A new design problem: changes in Dutch secondary education

One of the main pitfalls of architecture has been the tendency to reduce design problems to stereotypes and resolve them by falling back to known solutions. Examples of this tendency are abundant in the history of architecture, e.g. in the rise of both Modernism and Post-modernism. Mindless repetition, theorization and sanitization of means and ends reduces designing to proscribed results or prescribed routes that may be acceptable within a small professional domain for short periods of time but ultimately fail to appeal to the users of the built environment and reduce the respectability and the scope of the profession. We should therefore be thankful to all new design problems that arise from wider social changes and treat these problems with interest and respect, without arbitrarily and summarily reducing them to solutions we already know. The invigoration of architecture and especially of its methods and techniques relies heavily on new challenges.

One such new design problem can be found in Dutch secondary education, which has been undergoing a fundamental change as a result of the combined force of new didactic approaches combined with social and technological developments. The education provided at the end of last century no longer met the demands of the times. Knowledge gets out of date quickly; professions change and employees switch jobs all the time. Lifelong learning and adaptation to new circumstances become conditions for which pupils must be prepared especially in secondary education. The new didactic approaches are based on new ideas of learning and teaching. In essence it is about shifting from amassing knowledge to obtaining skills.

The consequences for the accommodation of Dutch secondary education have been extensive and what complicates matters is that the requirements underlying the educational change and building modification are continuously changing. The original educational changes of the 1990s as described above were initiator of a wave of new approaches to teaching and learning, as well as to new organizational concepts. Many schools are exploring and adopting new, even experimental ideas in open-ended processes of change. Such ideas have spatial requirements that deviate even further from the conventional classroom arrangement, both in terms of individual workplaces and with respect to scheduling. Finally, the necessity to modify existing buildings has also been treated as an opportunity to accommodate and anticipate future demographic changes. These influence the size and the specialization or type of a school.

Our interest in this new design problem relates to design support and guidance (Steijns and Koutamanis 2004a, 2004b). As outlined in the paper “The Chair for Computational Design in 2000-2005” (a description of the framework of the research is presented in the previous Chapter), using computer technologies for facilitating design information management is an unobtrusive way of enrich design thinking with explicit and well-structured information,

transparent and efficient communication and clear, well-founded analyses of form, behaviour and performance. Admittedly a better informed designer is not necessarily a better designer; however, we know of no other remedy for arbitrariness and conformism. It is worth noting that when confronted with the interpretation of the meaning of new problems clients and users of the built environment are keen on information and analysis and generally successful in motivating even reluctant designers to partake to an exploration of crucial details, alternative approaches and possible but unaccustomed solutions. Such explorations are also important for the evaluation of existing solutions that may serve as precedents or reference. In the case of school buildings the ongoing didactic and pedagogic changes are not the only problem: for quite some time now there have been complaints about e.g. the interior climate of classrooms or the efficiency and safety of pedestrian circulation. Still, new designs kept on reproducing the established patterns and forms thereby intensifying client / user dissatisfaction and making painfully explicit inadequacies in architectural design thinking.

## 2. Programmatic analysis

The spatial and functional requirements resulting from didactic changes in Dutch secondary education contrast sharply with the stock of existing school buildings. Most of these buildings are quite conventional in spatial terms and offer limited flexibility and transformability. Most schools therefore require extensive modifications not only when new didactic models are introduced but also in the future when these models will evolve and be refined both in theory and in practice. These modifications refer primarily to two spatial levels.

The first is local and concerns the workplaces of the students: instead of the conventional instructivist clustering around teachers in relatively large and passive groups, most new didactic approaches attempt to empower the individual student. In practical terms it means that emphasis is on the learning environment of a single student, including the possibilities for flexible transformation of individual workplaces into areas for small groups (with or without a teacher).

The second level concerns global patterns and configurations: with the emphasis on the individual and the abandonment of fixed clustering on the basis of subject matter or age / learning level, the global organization of a school building becomes less deterministic. Student movements are more intricate and variable, while the allocation of activities and users to different parts of a building is less subject to top-down regulation.

The resulting requirements for efficiency, social cohesion, acoustics, flexibility (including adaptability and transformability), security and safety are extensive and complex. Designing new school buildings and changing the existing stock ask for flexible and creative strategies which take the new demands into consideration and facilitate comparison of these demands with designs and buildings at various abstraction levels.

The first component of these new strategies is a coherent, consistent and complete description of the activities that take place in the building and of the general and specific requirements on the accommodation of these activities. In conventional briefs programmatic requirements are usually distributed into a number of complementary documents that specify behaviour and performance from different viewpoints relating to different aspects or disciplines. The modularity of conventional briefs allows for omissions, vagueness and even conflicts between different aspects. The first step towards the correlation of these aspects is a complete enumeration of stated and implicit requirements using the list of activities as a backbone.

The many and often complex activities that take place in a school building are variable in many respects, from the participants to these activities to the time and place where they occur. The new didactic approaches intensify this variability by creating more overlaps in functionality and localization. Consequently, the clustering of activities into larger groups should be flexible and adaptable. The resulting clusters should allow the analysis of programmatic problems at a higher abstraction level and support the recognition and treatment of wider issues (i.e. pertaining to larger parts or aspects of the design). This means that changes in clustering could be triggered by any party involved in the design process, including the clients and users of the school. In order to allow for changes in the primary clustering criteria (e.g. from user group to activity sort to building service type or intensity) as well as for cascades of secondary and tertiary criteria that refine and test the top-level clustering, we have implemented the brief in a relational database.

The brief database is modular, comprising a number of interconnected files. Each module contains a particular class of requirements (spatial, functional, environmental etc.) and represents a particular aspect or viewpoint of a discipline (i.e. sources and custodians of information). The connections between modules operate on the basis of individual activities. This does not imply that each module deals with each individual activity. Environmental requirements, for example, refer to types of activities, while floor area requirements relate to different classes of activities. In all cases, however, it is possible to present the complete set of specifications for a particular activity, as well as for collections of activities that share common characteristics (e.g. users, facilities or functional requirements) but may also be arbitrarily defined (e.g. a part of the building). This allows for the evaluation of consistency (i.e. that all aspects and activities are similarly specified), completeness (i.e. that all aspects are present and that all groups and clusters are similarly composed and equipped) and integration (i.e. that the specifications of different aspects are correlated and compatible or commensurate).

The choice of individual activities as the backbone of the brief database derives from an atomistic approach that allows for bottom-up abstraction and direct correspondence between design entities (e.g. spaces, building elements or wings) with programmatic requirements. These are important for continuity throughout the design process and make the brief an integral part of a responsive informational background for all actions and transactions concerning the design, evaluation and use of the built environment. The utility of the brief database can extend beyond designing, as the programmatic requirements of an activity underlie the facilities management of the space that accommodates it. In the particular case of schools, programmatic requirements and the possible clusters that emerge in the brief are also closely related to the scheduling of teaching and learning activities.

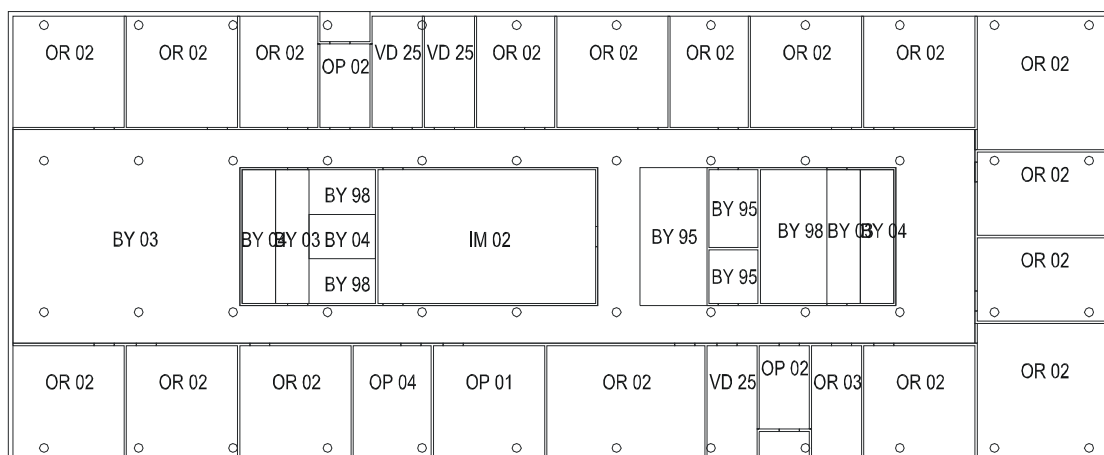
### **3. Building and stock analysis**

The integral brief used in programmatic analysis is one of the two main components of the design information system we have developed (demand). The second component (supply) consists of representations that describe a building or design and can be used for the analysis of formal and functional aspects (also with reference to the brief). Representations are structured and coherent descriptions of architectural designs. The goal is that each representation offers a complete and consistent reproduction of a number of specific aspects. The use of structured representations offers not only clarity and efficiency in the information registration and processing but also the possibility to quantify and computerize analysis. The information of every space and building element are not just interconnected, but also linked to external information. This makes it possible to automatically compare different data.

## Geometric representation

The main difference between our geometric representation and conventional floor plans lies in that each relevant entity, i.e. spatial or building element, is described uniquely by a single graphic object. This allows us to measure properties in relation to behaviour and performance (for example floor area, volume, daylighting or building cost). Each entity is annotated with reference to external information, such as the activities accommodated in a space or safety requirements. In most cases these annotations refer to other modules of the information system (Koutamanis 2003). For example, programmatic requirements are annotated to spaces through links to the brief database (described later in this paper). This makes it possible to compare for example the actual area allocated to an activity with the desired one but also to analyse complex patterns relating to global performance such as routing (Koutamanis, van Leusen and Mitossi 2001).

A small set of primary properties forms the basis for the classification of spatial and building entities into fundamental categories. These categories describe the major subdivisions of design entities, such as the load-bearing vertical elements on a specific floor level or spaces for teaching languages in a particular wing. Following the constraints of the two-dimensional representational basis, the floor levels form the initial classification property. The categories are implemented with elementary mechanisms that can be found in all CAAD systems, chiefly layers.



**Figure 1: Geometric representation (Johan de Witt College, The Hague) (Meijer and Drimmelen 1994).**

Other properties as well as most relationships between entities are implicit in the representation. These are recognized automatically only if and when needed. For example, normative evaluations of daylighting refer to the ratio of the floor area of a space to the vertical area of its openings that give on to the outside. In order to perform such evaluations, the external openings of a space are identified automatically on the basis of adjacency, measured and compared to the area of the space. The recognized relationships are explicit in evaluation reports but may also be recorded in the representation as semi-permanent properties (subject to dynamic change), especially if the recognition is cumbersome or time-consuming.

## Topological representation

The topological representation is complementary to the geometric one. By representing entities and relationships in a graph it is possible to describe explicitly relationships and patterns in the spatial and building structure. Our topological representation focuses on the spatial entities and access between them as the main relationship. The resulting access graph (Steadman 1983) forms a basis for the description and analysis of spatial articulation at a higher abstraction level, as well as of dynamic aspects such as pedestrian circulation (Koutamanis and Mitossi 1993).

Of particular importance to our work is the ability to recognize the topological structure of building types. The conventional types (corridor, hall and pavilion schools) have a clear topological basis, even though their topology is seldom described explicitly. By making it explicit we are able to study relationships between types (including the transition from one type to another) and identify the type of a building not only in whole but also in part. The latter is crucial for the study of transformation, as it helps identify typologically hybrid solutions and partial mismatches between accommodation proposals and the spatial articulation of a building.

The analytical power of the topological representation lies in its mathematical background, which facilitates transition from descriptive and qualitative statements to quantitative measurements. In addition, the abstraction of the topological level permits explicit and focused treatment of issues central to the programmatic, legal and other requirements on the building. The clarity of visualization in the topological representation also contributes to the transparent treatment of issues relating to for example type identification and analysis, matching of a design to a brief and interaction between users and the building.

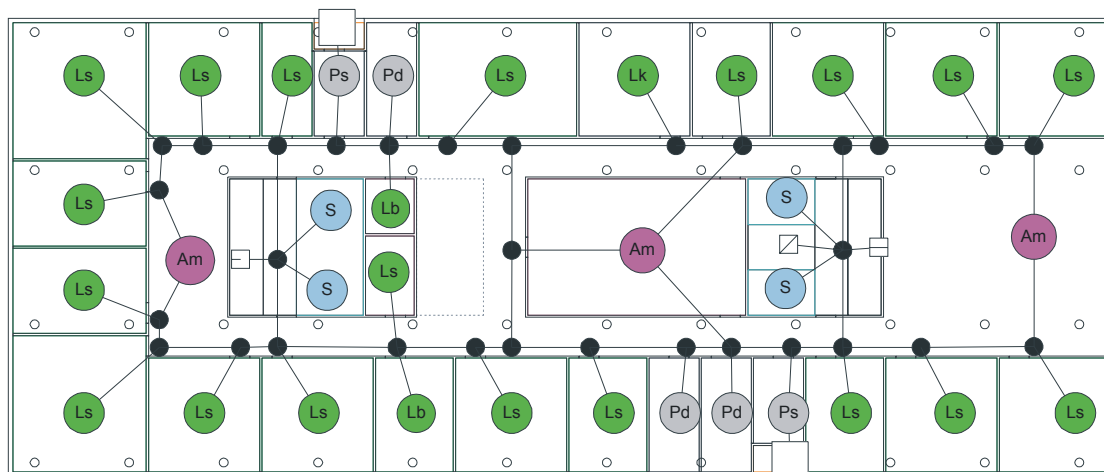


Figure 2: Topological representation of Johan de Witt College.

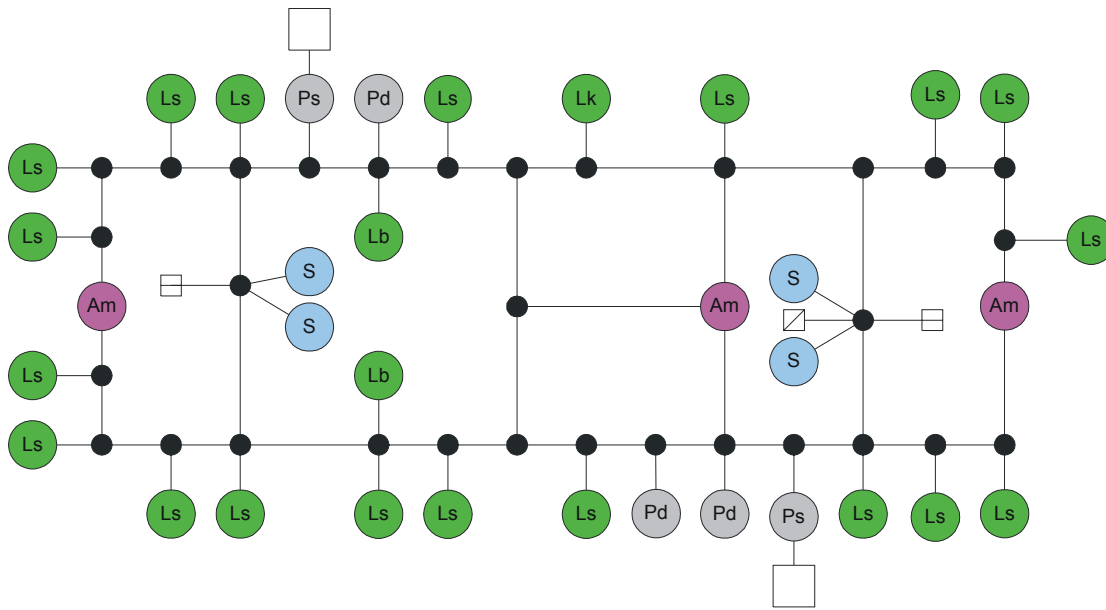


Figure 3: Normalized topological representation of Johan de Witt College.

### Zoning

The acknowledged types for Dutch secondary education buildings (corridor, hall and pavilion types) are essentially topological, as they refer to the articulation of use spaces with respect to circulation structures and features. The geometry of spaces, structures and wings appears to play a secondary role in the definition of type. One could argue that the topological structure imposes constraints for the geometric development of a design. These constraints determine the suitability of geometric forms for a particular type. We believe however that the relationship between geometry and topology in a type is more intricate than mere deterministic, directed constraining. In order to study this relationship we employ the concept of zoning by which the building is subdivided into usually fuzzy and frequently overlapping parts with a readily identifiable formal, functional and performance character. This character derives from a combination of constraints, ranging from building structure and suitability to particular uses to geometric arrangement and circulation organization. The resulting zones integrate geometric, topological and functional characteristics into subdivisions of a building that frequently play a prominent role in a study of possible transformations.

In the case of Dutch secondary education school buildings we employ a basic zoning scheme consisting of three main type zones. The first is the *use zone*, consisting of spaces for the primary uses in the building. In school building this encompasses most classrooms, offices and study areas. The second type is the *circulation zone*, comprising both vertical and horizontal circulation facilities and spaces. The third one is the *service zone*, usually the most fixed part of the building with the least flexibility and adaptability. The circulation and use zones are normally more flexible and offer possibilities for transformation limited chiefly by the construction and external envelope of the building.

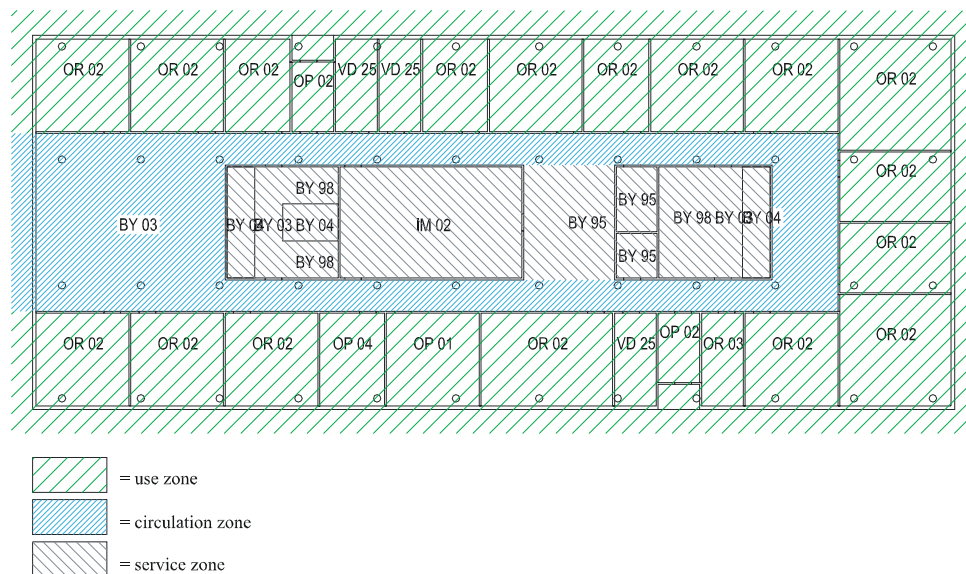


Figure 4: Zones in the Johan de Witt College.

The three zone types may be present in a building in a number of patterns that are closely linked to building type. For example, a three-zone pattern such as *use – circulation – service* is characteristic of the corridor type. A five-zone pattern such as *use – circulation – service – circulation – use* is common in buildings of the hall type.

#### 4. Automating analysis

A primary advantage of structured representations is that they make explicit specific aspects of a building, thereby providing a sound foundation for automating design analysis. An example of this is the analysis of routing in pedestrian circulation – a main issue in school efficiency and safety. Mapping a route from A to B involves identifying the spaces that must be transgressed after leaving A so as to arrive at B. In our representation A and B are by definition spaces and the route that connects the two a sequence of other spaces and doors or other elements permitting human access. Such sequences are subgraphs of the topological representation (Figure 5).

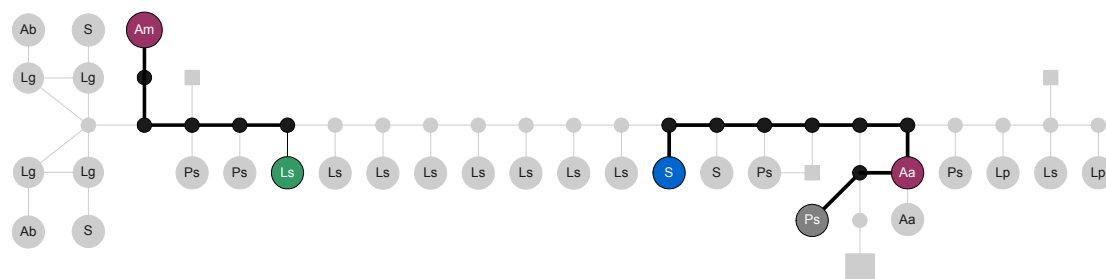


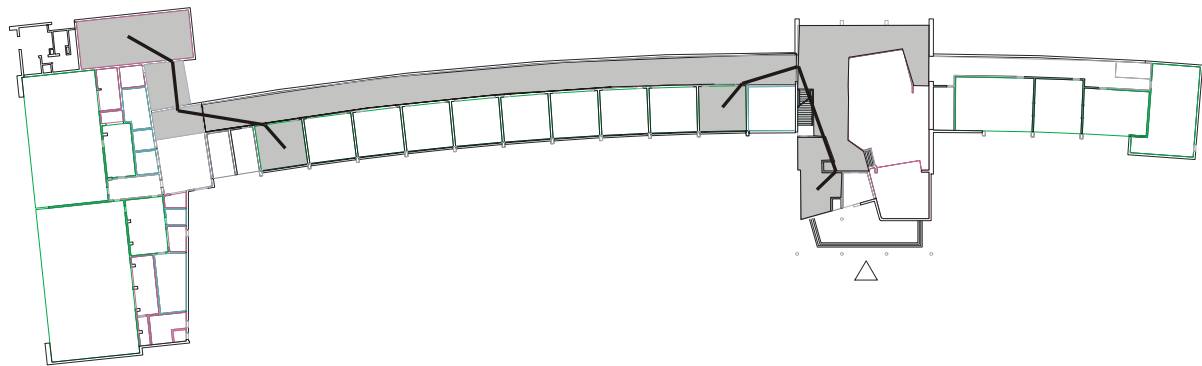
Figure 5: Routes in the topological representation.

The topological representation of a route connects the pedestrian circulation with the global spatial structure of the building. It offers a useful overview of all traffic patterns and the concentration of flows in critical parts of the circulation network. When more flows converge at the same corridor we can expect safety hazards, as well as possibilities for social interaction. This means that this corridor requires particular attention in the design and use of the building.



The depth of the topological representation (the number of nodes in the sub graph) is an indication of the complexity and psychological length of the route. Walking through a large number of connected spaces and doors to get from A to B mostly has a negative perception, even if the actual length of the route is relatively short.

The topological representation of a route can be automatically converted into a geometric one. This can be useful for example in analyses of fire safety. A direct comparison between entities in the geometric and topological representation means that every element in one representation is dynamically coupled to an element in the other: properties and patterns are translated from one representation to the other. This also applies to route patterns which are registered in the topological representation. The spaces and doors which are indicated by nodes and links of a route subgraph form the basis for the geometric description of the route (Figure 6). This description indicates the exact form of the route in space and can be used for the calculation of egress time in fire safety analyses (Koutamanis 1995; Koutamanis, van Leusen and Mitossi 2001).

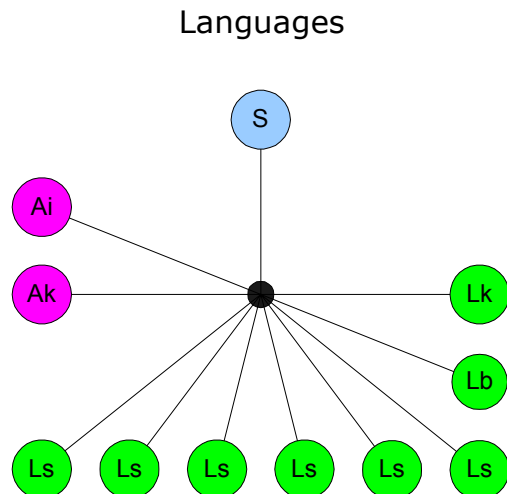


**Figure 6: Routes in the geometric representation.**

## 5. Topological representation of programmatic requirements

The topological representation of programmatic requirements is generated automatically from the brief database. Each activity and each (sub)cluster is defined by a node and each access relationship and the belongingness to a cluster is defined by a link between these nodes. This permits direct comparison between the brief with a floor plan both visually and mathematically. This comparison makes local and global problems explicit in the accommodation of a brief in a building.

The main difference with the topological representation of a building is that the topological representation of programmatic requirements does not normally contain circulation spaces. In the case of the building access graph these form the connecting tissue between the spaces. As a brief normally indicates circulation space as a mere percentage of the total floor area, the connecting tissue in the brief graph consists of abstract, cumulative objects that indicate the clustering relationship. This simplifies the matching of the graphs as it permits identification of subgraphs on the basis of stated clustering criteria.



**Figure 7: Topological representation of programmatic requirements for a cluster** ( $S$  = bathroom,  $L_s$  = classroom,  $L_b$  = storage,  $L_k$  = office,  $A_i$  = individual workspace,  $A_k$  = group work space).

Each node in this representation is annotated by means of dynamic linking with the corresponding activity in the brief database where they become properties of the node. Changes in the brief database are automatically propagated to the topological representation either as changes to the properties or as structural rearrangements of the graph (re-clustering).

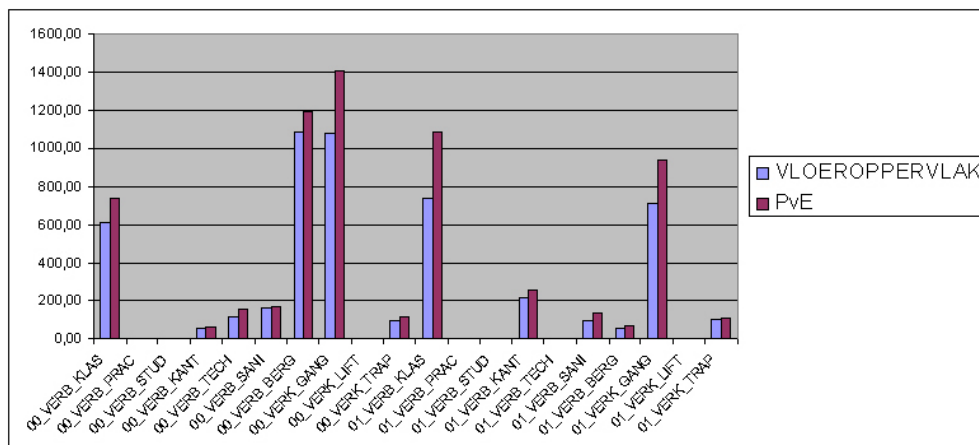
## 6. Design information management

The information systems and representations described so far represent independent modules that cater for specific aspects. Our assumption is that each module represents the subdomain of a particular discipline and can therefore be applied for the registration and communication of decisions taken by this discipline. By linking the different modules with each other we form a consistent system that makes possible the exploration of the total problem from all viewpoints. By means of the dynamic linking between the different modules the system remains automatically up to date and supports meaningful interaction between disciplines and aspects, including initiating analyses and suggesting alternatives.

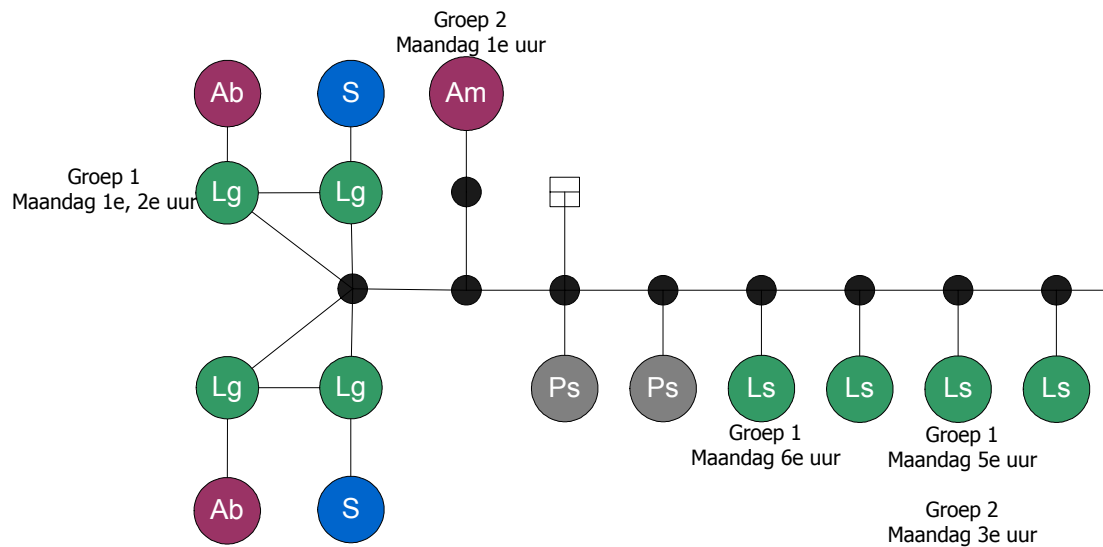
An example of a basic analysis that involves more than one module of the system and which can be performed automatically is the analysis of floor areas, both in comparison with the brief and with respect to general rules and regulations (Mitossi and Koutamanis 1998). Such analyses may seem trivial but in reality they are time consuming and often very inaccurate, despite their significance for the design process: they form the basis for e.g. cost estimations and the departure for modifications of e.g. the circulation network of a building or underlying grids (if a design is judged to be extravagant or miserly in the allocation of space to particular activities). Information derived from the geometric representation and combined with the brief database or with external guidelines provides a fast, accurate and reliable floor area analysis at any moment in the design process and without any effort on the part of the users.

**Table 1: Floor area analysis (comparison with brief).**

Category	Number	Floor area	Brief	Difference
00_verb_klas	13	610,01	738	-127,99
00_verb_prac	0	0,00	0	0,00
00_verb_stud	0	0,00	0	0,00
00_verb_kant	6	56,00	65	-9,00
00_verb_tech	3	116,99	154	-37,01
00_verb_sani	5	157,56	174	-16,44
00_verk_gang	15	1083,75	1192	-108,25
00_verk_lift	10	1078,82	1402	-323,18
00_verk_trap	0	0,00	0	0,00
01_verb_klas	7	93,42	114	-20,58
01_verb_prac	13	743,49	1085	-341,51
01_verb_stud	0	0,00	0	0,00
01_verb_kant	0	0,00	0	0,00
01_verb_tech	10	214,81	255	-40,19
01_verb_sani	0	0,00	0	0,00
01_verb_berg	10	92,56	135	-42,44
01_verk_gang	7	53,72	70	-16,28
01_verk_lift	8	711,27	938	-226,73
01_verk_trap	0	0,00	0	0,00

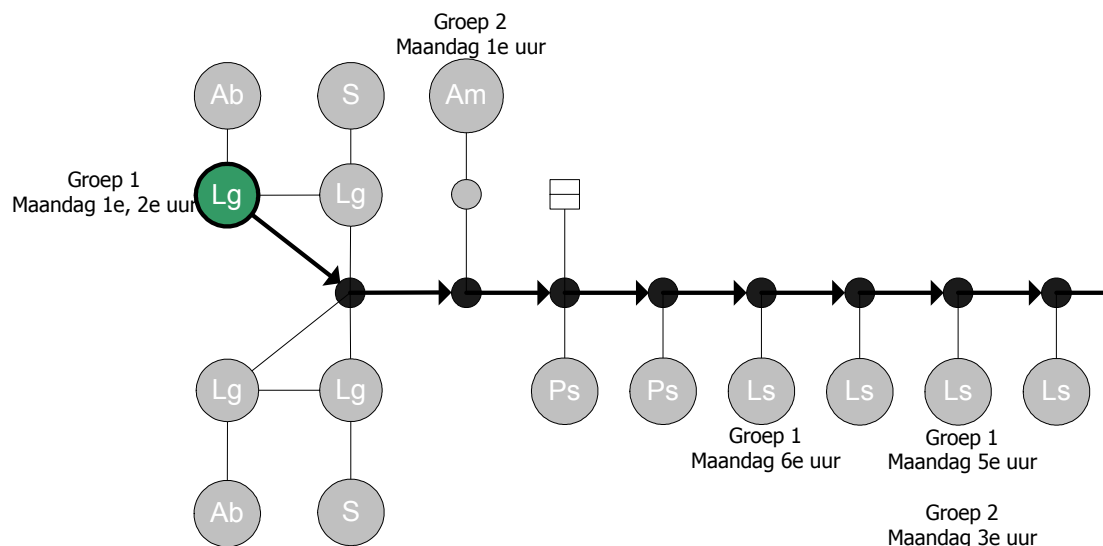
**Figure 8: Floor area analysis (comparison with brief).**

More advanced analyses relate to projected patterns of use. For example, every serious implementation of new didactic approaches inevitably challenges the way such patterns are regulated by hourly time schedules in conventional schools. The hourly basis is frequently abandoned in favour of longer periods that can extend up to two months. The exploration of the spatial possibilities and consequences of different types of schedules can be supported by the combination of programmatic information with the topological representation of the building. This representation is suitable for the representation and evaluation of static and dynamic patterns, i.e. the allocation of activities to spaces and the communication and traffic patterns that emerge as students and teachers move from one space to the other. Static effects are directly visible when the topological representation is annotated with relevant information from the brief (Figure 9).

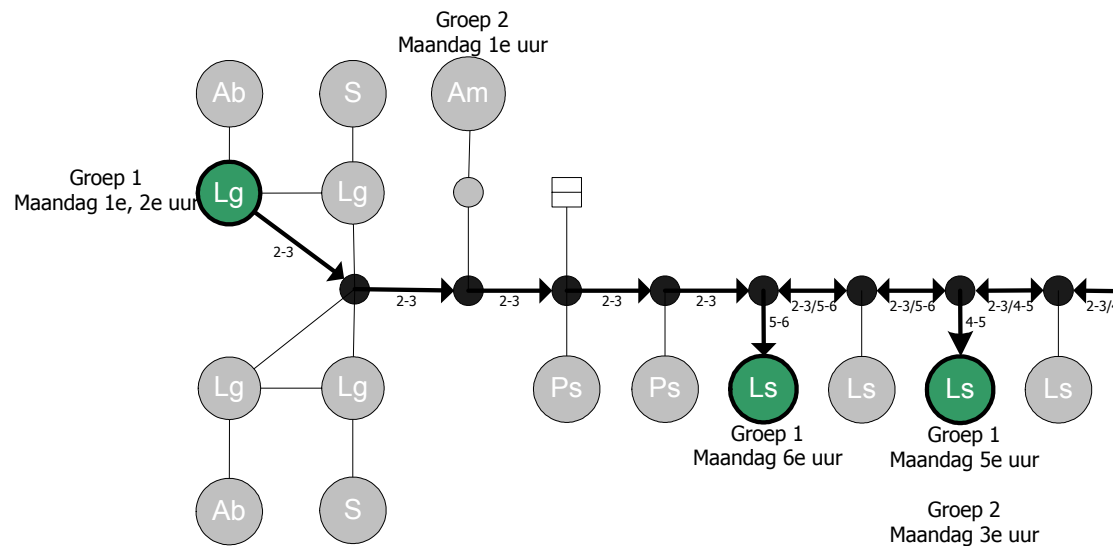


**Figure 9: Scheduling in the topological representation.**

This depiction of activity allocation can indicate a single time unit (hour, day, week) for one group of users (specific teachers or students) or cumulative (all users and all activities in a single time unit or all activities of one group for a longer period). This makes it possible to visualize and measure both the occupancy of the different spaces and the spread of activities. The subgraphs that depict the activities of a specific user group also form the basis for the analysis of dynamic circulation patterns. These patterns may refer to a particular movement (Figure 10) or to a cumulative representation over a period of time for one or more user groups (Figure 11).



**Figure 10: Traffic pattern of one user group in the topological representation.**



**Figure 11: Cumulative image of the schedule of one user group.**

Such analyses enrich the programmatic and design stages with the ability to make reliable projections of behaviour and performance and refine a design accordingly. Arguably more significant is that they are co-productions of different modules and hence common explorations of at least several parties that take part in a design process. In our system each party retains its self-sufficiency and responsibility for a part of aspect of the design, but at the same time it is offered connectivity to the others and through this the possibility of a global view of the design problem. This may not be high among the priorities in a common, predictable problem, but having to deal with a new problem with unknown or uncertain outcomes is generally seen as a valid reason for investing in the additional effort and organization.

## 7. Continuity

The educational system is continuously changing and a school building will have to anticipate all the time. By dynamically linking the integral brief to the building representation we can anticipate future didactic or logistic changes. This ensures continuity of demand-to-supply matching throughout the lifecycle of the building, including facility management, scheduling and minor or local building adaptations. The permanent focus of continuity is the registration of building behaviour and performance and re-evaluation of principles and solutions. The corollaries of that include:

- A better understanding of the effects of design decisions at many abstraction levels: evaluation of the accommodation of activities in a space reflects on the form of the space, its energy and climatic performance, the form and positioning of critical elements such as doors and windows, finishing (e.g. for acoustics and maintenance), the structure of the building (e.g. with respect to adaptability), etc.
- The ability to improve a building incrementally through either planned interventions or self-regulation: being able to discern differences between the projected and the actual behaviour and performance, to identify possible causes and test scenarios for the solution of problems makes designing and building permanent, dynamic activities.

- The necessity to maintain and augment information from the design process throughout the lifecycle of a building: information used in the brief and the design process re-emerges later not only in construction but also in the use of the building. We can understand better why and how a problem emerges in use if we keep trace of how relevant programmatic requirements evolved during the lifecycle and how correspond design decisions were made, implemented and finally understood by the users. Reversely and in true cyclic fashion, collecting and evaluating information on the relationship between user requirements and a building is a main source of knowledge for briefing and designing.
- The tools used for managing information remain essentially unchanged throughout the lifecycle: for example, the way we integrate information in briefing and connected with a design is also applicable to the correlation between user requirements and resources in facility management.

## 8. Discussion

Using design information management as a vehicle for design analysis and guidance is a powerful yet unobtrusive manner of promoting communication and integration, making issues explicit, utilizing participation and supporting continuity. The main prerequisites are two. The first relates to the main participants such as the architect and the client: commitment to developing, using and maintaining extensive interconnected information systems should be coupled to clear incentives and substantial benefits. This often means that the design problem should have a degree of complexity and difficulty that makes stereotypical solutions and processes less attractive as an easy way out. The second prerequisite relates to the tools and the underlying approach: proscriptive and prescriptive techniques which rely on acceptance of a frequently alien way of thinking and working offer little common ground with the interests and habits of the users and few guarantees for adequate performance beyond a generally small scope. Descriptive approaches fare better, provided they are effective in delivering insightful and comprehensive analyses of design information. Similarly, the tools that support information management should build on a thorough understanding of conventional processes and representations that allows us to retain their strong points, as well as identify and justify the introduction of new elements that improve on the weak points.



# The ID-StudioLab 2000-2005

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## 1. Introduction

In 1999 four research groups at the Faculty of Industrial Design Engineering of Delft University of Technology joined their forces in forming the ID-StudioLab, a multidisciplinary research community that aims to acquire and integrate knowledge on products, people, technology and context in order to support designers in creating conditions for meaningful and satisfactory product experiences. Traditionally, products have been designed for aesthetic appeal (aesthetics-driven), usability (ergonomics-driven), and/or for smart functions and possibilities (technology-driven). Well-designed as these qualities may be, they do not automatically lead to favored experiences on the part of the user. Identifying what these experiences should be, how they come about and, subsequently, taking them as starting points for further development radically reshapes the face of both design practice and design research.

The need for such a different approach has become more salient with new technologies and phenomena, such as digital photography, instant messaging and ambient intelligence which enable product designers to design products of seemingly ever increasing functionality and complexity. Knowing what users really want, what their dreams and wishes are, when they get lost, bored, surprised, excited etc, thus is essential for designers who have to translate and integrate all these technologies into meaningful products. To acquire this knowledge users could be involved into the early stages of the actual design process. Moreover, designers also have to manage the assimilation of new technologies into their own working practices. Design information is becoming more and more digital, allowing for fast transfer, flawless duplication, easy modification etc., which makes the design process more complex to manage, but also opens up opportunities for the development of new design support systems and tools.

In order to support the design community with these issues, the ID-StudioLab has taken product-user experiences and the role of the designer in creating these, as its research focus. This implies an integrated type of design research, not just regarding content, but also regarding the way the research is conducted.

In its first five years of existence the ID-StudioLab has established itself as an inspiring and leading research lab in the area of human-product interaction, as reflected through several projects, publications, dissertations, workshops and prototypes. Now, five years after its initiation, this paper presents a flashback of the past period as well as a flashforward of things to come. It describes the objectives of the ID-StudioLab and how these are translated into a specific research approach. Four research themes are described, each illustrated with examples of current Ph.D. projects. The paper ends with a reflection on five years of ID-StudioLab and its future.



## 2. Research approach and organization

The research approach advocated throughout the ID-StudioLab is a merger of design and research driven ways of working. It is felt that to fully come into contact with, understand and create product experiences the researcher should be actively involved in designing instead of positioning himself purely as an outside observer. To meet this requirement, product and interface designers, psychologists, physicists and other specialists in the field of ergonomics and human-computer interaction, work together in integrated design and research teams.

Furthermore the design researcher must have an eye for the full experience of the user, which not only covers the often studied perceptual-motor and cognitive skills of the user, but also emotional reactions. 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. Building working prototypes of products, experimental stimuli and design tools that are rich in experiential and aesthetic quality is therefore an essential element to this approach. These prototypes with design variables are then tested in real contexts, resulting in the generation of new design knowledge as well as the refinement of research issues.

Thus the objectives of the ID-StudioLab are reflected in the following three ingredients which ideally are present in each ID-StudioLab-project, although this ideal is not always feasible due to the specific character of some of the projects:

1. *SEARCH*ing knowledge and theories, both as input to designing and building, but also as a way of generalizing findings to other applications and disciplines in the realm of user experience.
2. *BUILD*ing experiential prototypes as a method of integrating, realizing, confronting and evaluating, to give flesh to theory, to generate knowledge, to empower. These prototypes are used as research instruments in tests and experiments, resulting in the generation of new design knowledge as well as the refinement of research issues.
3. *DESIGN*ing products with a focus on the user experience, which involves studying work in context in off-site locations e.g. user homes or in context labs.

To enable such multifaceted projects an infrastructure was created to bring researchers and designers of different disciplines together, both in terms of organisation, by having them work together on one of more projects and in terms of location, by putting them together into the same place. In one large space a design studio atmosphere was created, in which researchers, designers, engineers, psychologist etc. sit side by side, thus creating a constant, yet informal awareness of each other's activities. Besides mixing people of different disciplines this space also equips people of different levels of expertise, such as senior researchers, Ph.D. students and Master students working on their final project. Hence the name of this room: StudioMingle (Figure 1).

StudioMingle includes a technical facility, which supports the building of both software and hardware prototypes. Using tools such as Director and Max as well as sensors and other hardware equipment, working prototypes of high quality can be created. These prototypes are placed in StudioMingle, to serve as demonstrators for people coming from outside, but also, and perhaps more importantly, provide a hands-on feel of work, thus evoking feedback and design input from the whole ID-StudioLab community.

Although StudioMingle is the physical core of the ID-StudioLab, most of its members are not located in the space. However, by organizing workshops, lectures, visits etc. in which the entire community is involved, a constant flow of knowledge and ideas is facilitated which goes

beyond the walls of StudioMingle. In addition to research-related activities, more informal events are also organized, such as a monthly “design lunch.”

Another ID-StudioLab facility is StudioHome, a large room which has been turned into a living room to conduct research projects focused on interactive home products (Figure 1). Opened in 2003 the lab equipped with a custom built high speed two-way wireless network which enables products to be linked with each other, while offering centralized and decentralized user control of products.

To date StudioHome has supported research conducted as part of the Senter sponsored, Residential Gateway Environment project and more recently is being used to support research for the Bsik program on Smart Surroundings as well as for numerous internal internships, masters level education, industry sponsored work and PhD projects.



**Figure 1: Studio Mingle (left) and Studio Home.**

Studies in StudioHome have begun to consider the design consequences for creating user-system interaction given some level of system awareness of user activities. To this extent a localization system in the lab, together with staff from TU Delft EWI is being developed. Work is also now being initiated in the lab in the area of well-being and home, given the recent shift in application focus in industry research from consumer electronic towards products for personal health care and wellness.

StudioHome has been found to be a useful bridging resource, where by explorative studies in users home can be combined with controlled lab studies. For example studies were conducted with users in their homes to determine what type of atmospheres they would like to have in their living rooms. Physical objects and media from the home were then brought into the lab and used to create a customized content and a familiar physical living room setting. Where possible, furniture in the lab was also moved to match the user’s home layout. Furthermore, through this approach contrasts in controlling an interface with initial start content versus a system with familiar user content could be compared.

In addition to these two main studios a number of small rooms have been dedicated to specific activities, such as reading and writing or light design work like making collages or foam models.

### 3. Research themes

Regarding content, four research themes have been defined within the ID-StudioLab, which all are concerned with relations between people (both users and designers), products and technologies within certain contexts, each however from a different perspective: Designing for the Senses, Design and Emotion, Intelligence in Products and Inspiration Engineering.

Designing for the Senses aims at gathering knowledge about perceptual processes that will enrich human-product interaction by broadening the sensorial scope of interaction. While basic visual processes have been widely studied under controlled laboratory conditions, little is known about other sense modalities and about how people perceive everyday products. Example projects: Gestural Design Tools by Caroline Hummels (Hummels 2000); The Aesthetics of Touch by Marieke Sonneveld (Sonneveld 2004); Sensory Dominance in Product Design by Jacco Otten; Surprise in Product Design by Geke Ludden (Ludden et al. 2004), Verbal Attributes of Product Sound Design by Elif Özcan (Özcan and van Egmond 2004).

Design and Emotion investigates what critical factors of human-product interaction contribute to an emotional experience. One can feel happy about the car that functions properly, aesthetically pleased by the gentle curve of a mobile telephone, proud of possessing a particular necklace, feel indignant because the intelligent product used seems to have a (stupid) mind of its own, and angry because the drawer makes a grating sound. Although there is some insight in these critical factors of emotion elicitation, more research is needed to understand how emotions arise from, develop during, and subsequently affect the perception of products and the interaction and relationship between user and product. In the quest for emotionally intelligent products and systems, such an understanding is inevitable. More and more, products, from toys to refrigerators and computers, are provided with built-in intelligence to adapt to user behaviour in order to make product use easier or more pleasant. Example projects: Designing Emotions by Pieter Desmet (Desmet 2002); Affective sustainability: Towards a model of long term consumer-product relationships by Rick Schifferstein (Schifferstein 2004); Embodiment in the Experience of Design by Thomas van Rompay (van Rompay et al. in press).

Intelligence in Products aims at establishing ways in which a product may increase the ease with which a user communicates with a product, e.g. the product's ability to elicit, understand and reflect user intentions. Research work is driven by empirical studies combined with concepts and prototypes. Results are considered in terms of the overall user experience and quality of interaction as compared to existing products. Human-product communication design concepts are sought which are as far reaching as possible, towards exploring new paradigms of user-product interaction. From a hedonic and ergonomic perspective natural and integral paradigms of human-product interaction are being explored. Combined with natural interaction, research focuses on how embedded intelligence can enable task-level communication with the user, thus reducing the amount of mental effort required when interacting with a product. Example projects: Designing collaborative consumer products by Elyon Dekoven (Dekoven 2004); Designing for the intensive care nursing process by Marijke Melles (Melles et al. 2004); Designing Pleasurable Multimodal Interfaces by Marco Rozendaal; Situated Preferences in Aware Environments by Martijn Vastenburg (Vastenburg 2004); Affective Tangible Interaction Towards Stress Reduction by Miguel Bruns Alonso (Bruns, Alonso and Keyson 2005); StudioHome (Keyson et al. 2004).

Inspiration Engineering focuses on the development of tools and techniques for designers and design teams to support idea generation, integration and communication in the early phases of design. Computer technology plays an important part in (1) realizing dynamic and interactive tools for expression, communication, experience, and inspiration, (2) bridging the gap to later phases in the design process, where stricter verbal-representational modes of computer use are the dominant tools. Currently, however, computers are rarely used in the early phases of design, because their user interfaces hinder, rather than support, idea generation and creative activity.

Research in Inspiration Engineering draws on the other research lines for theories, models, and techniques on *what* knowledge the members of the design team need to share in order to design for emotion, perception, or cognition. In cooperation with those research lines this research work aims at building knowledge and methods on *how* integration of required design knowledge in the design process can be supported. This 'how' question is treated within the overlapping theoretical frameworks on design methodology and creativity theory, and by considering the perceptual-, motor-, and cognitive- skills in designer-tool interaction as a special case of human-product interaction. Example projects: Designer Interaction with Informal Collections of Visual Material by Ianus Keller (Keller et al. 2004b); Designing with Precedents by Gert Pasman (Pasman 2003); Communicating User Experience by Froukje Sleeswijk Visser (Sleeswijk Visser et al. 2004); Exploring Materials: Mixed Media in Design Tools by Daniel Saakes (Saakes and Stappers 2003).

#### 4. Example Projects

In this section four Ph.D. projects currently running in the ID-StudioLab, will be highlighted. Each project is carried out within one of the research themes, but the ingredients of building, searching, and designing are present in each of these projects.

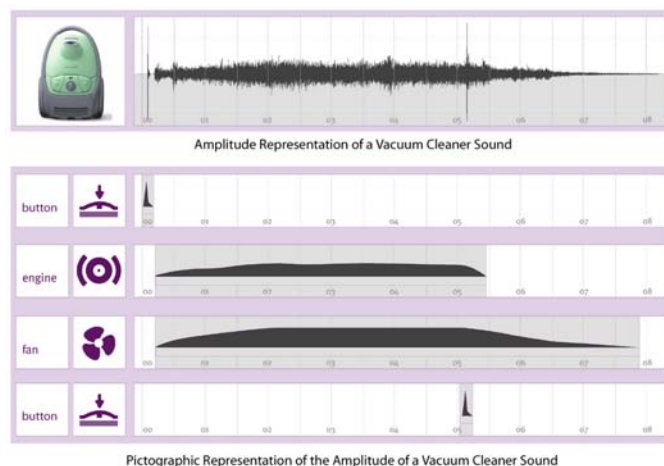
##### **Product Sound Perception and Its Implications on Verbal and Visual Communication, Elif Özcan**

Sound is an inevitable consequence of operating a product and users are confronted with it each time they interact with a product. It is interesting to see how users benefit from product sounds. A product sound *warns* (low battery of a toothbrush), *alerts* (finish-beep of an oven), *supplies feedback* (key-stroke of a keyboard), *triggers reasoning* (malfunctioning engine), *influences the mood* of a listener (creepy epilator), *informs* (coffee ready in 30 sec), *conveys* brand values (Plop! Grolsch beer bottle), and etc. These examples exhibit a great deal of interactivity between a user and an emitted product sound. They also indicate that a generated sound is a functional feature of a product rather than a consequential event in product usage and it should be taken into consideration for the total design of a product. In this sense Özcan's main aim of her Ph.D. project is to provide designers with fundamental knowledge on how users perceive product sounds, and subsequently, to create a systematic verbal and visual language to support the communication of product sounds among the multidisciplinary design team.

As a first step, the main domain of product sounds was investigated through free categorization and labeling tasks. Afterwards, semantic associations of product sounds were investigated by a series of verbal attributes rating tasks. Finally, all these findings were gathered within a perceptual framework that describes the identification process of product sounds (Özcan, van Egmond, and Jacobs, submitted 2005a). In this framework three main consecutive stages (i.e. perception, recognition, and identification) constitute the product sound identification process which results in three levels of outputs: descriptions of structural, emotional, and

acoustical properties (no recognition); location and/or action description (recognition with loose associations); sound source description (perfect identification).

This framework makes it easier for designers to overview the verbal language that the listeners use during their interaction with sound generating products (Özcan and van Egmond 2005b). However, despite of the support of the framework, designers might fail in the communication of product sounds to the other designers, engineers, marketers, etc. during the design process of a product. This research also explores the suggestion that product sounds are not represented by a unique way in a user's mind. Therefore, Özcan (Özcan and van Egmond 2004) has designed a visual language which describes product sounds using the pictograms of the possible associative meanings of a product sound (Figure 2).



**Figure 2: Pictographic representation of a product sound.**

In this example, a vacuum cleaner is decomposed into its parts that generate sound (e.g. button, engine, and fan). The pictograms, which represent the sounds of these parts, are attached to the physical property of the sound (i.e. amplitude). The figure depicts four separate sound events, which start and end at different points at the time line.

The philosophy of this pictographic language stems from the knowledge coming from the ‘research’ into the perception of the product sounds. Some effort has already been put into the ‘design’ of the pictograms as well, however, to create a systematic language more research into the visual communication area is needed, and consequently the design of the language has to be finalized. In addition, this systematic language should be accessible for the design team. Therefore, it has to be ‘built’ and implemented as a software application to provide a dynamic information flow. Ultimately, the validity of the created language and its implementation as a software application needs to be tested in international product design offices.

### **Product Surprises, Geke Ludden**

When perceiving an object, people usually perceive information through more than one modality. The information perceived through different modalities may conflict, which can result in a surprise reaction. The Ph.D. project of Geke Ludden focuses on how product experience and evaluation is affected by incongruity between the inputs derived from various modalities. How can a designer evoke a desirable user reaction by designing incongruent sensory information that leads to surprise?

The research builds on theories in experimental psychology and emotion theory. These theories (in particular, theory on design strategies that can be used to design surprising products) will be used to design products and build prototypes that can be used as stimuli in future experiments within this project. In this way, reflection on and evaluation of our theory on designing surprising products can take place, gaining further insight into users' evaluation of sensory incongruities in products. So far, products designed by designers in the field have been used as stimuli. Therefore, it is not certain whether these products were all designed with a focus on the user experience. However, first results from interviews with designers of surprising products indicate that these designers aim to design products that provide 'new experiences.'

Stimuli are used that convey different messages through different modalities. Experiments have been carried out with stimuli that had either visual – tactual incongruities or visual – olfactory incongruities. Other combinations of modalities will be used in future experiments. The experiments typically use the following procedure: subjects first experience a product through one modality (e.g. vision) and consecutively experience the product through another modality (e.g. touch). Users' reaction to the perceived incongruity is measured in terms of emotional responses (i.e. surprise, disappointment, annoyance) and aesthetic appreciation (i.e. pleasantness, interest). Both self reports (e.g. questionnaires and drawing of Time-Intensity curves) and behavioral measures (e.g. analysis of exploratory behavior and facial expression) are being used.

Within the set of products with visual – tactual incongruities, two types of surprising products are distinguished based on the certainty of the expectation users have about how the product will feel. Figure 3 shows examples of products in both types. The vase on the left is surprising because it looks unfamiliar, an observer may have the uncertain expectation that it is soft. The vase is however made of ceramics, a hard material. The vase on the right is surprising because it looks exactly like a crystal vase, an observer will be certain that it feels heavy. However, it feels much lighter than expected because it is made out of plastic. Different design strategies seem to lie at the basis of these different types of surprises in products. For products with visual – tactual incongruities, as well as for products with visual – olfactory incongruities, users' evaluation of the experienced surprises is mostly positive.



**Figure 3: Vases with visual - tactual incongruities used as stimuli. Designs by Hella Jongerius and an unknown designer.**



### **Cabinet, a collecting tool for designers, Ianus Keller**

Designers collect and surround themselves with all kinds of rich visual material from advertisements and magazines. These materials are traditionally used in the conceptual phase of design to make collages or moodboards, which is on the one hand a way to map form and attributes to the atmosphere or context of use, and on the other hand a way to communicate the design direction to a client.

Though the use of computer tools has increased dramatically in the design process, there has been hardly any development in specific tools for collecting images and making collages. New media tools provide dramatic possibilities in image manipulation (e.g. Photoshop) and the storage and digitization of images has enabled us to fill huge libraries of image data (e.g. Getty Images), yet the tools offer no real way of expressively selecting the right images and making collages that help communicate the design vision. Current software tools for keeping collections of digital images either use an extreme verbal, database approach or they simply provide an optimized interface to the images on your hard disk using the powerful optimized “thumbnail grid”. These latter applications organize the images on data that the computer understands, either sorting the images by name or by date. The whole point of making collages is to create categorizations that offer new insights and allow for interpretation in the design process.

As part of his Ph.D. project Ianus Keller therefore developed the Cabinet (Figure 4), a dedicated device designed specifically to support designers in collecting, organizing and communicating visual material in the conceptual phase of their design process. Cabinet aims to bridge the digital-physical divide allowing designers to collect both real pictures and objects and digital imagery in one place. It combines image capturing and organizing facilities into one physical setup, allowing for a rich interaction which can inspire designers while generating new concepts.



**Figure 4: The Cabinet, developed by Ianus Keller.**

The Cabinet has been built as a one-off experimental working prototype. It consists of a table sized work area on which digital images are projected through a beamer. The light of the beamer is mirrored in the overhead mirror and above the mirror a digital camera is positioned aiming at the projection surface. Below the projection surface a touch sensitive tablet can measure the movements and interactions done with a pen-like input device. All the elements are controlled by a Macromedia Director application running on a portable computer stored below the table.

To get the process of collecting on the surface and to find out how new media tools can enhance this interaction, Cabinet was set out at three design firms for an extensive period of time. Over a period of four weeks, designers were asked to use Cabinet in their current design projects with instructions on how Cabinet worked. Designers were invited to integrate Cabinet in their work process as they seemed fit. Three designers at well-known Dutch design firms WAAC's, Fabrique and Smool have used Cabinet. Through experimental sessions at their workplace, evaluative interviews and analysis of logfiles the importance of collecting visual material in the design process and the possibilities of spatial layout and composition in offering a solution space were made apparent.

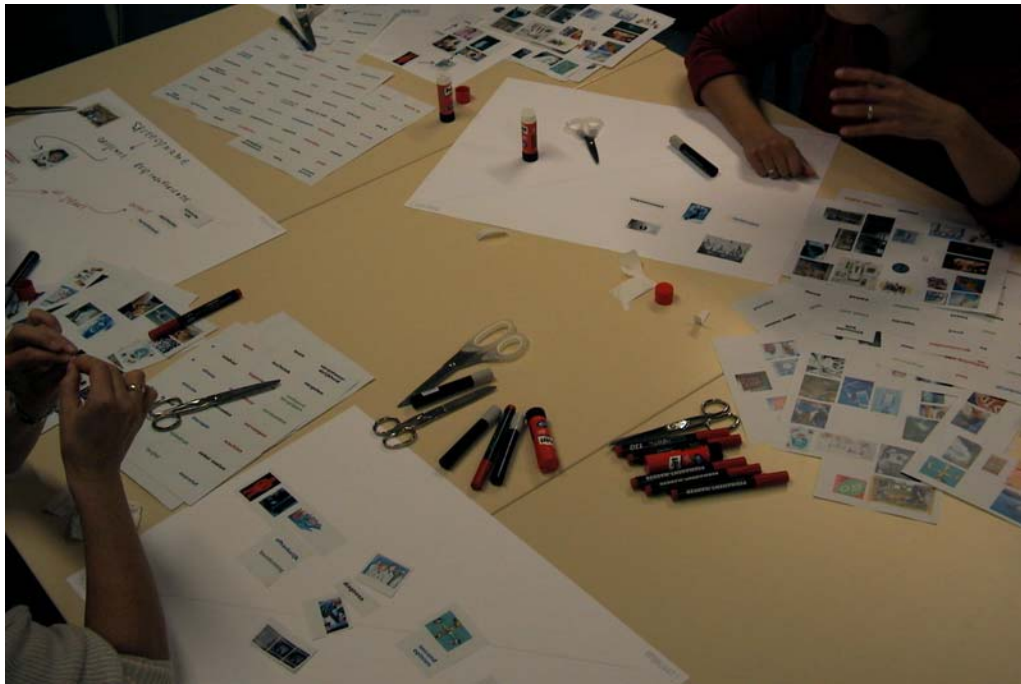
### **Designing for the intensive care nursing process, Marijke Melles**

Advances in technology have opened up a vast amount of opportunities for developers of intensive care equipment. Examples include equipment which autonomously adjusts its settings to the altering condition of the patient, or interfaces which can adapt to the nurse's level of experience. Despite the opportunities, new applications do not always seem to match the actual work situation at an intensive care unit. Current systems, for example, present the user with an ever increasing amount of patient-related data without respecting the cognitive limits of the intensive care personnel, or autonomously take actions conflicting with the specific working methods of the nurse. Developers of current systems do not always seem to be adequately aware of the delicate complexity of the work processes involved at an intensive care unit.

The basic assumption of this study is that in order to effectively apply technological innovations in the intensive care unit designers should start from the entire set of work processes involved. The aim of Melles' investigation is therefore to envision how, from a contextual user's perspective, the nursing process can be enhanced by means of future technology. The results of this study are insights into the intensive care nursing process and a design approach implemented as a design proposal and a prototype.

Initial insights into the intensive care nursing process were acquired through observations at a range of intensive care units and interviews with intensive care personnel. Then, in order to get a more precise view of the user needs and requirements regarding intensive care nursing, this research was augmented with methods aiming to make the tacit knowledge of users more accessible (Melles and Freudenthal 2003). For example, during participative sessions nurses were asked to create collages visualizing several topics and to then discuss them (Figure 5). In this way insights were revealed regarding contextual influences affecting nursing routines (e.g. the composition of the nursing team, questions of trainees) and work-related emotional values (e.g. the importance of humour as stress reliever, the attractiveness of the unpredictable character of an intensive care unit). In addition several user needs were identified and classified.





**Figure 5: Making collages in participatory sessions.**

Based on the insights acquired a computer-based tool has been designed (Melles et al. 2004). Point of departure of our design was that it respects the three different roles an intensive care nurse fulfils; nurse, expert and human being. In each role, the same situation is approached from an entirely different point of view, requiring completely different information. This tool should provide the nurse, being a nurse, with more insight into her actual work process by providing contextual information about her work environment which is needed to assess the current situation and also anticipate future actions. Additionally, this tool should provide the nurse, being an expert in intensive care nursing, with the information required to reflect on and learn from her actions and those of others. And last but by no means least; the tool should provide the nurse, as a human being, with the feedback and communication needed to reflect on personal experiences.

We are currently creating a prototype of our design, which will be tested with intensive care nurses at several hospitals in a simulated intensive care setting. The various design presumptions and product features will be evaluated as well as their effects on the nursing process. These results will be generalized in the form of design guidelines for future intensive care products.

## 5. Reflection

Despite the apparent diversity in the overview of research projects presented, they all contain to more or less extent the three ingredients that were listed in the research approach. All projects are design(er)-centered 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.

Because of their rich and innovative nature, the projects and activities of the ID-StudioLab projects have received considerable attention from within as well as outside the design

research community. Many visitors to the lab have themselves experienced the many prototypes that are integrated into the lab environment, thus affording quick and easy demonstration. Several guest researchers have participated in the lab for short or long-term projects and research collaborations have been established with companies such as Proctor & Gamble and Philips.

Next to scientific publications, ID-StudioLab projects have also been featured in national newspapers, magazines and the Delft Outlook, which is the research magazine of the Delft University of Technology. With such a large diversity of people, skills and disciplines it is not always easy, however, to present a consistent image to the outside world. A key element in the communication strategy of the lab is therefore its website (*studiolab.io.tudelft.nl/*) which presents an overview of all members and their projects as well as a special newssection only accessible to members, on which interesting news, thoughts or issues are posted.

The ID-StudioLab has also established strong ties with the educational program of the Faculty of Industrial Design Engineering, with its members being involved in several courses on both Bachelor and Master level, especially in the “Design for Interaction” Master, which started in 2003. Students contribute to the research by doing small or final projects or by participating in special workshops or events that are organized or facilitated by the ID-StudioLab staff. Successful examples of such collaborations are the Carrousel by Philip Ross, a tangible interface for navigating through mood-based atmospheres, that won the Zuid-Hollandse Vormgevingsprijs 2004 (Keyson et al. 2004), and the Microsoft Design Challenge, an annual competition in which students from a number of invited design schools participate, which was won in 2003 by a Delft team called the Mama’s Boys with their design of the GustBowl, a concept to connect mothers with their sons through an interactive bowl (Keller et al. 2004a).

## 6. Conclusion

Design research, like designing, is integrative by nature. It requires contributions from many perspectives, even if individual projects are carried out in specific disciplinary frameworks. Perhaps the most important aspect of the ID-StudioLab’s organization is its value as an informal forum, where researchers, teachers, and students who work on problems of human-product interaction (where ‘human’ may include ‘designer’) are aware of each other’s problems, solutions and knowledge, and allow each other’s views to seep across the boundaries of individual projects. For example, although not all projects are conducted by researchers with a design background, through the specific organization of the ID-StudioLab they can tap into a rich source of design knowledge and skills, enabling them to bring in designerly aspects into their work.

Five years of ID-StudioLab have clearly shown that this brings an additional value to the research. Over this period, connections and integrations have grown, often because of particular interests of individuals across separate projects. Seeing other people’s projects ‘in the corner of your eye’, and meeting them on a variety of topics, generates different connections, and unexpected feedback. Especially projects with a designer-centered character, where design artifacts (prototypes, tools) are visible carriers of what’s going on, lend themselves to an undercurrent of ongoing communication.

In this, an informally organized community has different strengths than those of a formal program, where often communication is about global questions and results, rather than on the level of methods, tricks, and unexpected perspectives. Next to the studio as a way of working, the maintaining of a living website, featuring internal newspages, helps to engage and promote the visibility and connections of the group.

The resulting projects show both a coherence of human-product interaction issues across a wide range of application areas, while pointing the way towards future research and design needs. By embedding research in design many of the dreams set out five years ago have come to fruition. In particular, the capability developed in the ID-StudioLab for rapidly building working prototypes, using a range of custom and off-the shelf design tools as well as standard and custom hardware, has proven to be a vital asset in jump starting internal lab and collaborative research projects with industry and academia.

However, the ideal integration of all three ingredients is not yet achieved in all projects of the ID-StudioLab, some projects only including one of two ingredients due to the specific nature of the research. In the future a further integration of skills, disciplines and ingredients is therefore pursued, stimulating projects that go beyond the traditional disciplinary boundaries in addressing the full experience of the user in his or her interaction with products within the context of this experience.

## **7. Acknowledgements**

The authors would like to thank Elif Özcan, Geke Ludden, Marijke Melles and Ianus Keller for their contributions to this paper.

# Understanding Design Through Design Support Tools

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## 1. Introduction

The Design Systems (DS) group of the Faculty of Architecture, Building and Planning of Eindhoven University of Technology deals with Computer Aided Architectural Design (CAAD) support. We can note that even after many years of development, mainstream CAAD software remains notoriously bad in design support. This concerns aspects such as concept generation, maintaining divergent thought processes, offering fast and numerous sketch-like representations, propagating design concepts to final design, and so forth. Good support in this phase can help the designer identify critical issues beforehand, understand implications more deeply than by manual methods, investigate more alternatives before settling on a design move, and so forth.

Obviously, we are not alone in trying to improve design support in the early phase. There is much academic research in this area. Very often such work is explorative and technology-driven through prototype systems that demonstrate how various techniques can be applied. Examples of such work are found in great numbers and in a great variety of applications – to name just a few: Esquise (Leclercq 2001), Electronic Cocktail Napkin (Gross 1996), Phidias (McCall 1999), and Sketchbox (Stellingwerff 2005). This kind of work is important to show the potential of CAAD for architects. Indeed, one cannot even do without this exploratory work if genuinely novel systems should be created – much of our research reported in the previous DRN symposium falls in this category (Achten, de Vries and van Leeuwen 2001). The creation of a new system however, answers only *how* we may improve design support, but not *whether* a system actually supports the design process, and if so, to which degree. Questions that we need to answer are “how do we define support,” “how do we measure degree of support,” and “how do we infer the influence of the support tool on the design itself?”

The research in our group therefore, has evolved from explorative to the development of innovative systems and subsequently testing these systems on their performance as design support tools. In this paper we will focus on two main areas in which we look at design support and the measurement of improvement: novel user interfaces and Bayesian networks. This will take place after an overview of Design Systems and a brief sketch of the context. Following this, we present a recently started applied-research collaboration called Janus. In the conclusion, we summarise our findings from the past years and sketch our view for the near future.

## 2. Development of the Design Systems group

At the last DRN symposium in 2000, the Design Systems group had been recently established and at that time did not have a professor. A dedicated research programme termed VR-DIS was started in which the expertise of the group, in particular Virtual Reality (VR) and design knowledge modelling, was applied in research projects ideally facilitating all disciplines in the

Faculty of Architecture of Eindhoven. In a larger framework, the research of Design Systems was part of the Design & Decision Support Systems (DDSS) research programme. In this programme we participate with the Urban Planning group (UP) headed by professor Harry Timmermans. Design Systems and Urban Planning share strong methodological viewpoints, but applied on different levels (architecture and urban planning), and with different perspectives (design support through VR-DIS and planning support through choice modelling and prediction).

In terms of staff, the Design Systems group has seen a number of changes. Most importantly, in 2001 Bauke de Vries was appointed professor of Design Systems. In 2000 Henri Achten became associate professor (UD) in Design Theory and CAAD; in 2002 Jos van Leeuwen became assistant professor (UHD) in Collaborative Design, and Aant van der Zee became associate professor in Evolutionary Design. With the retirement of John Carp in 2004, much of the first-hand knowledge of the Stichting Architecten Research (SAR) disappeared from the group. We are maintaining however, a course in this area on MSc-level. In the period 2001-2002, Sverker Fridqvist worked on a post-doc project concerning Feature-Type modelling, recognition, and management.

**Table 1: Finished, running, and related PhD-projects in the period 2001-2005.**

PhD Candidate	Title of thesis	Collaboration
<b>Finished PhD-projects at Design Systems</b>		
Amy Tan	The Reliability and Validity of Interactive Virtual Reality Computer Experiments	DS & UP (-2003)
Nicole Segers	Computational Representations of Words and Associations in Architectural Design	DS & ID (-2004)
Maciej Orzechowski	Measuring Housing Preferences using Virtual Reality and Bayesian Belief Networks	DS & UP (-2004)
<b>Running PhD-projects at Design Systems</b>		
Jan Dijkstra	Simulation of Pedestrian Flow in Urban Environments	DS & UP
Aant van der Zee	Computer-Aided Evolutionary Architectural Design	DS
Vincent Tabak	User Simulation of Space Utilisation	DS & UP (2003-)
Jakob Beetz	Multi-Agent Systems for Collaborative Design	DS (2003-)
Nischal Deshpande	Co-located, Multi-Disciplinary, Collaborative Design Space	DS & CBS TNO-TU/e (2003-)
<b>Related PhD-projects with other groups</b>		
Dima Aliakseyeu	A Computer Support Tool for the Early Stages of Architectural Design	DS & ID (-2003)
Slava Pranovich	Structural Sketcher: A Tool for Supporting Architects in Early Design	DS & CE-V (-2004)
Maxim Ivashkov	ACCEL: A Tool for Supporting Concept Generation in the Early Design Phase.	DS & CBS TNO-TU/e (-2004)
Shauna Mallory-Hill	Supporting Strategic Design of Workplace Environments with Case-Based Reasoning	DS & CBS TNO-TU/e (-2004)
Ilse Oosterlaken	Scenario Methods Within a Development Planning Approach Towards Complex Urban Sites (Re-) Development	DS & CME (2005-)

During 2001-2005, three PhD-theses were completed within the Design Systems group (see Table 1). Currently, we have five running PhD-projects. In collaboration with other chairs and faculties of Eindhoven University of Technology, we were also co-promotor or advisor in four other PhD-projects. The abbreviations in the Table are used for the following institutes with whom we collaborated:

- *CBS TNO-TU/e*: Centre for Buildings & Systems TNO-TU/e;
- *CME*: Construction Management & Engineering (Faculty of Architecture, Building and Planning, TU/e);
- *ID-UC*: User-Centred Engineering (Faculty of Industrial Design, TU/e);
- *CE-V*: Computational Engineering, Visualisation (Faculty of Mathematics & Computer Science, TU/e).

In the past five years, apart from the *DRN Symposium* (2000, 2005), Design Systems has co-organised the bi-annual *Design & Decision Support Systems in Architecture and Urban Planning* conference (2000, 2002, and 2004), and the *CAAD Futures 2001 conference*. We are currently in the process of organising the 2<sup>nd</sup> *International Conference on Design Computing & Cognition* which will take place in Eindhoven in 2006.

In our educational programme, design research features on the interaction between design theory, CAAD, and design methods (Achten 2003; van Leeuwen, van Gassel and den Otter 2004), and the integration of MSc.-graduation projects with our research work. In the past five years, this has lead to 10 MSc.-degrees with a specialisation in Building Informatics and a number of publications (de Vries, Verhagen and Jessurun 2004; Willems 2004; de Vries, Tabak and Achten 2005; de Vries and Harink 2005; van Leeuwen and Jansen 2005). Currently, we have five MSc.-students in the area of Building Informatics.

### 3. Design support: user interfaces

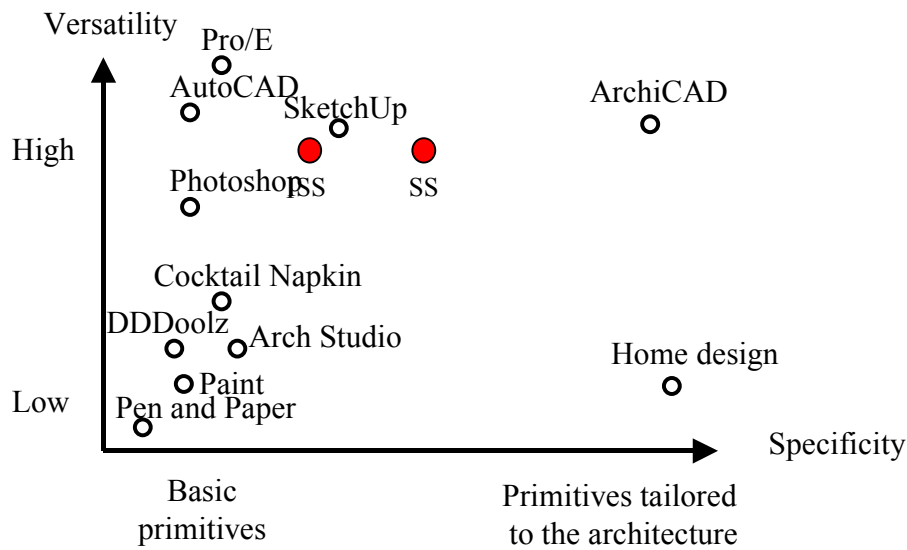
Many different systems have been developed and are used for computer-aided architectural design during the early stages. These tools present a large number of useful ideas, many of which have influenced our research. In this section we give an overview of some design tools that are currently available or still under construction. We cannot be exhaustive (see de Vries et al. 2003 for a lengthy overview), but we tried to select a number of solutions that are typical for a certain class. These tools intend:

- to mimic the traditional architectural environment;
- to simplify interaction with the system (input, manipulation, and presenting design information);
- to support various design aspects (e.g., visual, spatial, structural);
- to bridge the gap between early stages of design and following stages.

The kernel of a design system consists of the design model and processing unit. They provide design elements and operations on them. We propose a classification of design systems on the basis of two criteria:

1. *Specificity to the architectural domain*: this criterion distinguishes generic systems from systems that are specifically oriented towards architectural tasks. The connection to architecture is defined on the basis of design elements that are provided in the system.
2. *Versatility of provided support*: this criterion is related to the number of different techniques that the system offers for the support of designing and for structuring relationships between design elements.

Figure 1 classifies a number of drawing systems that can be used for architectural design.



**Figure 1: The classification of drawing systems.**

The horizontal axis shows specificity: some systems are based on generic primitives such as circles, rectangles, etc.; other systems are based on primitives that are tailored to the architectural domain, such as walls, doors, windows, etc. The vertical axis in this graph displays the versatility of techniques that are offered for managing design elements. Some systems provide only basic manipulations, while others offer an extensive set of operations, options to define macros, constraints, etc.

Below we present two design support systems the intend to fill the gap in Figure 1, namely the Idea Space System (ISS) and Structural Sketcher (SS).

### **Idea Space System (ISS): digital graphics and annotations**

Architectural design proceeds very much through the production of sketches. An often neglected aspect concerns the annotations that architects make while sketching and designing. What can happen to the design process if a design system could capture the annotations and offer verbal associations to the designer while he or she is designing? Would such help improve the flow of divergent ideas and lower the risk for fixation?

This question is addressed in the PhD-work by Nicole Segers on the Idea Space System (Segers 2004). The interface is built in the Desk-Cave (Achten, Jessurun and de Vries 2004), integrating the Visual Interaction Platform (VIP3), developed earlier by Dima Aliakseyeu (2003). VIP consists of a table top on which a desktop is projected, and which is also recorded with a camera. The camera tracks physical objects (movement and rotation) and uses this information to manipulate the underlying projected desktop. In this way, a physical interface is connected to virtual objects. The Idea Space System enhances this platform by adding an additional vertical screen, and using as input devices pens and a tablet. On the desktop, projected paper is used, which can be displayed in various transparency settings. Therefore, the architect works as if using a big sheet of paper. The ISS system has handwriting recognition, so there is no need for the distraction caused by a specialized input device for text.

The effectiveness of the system was measured with practising architects who were given two different design tasks, one to make with the system with word associations, and one task to make with the system without word associations. We measured several aspects: periods of activity and inactivity and their correspondence with acceptance of word graphs; judgement of a panel on the quality of the design; the word graphs displayed and words written down on the page, and so forth (see Segers 2004 for more details). We found that the system did not influence all architects equally; only those who indicated they verbally engage design tasks seemed to profit from the system – for the others we could not determine a significant difference.

Although pen and paper makes an almost unbeatable combination in terms of ease of use and speed of production, improvements are not too difficult to think up: what if the sketched elements remain persistent and do not have to be drawn time and again; what if implicit relationships in a sketch are maintained when the architect only wants to rearrange some elements? For this purpose, Slava Pranovich (2004) developed Structural Sketcher, which utilises a number of architectural graphic primitives – graphic units, see Achten (2004) – as a basis for a more structural approach to sketching.

In order to make Structural Sketcher simple and natural for the architects we developed new interaction techniques. These techniques are based on architectural metaphors of the early design process that are easy and intuitive for the architect. We define interaction techniques on top of the geometry engine that provide a possibility to explicitly/implicitly control interactions



between objects from different layers. For example, the architect can define relations by changing the rank and the layout of graphic units, and he can use layers to structure the relations between graphic units. With straightforward metaphors (*pins* and *clips*) he can determine more advanced manipulation relationships. The *pin* is used to connect a pair of graphic units and to block propagation of particular transformations. It is visualized as a nail-head pyramid, where each nail-head has its own colour and marks the blocking of a particular transformation (see Figure 3 Left). The user can modify the transmission properties of a pin using a special properties manipulator called *Kite* (see Figure 3 Middle).

The *Kite* combines several operations (skew, scale, rotate, and move) in a single metaphor. A mouse click on a corresponding zone of this manipulator switches on/off the transmission of related transformation (the centre of the manipulator for rotation, the corner for scaling, and the bars for skewing). If the transmission of a transformation is blocked then a corresponding zone in a manipulator is highlighted with red. The *clip* is provided for connecting objects, and is visualized as two balls that are attached to graphic units and are connected by a line (Figure 3 c).

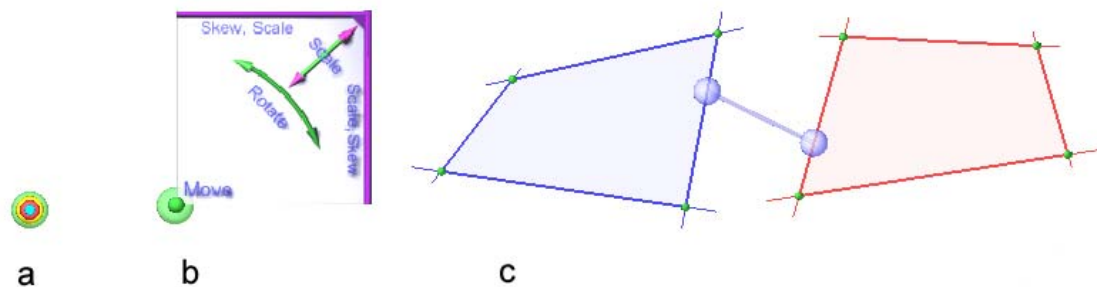


Figure 3: (a) The pin, (b) the Kite manipulator projected on a pin, (c) the clip.

The visualization of transmission properties and the manipulation of these properties is similar to the pin. The interaction mode is defined automatically: if the user manipulates graphic units, then natural mode is implied; if the user manipulates layers, then layers mode is implied; if the Ctrl button is pressed then manual mode is implied. Figure 4 shows a number of elements created in Structural Sketcher.

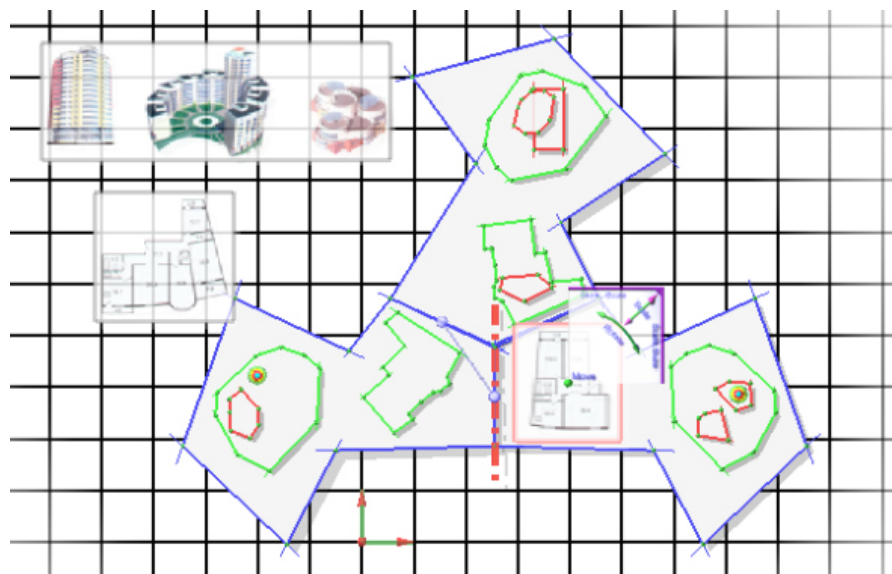


Figure 4: Example created in Structural Sketcher.

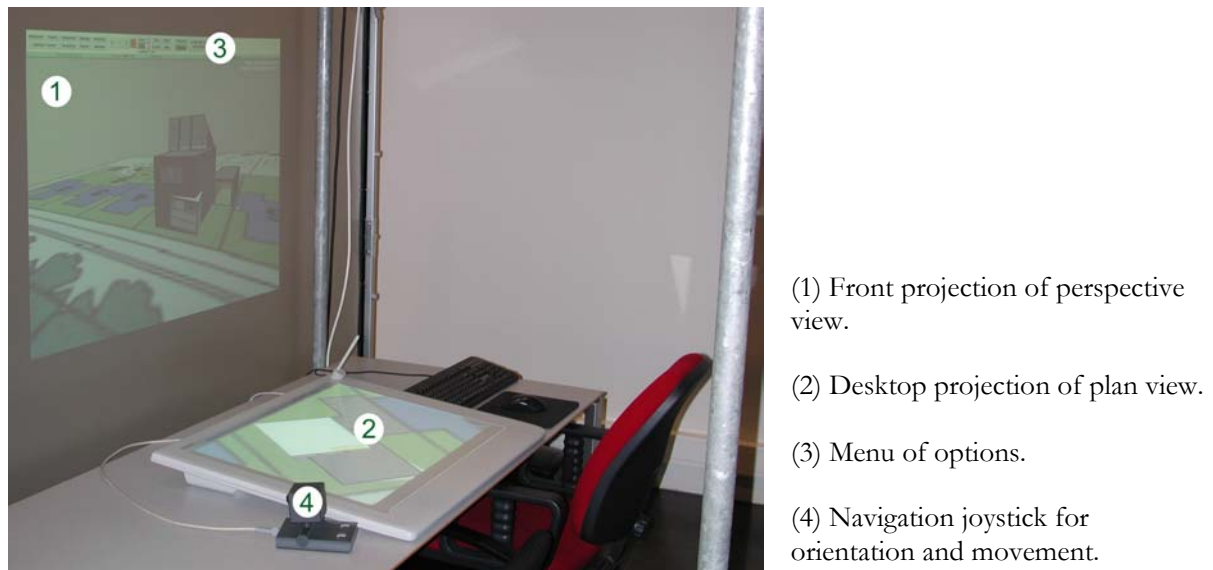
The system was tested in a qualitative manner by asking a number of architecture students to work through a number of prepared exercises, ending by making a small design for a doctor's practice, and asking them to rank-order Structural Sketcher relative to some major design software on several aspects. The system was tested in a quantitative manner by measuring over the prepared exercises the minimum number of required user-interactions compared to some major design software. The qualitative tests clearly placed Structural Sketcher between pen & paper (which usually ranked first) and the other software. The quantitative tests showed a reduction of user actions of 60%, 45%, and 30% compared to other software. We infer from this that the user-attention to interface issues is greatly reduced and this allows at least in principle more focus on design work.

#### **4. Measuring the effectiveness of design support: Bayesian networks**

Understanding preferences of future house owners is important to design close to the desires of customers – even when they are unknown as in the case of many project developments. Current inquiry methods employ stated-choice or conjoint measurements that have two distinct disadvantages: they are text-based, and they involve judgement of many (often unlikely) profiles before reliable inference is possible. While Virtual Reality is commonly assumed to provide an experience much closer to lay-people's understanding, it remains a question whether the employment of this technique actually brings about more accurate measurement of preferences. Maciej Orzechowski (2004) developed a VR-based system – MuseV3 – in which future home owners adapt a design to their own preferences. For measurements we used the technique of Bayesian networks.

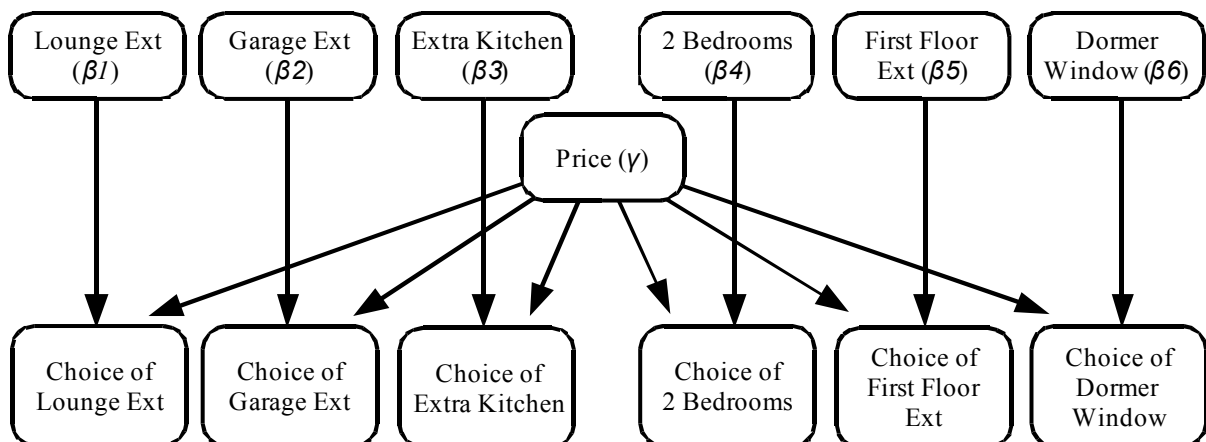
Bayesian methods provide a formalism for performing reasoning using partial beliefs under conditions of uncertainty. Propositions are quantified with numerical parameters indicating the strengths of beliefs, based on some body of knowledge. These parameters are combined and manipulated using the rules of probability theory. The Bayesian view of probability provides a natural way to encode expert knowledge in domains where little or no direct empirical data is available. An attractive feature of the approach is that when data becomes available Bayesian reasoning gives a consistent method for combining data and judgment to update beliefs and enhance knowledge. In this way a Bayesian network captures believed relations (which may be uncertain, stochastic, or imprecise) between variables that are relevant to some problem - in our case user preferences for a set of alternative housing designs or design attributes.

In order to acquire measurements that can be compared, we used a concrete project of a project developer, and asked potential house-buyers who were interested in that project to adapt a base-line design to their own preferences – much in the way as the project developer interviews their customers. The people could adapt their house according to the same possibilities as the real project, using three-dimensional projection and navigation (the VR-part) and a plan view (Figure 5). In both views, the house could be adapted. The changes were recorded by the system, and the values of Bayesian network adapted to the new evidence (the state of the house). The network was finalised for each project after the users indicated they were satisfied with their design.



**Figure 5: The MuseV3 setup.**

Figure 6 shows the structure of the Bayesian network. We can distinguish two levels. In the first, top most level, there are the variables expressing a subject's preferences for each design attribute. The second level contains variables representing probabilities of choosing a design attribute. At this level, the actual choices captured from the virtual environment are entered into the network. Consequently, each attribute creates a separate vertical branch. The price is treated as overall cost, represented by variable gamma. The actual cost of each design option is encoded in its corresponding conditional probability table attached to the corresponding attribute node. Prices for options remain constant for all subjects.



**Figure 6: Bayesian Network for the experiment case.**

When the experiment starts, the initial conditional probability tables for the parameter nodes has uniform distributions – meaning that every outcome is equally likely to occur (no preference is inferred). After each session, the network is updated, and the distribution changed accordingly. As can be imagined, the accuracy of the network increases when the number of cases increases.

We measured the effectiveness of the system in two ways: by examining the internal consistency of the Bayesian network, and by offering advice to the users after a session based on the differences between their final design, and the expectations encoded in the network. Considering the first, we found that with the 64 respondents in the experiment, the network was still subject to changes in values when a greatly divergent design was offered. Numeric simulation showed that the network becomes robust with 100 respondents. Considering the second aspect, we could make two observations: (a) the number of suggestions that were accepted by the respondents increased during the course of the experiment; and (b) the number of differences between the network and the realised designs decreased during the course of the experiment. This indicates that the system is indeed learning preferences, and that these increasingly matched the preferences of the respondents.

## 5. Janus: Joint Architectural Network for Urban Synergy

The Joint Architectural Network for Urban Synergy, or briefly put: *JANUS*, is a recent initiative launched in the beginning of 2005. This network was initiated in collaboration with a Dutch CAD software developer, with the objective to combine the best of the two worlds of scientific research and daily practice in design offices ([www.urban-synergy.org/](http://www.urban-synergy.org/)). It is established in the form of a foundation that acts as initiator and co-ordinator of research projects targeting issues of communication in the construction industry. The focus in these projects is mainly on *what* is (or should be) communicated between partners in construction, rather than on *how* they are doing this. The rationale behind this is that in most innovation projects, the development is driven by the technology itself, rather than based on a thorough analysis of requirements. In our projects we aim to bring professionals together and ask them what they need to know from each other to be able to collaborate, and why they need this information.

To perform this research, the foundation develops a national network of professionals in all disciplines involved in urban development and construction projects. The network currently includes architects, contractors, principals, and representatives from both national and municipal authorities.

Some of the topics that are being developed in these projects are the following:

- Digital code checking.
- Online building permit requests.
- Bill of Experiences (compared to Bill of Requirements).
- Architect-Contractor communication in early design and in procurement procedures.
- The role of art and history in urban development.

One of the first projects that will deliver tangible results is the *Digital Dormer* project (“*Digitale Dakkapel*,” see van Leeuwen, Jessurun and de Wit 2004). The Digital Dormer is a website where house-owners who want to build a dormer on the roof of their house can make a design of the dormer that will be automatically checked against the national building codes, the municipal aesthetics rules, and a number of technical requirements. Once the design is satisfactory, the user can use the system to generate and submit all information that is necessary to request a building permit for the dormer. The municipality can easily check if this information is complete and can follow up with a much enhanced procedure of granting (or rejecting) the request for permission. Nationally, dormers account for 10-15% of all smaller construction projects (< € 100.000) in the Netherlands. Apart from the direct benefit of this application, the knowledge that was gathered in the project will also be used in following projects that involve digital code checking and communication procedures between civilians and authorities regarding the built environment.

## 6. How to understand designers through tools?

We have learned that study of new techniques isolated from the design activity is not very informative about the impact of such techniques on the design process. The integrated study in a design context however, greatly complicates research methodology as many additional factors are introduced. It also places our work in a sometimes uncomfortable duality between systems developers – who usually consider the work finished after a prototype has been built – and psychologists – who care not much for the design context. As our experience grows with the research projects, we feel more confident about the methodological approach, although we still have a lot to learn.

Very often we find that our initial expectations what a technique or system “will do” are unsophisticated or simplified. In many cases complicating circumstances occur, and designers prove more varied than anticipated from the literature or our intuitions. This points to the limited value of broad, sweeping theories of design(ers). The conclusions that we draw from our work have to be understood within the sharp limits of the system, the experiment, and design task. Outside these limits generalisations are very likely inaccurate. We increasingly understand the complexities of computer aided design support, and the varied relationships that designers can have with such tools.

Research through tools offers two kinds of insights into designers. The first insight is a ‘productive’ insight, in terms of the problems designers encounter, what kind of tools they employ, and how they would like to employ these tools. We find that designers are often incapable at describing their needs in terms of design support, or to assess without hands-on experience how a given technology might work for them. Prototypes prove invaluable in this respect, and measured experiments are necessary to determine the actual use. The promise of new technologies is often exactly what it is – just a promise, without any specification what exactly will improve (and, equally important, what exactly will remain unchanged or even degrade). Experiments in design settings are modest in explanatory scope, but form an effective antidote to inflated expectations of new technologies.

The second insight is a more indirect ‘cognitive’ insight, in terms of reasoning mechanisms that designers employ. A particular tool or technique assumes certain behaviour or structures that will be supported, and thus that a particular task dependent on these structures or behaviour will be improved – in the examples discussed here, associations and creativity (ISS), graphic structures (Structural Sketcher), and spatial reasoning (MuseV3). We are not doing cognitive research per se, but we do find that our work yields insight in design cognition in particular through revision or refining of our grounding assumptions. In this sense we learn a lot about the complexities involved in design support.

## 7. Acknowledgements






















The work in the Design Systems group is very much the result of teamwork, and a shared interest between all members of the group in each other’s work, both in the current staff and the people who have been with us in past five years. Working together with other groups in the Faculty and other Faculties of the university has proven very rewarding and stimulating. We gratefully acknowledge their contributions and collaboration.

## References

### made in Holland

The accumulated references in this volume provide an indication of the sources that design researchers in the Netherlands are referring to, as well as their own contribution to this field. The table below summarises the number of publications of each type, and the ‘dutch share.’

**Table: References in the proceedings.**

Type of contribution	All	NL	
Publication in proceedings	123	98	
Article in journal	97	56	
Scientific monograph	72	13	
PhD-Thesis	33	33	
Report	23	15	
Non-scientific monograph	23	18	
In scientific monograph	17	12	
in non-scientific monograph	8	5	
Edited proceedings	7	6	
Professional magazine	7	5	
Philosophical monograph	7	1	
E-publication	5	0	
MSc-Thesis	4	3	
Educational publication	4	4	
Inaugural lecture	4	4	
Unpublished notes	3	0	
Other lecture	3	3	
Patent application	1	1	
Project proposal	1	1	
Poster	1	1	
White paper	1	0	

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