Design research in the Netherlands 2010 : proceedings of the symposium held on 20-21 May 2010, Eindhoven University of Technology

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THE WIDENING SCOPE OF DESIGN RESEARCH IN THE NETHERLANDS 2005-2010

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Design Research in the Netherlands 2010 is the fourth symposium on research on design following earlier editions of 1995, 2000, and 2005. The audience for the symposium cuts across all the designing disciplines. This edition features contributions from architecture, industrial design, civil engineering, machine engineering, landscape design, management, curriculum design, and electrical engineering. Most of these can be characterised as engineering studies, which already have a long tradition of scientific reflection on the nature of design. This does not mean however, that in other domains of design (such as graphics, fashion, or games) which are less characterised by an engineering background, there is no reflection taking place. Rather it indicates that there are likely two different worlds of discourse – each with their established scholarly traditions and channels of output – that simply do not mix. This is a pity and a disadvantage for each of the domains.

Developments in industrial design engineering and architecture

The last five years showed several developments in the field of Industrial Design Engineering in the Netherlands, concerning the Dutch situation, international practice, the tools and objects of design, and a further maturing insight in the relation between design and research. Regarding the Dutch situation, there is now a clearer, and more varied, design research landscape with not one but three technical universities (TUs) having established research portfolios and taking part in research visitations, and with a growth of research links between the TUs and the universities of applied sciences (HBO) increasing the connections between research and practice outside the research departments of larger industries. At the same time, grand themes, such as emerging markets, global production, and sustainability are fuelling the research agendas and visibly direct programs.

Regarding tools and tools research, issues of how can creative processes of individuals and teams be supported are still strong, and broadening to new concerns, often with an emphasis on interaction design, and increasingly focusing managing complex information sharing and sense-making in teams. User-centered design, traditionally strong in areas of usability, had grown in the previous period into cover emotion and experience, a trend that continued and has extended to contextual studies and design ethnography. In these areas we see a tight coupling between research, education, and practice, with equal emphasis on developing measurement techniques to evaluate *design (e.g. products and product concepts)* as well as frameworks and techniques to support *designing* for these concerns.

These developments reflect changes in design practice, where emphasis is growing on understanding and supporting early design, often referred to as the fuzzy front ends, and bringing attention for evaluating, modeling, conceptualizing and prototyping user experiences. The last period has shown an increase in attention for user involvement (contextual studies, co-creation), and covering more perspectives into design. We also see a broadening of the range of outcomes that design is producing: besides classical ‘products’ and interfaces or interactions, the outcomes can include services (on their own or in combination with products), and solutions often span traditional domains, such as product design, interaction design, communication design, architecture, and service design. Design is becoming more complex, and involves more people (users, varieties of experts and stakeholders).

As a result, the tools and skills of designers are changing, and research projects are emerging (or maturing) that explore, instantiate, and evaluate new tools and principles.

Nevertheless, classical topics of creativity and expressiveness are still going strong, and the last five years have shown a consolidation of the role of design in research. Earlier discussions on how to define the relation between design and research, with the colorful phrases of research for/through/by/in/etc design, are settling down, with a clearer understanding of the ways in which design and research are related, and a more confident variety of ways to combine research and design.

In design research in architecture no major shifts can be observed over the period 2005-2010. Most issues that were discussed in 2005 like the effect of digital tools on architectural design, the need for integral design and the legitimacy of scientific design research still exist in 2010. These issues returned on the research agenda but they have become more prominent. Advances in digital design tools make it much easier to use these tools for modelling support but also new areas are explored such as scripting. In 2005 no architectural designer was interested in applying scripting languages for form generation. Recently new intuitive form scripting platforms have been pickup by architectural designers enthusiastically. Free form shapes are generated while maintaining constructability. Technical changes in computer aided design challenge design researchers to reconsider design methods and requires significant effort from teachers and practitioners to catch up. Integral design has found its counterpart in the Building Information Modelling development. Concurrent work process models can be put into practice now communications standards have been implemented by software industry.

Many disciplines in the building design and construction process are reconsidering their role. Integral design requires designers with the right attitude and with the right technical and social skills to be part in a successful collaboration. Since design offices increasingly operate in an international context, international standardization of design data and processes is needed. Obviously standardization is in conflict with the architectural demand for free form design. Future design research has to find the right balance between the inability to communicate on a free form design and unobtrusive communication on uninteresting architecture. The debate whether or not design research is science or not continued from 2005-2010. The gap between fundamental research and applied research seems to widen. Technical universities over the past years inclined to fundamental research but recently more attention is paid to innovation in collaboration with industry. Design education has become more professionalized. Practitioners from outside the university play an important role in design education. The number of full time architectural design academics is decreasing which limits design research capacity. Design research in the next five years is probably driven by global issues like climate change, security, health, etc. In these contexts design competences are crucial and will develop further.

Design research in the Netherlands 2010

We are very fortunate to have John Habraken as the keynote speaker at this year's symposium. In many ways Habraken is connected to the symposium. As the founding father of the Faculty of Architecture, Building and Planning at TU Eindhoven, he has set the initial direction and characterisation of the Faculty. When he was appointed Head of the Department of Architecture at MIT, Cambridge (MA) 1975-1981, his work was continued in the Design Methods group. The chairs of that group, at the time Robert Oxman and Thijs Bax, initiated the first Design Research in the Netherlands symposium in 1995 (Oxman, Bax, and Achten, 1995). The Design Methods group investigated and developed methods for architectural design up until the merger with the Building Informatics group in 1997-1998 into the Design Systems group (reported in Achten, de Vries, and Hennessey, 2000). The new Design Systems group combined the strong methodological approach with Information and Communication Technology, in this way preserving a strong interest in the characteristics of design, designers, and designing (as presented in Achten, Dorst, Stappers, and de Vries, 2005).

The contributions in the current proceedings show a wide variety of design research across many disciplines. In this edition of the symposium, we have invited both group papers as in earlier cases, and we have introduced PhD position papers. The PhD position papers are presented in pecha kucha sessions, in which each researcher has the change to present their work. Following the presentations an intensive discussion round is planned in which all participants are invited to take part. The PhD position papers can be found everywhere in the proceedings, as we did not find it necessary to group them separately. Group position papers are about twelve pages long, and PhD position papers are about six pages long.

Although each subdivision has some arbitraniness, we have grouped the papers according to the following main themes: Group one deals with *methods, processes, and design*; group two deals with *design, research, and education*; and group three deals with *methodology and practice*.

Methods, processes, and design

In this group there are contributions from (1) Innovation, Technology Entrepreneurship and Marketing group – TU/e, (2) Reliability and Durability group – TU Delft, (3) Human Information Communication Design/Medisign – TU Delft, (4) group consisting of Green Building Innovation & Product Development; Electrical Sustainable Energy; Applied Ergonomic and Design; Technology Dynamics and Sustainable Development; and Valorisation Centre – TU Delft; (5) Design Systems – TU/e; and (6) ID-StudioLab – TU Delft.

The papers in this group have a strong focus on the process of design, and how to design processes. Reymen, van Burg, Romme, and Berends (pp. 13-22) are concerned with management processes which up to now have not benefitted much from insights from design research. In their work they demonstrate how creating business processes are in fact design processes, and how traditional approaches can be changed to take this aspect more into account.

Jiang, Freudenthal, and Kandachar (pp. 23-28) deal with two issues: design for the so-called Base of Pyramid group (people who live on less than three US$3 per day), and introducing user-centred design for this group in China in the area of healthcare design. As this approach is virtually unknown in China, they are dealing with both a learning and change process.

Freudenthal (pp. 29-40) outlined the work done in the Medisign group, which deals specifically with developing multimodal and interactive support for medical applications. Their work is highly collaborative between industrial designers and medical specialists – therefore again a typical example of learning and change processes. This process has more or less matured through a series of dedicated projects, and now they are looking at industrial applications that can be realised for a wider market.

Van Timmeren, Bauer, Silvester, Beella, Quist, and van Dijk (pp. 41-52) present the results of an interdisciplinary design team that created a future plan for the use of electric vehicles on Schiphol. Electric vehicles have many benefits but pose high demands in terms of available charging stations because of limited range. In the project the authors show how these demands can be met through a network of green energy powered charging stations and dynamic and static inductive charging lanes.

De Vries, Beetz, Achten, Dijkstra and Jessurun (pp. 53-63) argue that in order to support architectural design processes it is necessary to have a formalism that can precisely describe products of the design process as well as the process (product and process modelling), and that in order to improve architectural designs, it is necessary to have a rigorous understanding of human behaviour in the built environment – they aim to achieve this through simulation techniques.

Van der Helm, Stappers, Keyson, and Hekkert (pp. 65-78) present the ID-StudioLab which is a multidisciplinary collaborative work environment at the Faculty of Industrial Design Engineering. They show that collaboration or cross-fertilization of ideas does come about simply by putting a number of people together, but that it requires a careful balance of personal approach, environment, and facilities. In their contribution they outline the development of the studio and present a number of key projects that have benefitted from this setting.

Design, research and education

In this group there are contributions from (1) Design Theory and Methodology – TU Delft, (2) Landscape Architecture group – Wageningen University, (3) Product Innovation Management – TU Delft, (4) Product Development – TU Delft, (5) Architecture – TU Delft, (6) Netherlands Institute for Curriculum Development – Enschede, and (7) Product Innovation Management – TU Delft.

Badke-Schaub, Cardoso, Daalhuizen, Lauche, Jalote-Parmar, Neumann, Roozenburg, Secomandi, and da Silva Vieira (pp. 79-90) note that current general theoretical frameworks of design do not offer many handles to address the design needs of designers. Therefore they look in more detail at the cognitive, information, and process needs of designers and try to gain more knowledge about the specific needs of the designer. This in return feeds back to the general models.

Koh (pp. 91-100) outlines similarities and differences between landscape design and architectural design, as in particular in the modernist period landscape design was influenced a lot by an architectural approach. As landscape design deals with different issues however, it has generated its own strategies and methods. In particular the connection between research and design seems to be underdeveloped and needs more attention. Koh shows how this is done at the Wageningen University and presents a number of research-design projects as examples.

Deken and Lauche (pp. 101-106) use cultural historic activity theory to study interorganisational designing. From many different possible approaches they choose to focus on the objects of design (sketches, drawings, models, and so on) and investigate how parties from different organisation deal with these objects in the design process. Through so-called distruptions they hope to find more information about these dynamics.

Lockefeer (pp. 107-112) investigates the influence of the computer in the design of free-form shapes. For this purpose he reconstructed the design of fourty free-form shaped buildings by means of the computer. After analysing similarities in these projects, he defines four different strategies of computer use that each has a different method and impact on the design process.

Van Dooren (pp. 113-116) studies the education of designing, in particular what should be made explicit for a student while (s)he is learning to become a designer.

Various frameworks are investigated among which Schön’s reflection-in-action approach.

Nieveen, Folmer, and van den Akker (pp. 119-128) look at the design process of curricula in general. They notice that in general there is no methodical evaluation phase, so that mostly programmes are created but not checked whether they actually fulfil the stated goals and purposes. Therefore they propose a more design-oriented process in which such evaluation actually does take place, and test this within their institution which is responsible for the development of learning programmes.

Finally, in this group, Sobotie, Deken, and Kleinsmann (pp. 129-134) investigate what is actually happening between novice designers such as students and experts. This is quite relevant research given the fact that the major pedagogical model to teach designing is in a design studio setting under guidance of a (master) designer. Through a number of studies they find that where novice-expert engage in a collaborative design mode, the exchange of knowledge and information becomes more dynamic than in a traditional teacher-student relationship. Both novice and expert are actually together learning about the problem and potential solutions.

Methodology and practice

In this group there are contributions from (1) Product Development, combined with (2) Octatube International – TU Delft, (3) 3TU Building Research – Delft, Eindhoven, Twente, (4) Installations – TU/e, (5) Building Physics and Systems – TU/e, and (6) Building Technology – TU Delft. All papers are from architectural design. At one point in design research history, architectural design was one of the forerunners in terms of design methods. However, after the first crisis in design methodology (see Cross 1984, Introduction chapter for a historical outline), architecture for a long time resisted methodological research. The returned interest in methods and how they apply in architecture seems to be prompted by two main causes: the demand for more sustainable designs which require intensive collaboration between various partners in the design team, and the appearance of a new generation of design methods and support (see for example Achten (2009).

Van Gelder and Eekhout (pp. 135-141) look at methods for support of free-form designs – buildings that typically have a non-rectangular shape, the design and realisation of which depends on innovative use of materials, design support, and design processes. By means of case studies they aim to identify key aspects of successful design methods, which can then be generalised to architectural design.

Eekhout (pp. 143-154) investigates the often problematic relationship between research as an academic activity and design as an office-based activity. He notes that working by means of prototypes research and design can be integrated in a quite productive way. Doing this however, requires a specific methodology that still is in development. The most part of this contribution is aimed at showing how he approaches this question.

Eekhout (pp. 155-165) presents a new integrative approach between the faculties of Architecture of the three Universities of Technology Delft, Eindhoven, and Twente. Research in architecture in fragmented and has a very low scientific impact compared to other engineering domains. The so-called 3TU spearhead building research programme must bring more focus to the research and enable more and better communication between various research groups. He proposed four major themes for research: mobility, environment, health, and energy. Each theme has two sub-themes that give a more direction. These sub-themes are respectively: space & infrastructure; town & renovation; health & safety; and energy & sustainability.

Zeiler, Savanic, Quanjel, and Harkness (pp. 167-184) propose Integral Design as a design methodology to incorporate expert knowledge of the various parties in a design team in a better way. The work presented here has two tracks: first is the development of the design method – integral design, and second is the testing of the method by means of a series of workshops. In the analytical research they demonstrate that integral design does seem to be an effective way to generate novel designs.

Harkness and Zeiler (pp. 185-190) continue with the Integral Design method as investigated in the earlier chapter, and investigate additional requirements to successfully implement this method in practice.

Shahnoori and van den Dobbelsteen (pp. 191-198) also investigate methodological support in architectural design. They keep the specific method as an open question and first aim to arrive at a general process model by which they can capture complex architectural designs. Through literature study they draw up an overall model (Glocal Process Model) that forms the basis for further research.

Conclusion

In previous editions of Design Research in the Netherlands there was a substantial amount of theoretical and philosophical models about design. We can see that there is a shift from these theoretical models to a larger involvement with the designer and practice. The theoretical models give us a base approach that is now being tested – and confronted – with reality. It provides new insights and enrichens our understanding of the complexities of design. We can also see a more intensive application of design methods and theories in particular in architectural design. Many of these investigations are in an early stage. Therefore, it should be interesting to see what the next Design Research in the Netherlands 2015 will show as result. Most likely it will be a more colourful palette of options and understanding of design, the foundation of design, and the relationship between practice and theory.

DESIGNING INNOVATIVE ORGANIZATIONS
Design science research in the management field at TU/e

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Introduction

Eindhoven University of Technology has a strong focus on design. The Department of Industrial Engineering & Innovation Sciences includes a group (ITEM) conducting design research in the management sciences. This introduction starts with a short introduction of the department. Thereafter, the specific research focus of the Innovation, Technology Entrepreneurship and Marketing (ITEM) Group within the department is briefly introduced.

The Department of Industrial Engineering & Innovation Sciences (IE&IS) (formerly Technology Management) engages in education and research in the area of business processes and transitions in societies in relation to technical changes. In the IE&IS department, scholars and students work together on critical problems at the interface of engineering, management, innovation, and human behaviour. The department has two schools: the School of Industrial Engineering and the School of Innovation Sciences. The ITEM group is part of the School of Industrial Engineering

Within the School of Industrial Engineering five degree programs are taught: BSc in Industrial Engineering & Management Science (Technische Bedrijfskunde), BSc in Industrial Engineering for Health Care, MSc in Operations Management & Logistics, MSc in Innovation Management, and PhD in operations, logistics and innovation management. The PhD program is embedded in the research school Beta. The School of Industrial Engineering also participates in the Logistics, Operations & Information Systems (LOIS) research cluster of the TU/e.

The ITEM group within the School of Industrial Engineering performs design research from two perspectives. First of all, research focuses on innovation and design processes, i.e. processes that create new products and new businesses. The group aims to increase understanding of these processes from an organizational point of view and contribute to improving these processes by developing design principles that can be used in practice. Second, methodology is developed for bridging the science-practice gap, focusing on the development of these design principles, thereby increasing relevance of science for practice. Projects and key findings from both perspectives are highlighted in this paper. Furthermore, the presence of the ITEM group in the design community is indicated.

Studying design processes

The interest in design and designing in the management literature (e.g. Boland and Collopy, 2004) has recently been increasing. Managing is not only seen as decision making, but also as the creation of solutions for problems and the changing of existing situations into desired ones; so, managers are also designers. The students at the Industrial Engineering school are for many years already trained in (re)designing business processes.

Since the focus is on the study of design “processes,” often a process approach (Langley, 1999; Poole et al., 2000) is chosen. By adopting such a process research approach, we are able to analyze how issues emerge, develop, grow, or change over time, i.e. how the processes unfold through sequences of events (Van de Ven, 2007).

Process research allows the investigation of design processes over an extended time frame.

In the remainder of this section, an overview is given of all recent ITEM projects performed from the perspective of studying design processes in the management field. The projects can mainly be categorized according to three themes: new product development, design of new venture creation and design and development of business models.

New product development

In new product development (NPD), the "traditional" role of designing a product is very evident. An example of a recent project studying design processes in NPD context is the master thesis project of Rutger Stultiens (2009) focusing on *external designers in product design processes of small manufacturing firms*. Small manufacturing firms often fail to reap the benefits of good design practices and make limited use of external designers in their product development processes. The study investigates how the involvement of external designers influences the evolution of product design processes in small manufacturing firms. Qualitative and quantitative process research methods were used to study 352 events in five joint product design projects. The findings show how these processes iterated between divergence and convergence and between goal setting and idea development. Moreover, higher involvement of external designers was associated with more frequent iterations. Designers offered a broad set of skills and activities that were complementary to the small firms. In sum, the study underlines and explains the value of external designers for small manufacturing firms.

The same project also found that product innovation in small firms is not merely unplanned, chaotic, improvisational, or ad hoc, but is guided by underlying "*effectuation*" logic (Sarasvathy, 2001). This effectuation theory originates in the entrepreneurship field. Sarasavathy contrasted effectuation with causation, as two different decision making logics. Causation takes a certain goal or effect as given and focuses on selecting the means to reach that effect; like cooking based on a recipe. Effectuation takes a set of means as given and focuses on selecting possible effects that can be created by these means; like the opening of the refrigerator and determine what can be prepared with the given ingredients (Sarasvathy 2001, pp. 245; Sarasvathy and Dew, 2005). Effectuation puts low emphasis on prediction, but much on control; causal thinking puts a lot of emphasis on precise prediction and clear goals and planning (Wiltbank et al., 2006). Effectuation is a process of creation that is particularly appropriate under uncertainty, when knowledge of key phenomena does not yet exist.

It is interesting to see that effectuation not only fits the approaches of small firms, but can also be linked to approaches of design processes. The many approaches to organize design processes can roughly be divided into two main categories, namely top down, expert-driven, rational problem solving approaches, versus more bottom-up, participative, reflective practice approaches (cf Dorst, 1997). The first category is often represented in well-known linear and incremental models. The second category more participative processes is modeled as evolutionary or agile approaches (Benediktsson et al., 2006). Effectuation theory fits in the second category of more participative approaches. Sarasvathy (2003) linked effectuation already to designing and mentioned the agile technique SCRUM (Schwaber and Beedle, 2002) as a method using effectuation principles. We are interested in the applicability of the effectuation theory for organizing and supporting (flexibility in) design processes. In the future, more research on effectuation processes will be performed, answering research questions like: where do effectuation and design thinking differ? Can effectuation be recognized in design processes? Under which conditions is an effectual approach more suited, when is a causal approach suited?

Another study investigated the impact of nine new product development acceleration *approaches on development speed* (Langerak and Hulting, 2008). The findings from 233 manufacturing firms show that five approaches (supplier involvement, lead user involvement, speeding up activities and tasks, training and rewarding of employees, and simplification of organizational structure) increase development speed, whereas two approaches (implementing support systems and techniques and stimulating inter-functional coordination) decrease development speed. Two approaches (i.e., reduction of parts and components and emphasizing the customer) have no effect on development speed. The results further show that firms developing different types of new products should use different NPD acceleration approaches, as the speed impact of six out of nine approaches is dependent upon the degree of product innovativeness.

A completely different topic is studied in the recently started master thesis project of Laurie Scholten (2010). It concerns customer involvement in design processes and in particular harnessing the *re-invention processes* that take place by these customers after a product has entered the market. The main research questions are “how can a company create products that can be seen as platforms and triggers for re-invention (by expert and/or novice users)?” and “how can a company effectively use re-invention in the NPD process for creation of the next product line or the improvement of existing products by add-ons or updates?” We are still looking forward to promising results.

Another topic studied in recent years is the *co-evolution of problems and solutions* in architectural meetings in design practice (Reymen, Dorst, and Smulders, 2009). Co-evolution is considered as a key characteristic of designing. Several authors have described design thinking processes as the co-evolution of design problem and design solution. Its theoretical grounding is, however, still in an early stage. In the paper, we aimed to bring further the concept by studying a real life design meeting of an architect and a client. We developed a model of how co-evolution in a multi-party setting might work. We discerned thirteen co-evolution episodes in the two studied meetings. We looked in detail at the utterances in two co-evolution episodes. It turns out that modelling co-evolution in terms of problem and solution does not work. Conversation in an area in between problem and solution, like ‘use,’ seems to be more accurate to describe how the actors reach agreement. We proposed alternative ways for modelling co-evolution.

Based on the same raw material, another project was started, focusing on *purposive interventions for creating shared understanding* in design processes (Reymen, Jelinek, and Berends, 2009). Design participants need shared understanding to proceed, and some at least deliberately aim to develop it through interventions in design processes. Process study methodology was used to analyze video recording transcripts of actual architect-client meetings for the design of a crematorium in UK. We concluded that the development of shared understanding can be fostered by deliberate interventions; that nested sub-processes help to explain why and how shared understanding develops in the course of design processes; and that the recurrent patterns that comprise these processes are deliberate and systematic. The study contributes a more detailed model of the development of shared understanding in design efforts.

Finally, we participated in two National Science Foundation workshops on *Design Requirements*, in Cleveland, Ohio and later on also in Dagstuhl, Germany (Reymen and

Romme, 2009). Since managing design requirements of complex socio-technical designs in heterogeneous and rapidly-changing environments demands new approaches, we developed a research agenda. We used the framework described by Krippendorff (2006) as a starting point to describe the evolution of requirements thinking. Krippendorff's trajectory of artificiality shows an increasing dematerialization and human-centeredness of artifacts. He distinguishes six kinds of artifacts, namely material products; goods, services, and identities; interfaces; multi-user systems and networks; projects; and finally, discourses. Based on a review of the design literature, involving two major design journals, we found that the design of socio-technical systems currently tends to be situated on the level of multi-user systems and networks. Projects and discourses hardly get any attention in requirements thinking. We therefore developed an agenda for future research directed toward advancing requirements thinking at the level of projects and discourses as artifacts of design.

Design of new venture creation

Entrepreneurship is an emerging and fast growing field in the organization and management literature. In this discipline, the creation of a new venture is the central phenomenon, which is increasingly considered as a design process, where design knowledge is essential. For example Sarasvathy (2003) views entrepreneurship as a ‘design science.’ The opposite trend can also be observed: more entrepreneurial thinking in design processes (cf. Dorst, 2008): more attention for thinking in terms of markets and value instead of costs. From our research group, we have contributed to the entrepreneurship literature with a number of design-oriented studies.

A group of studies, around one dissertation (Van Burg, 2010), has focused on the design of entrepreneurship conducive universities. University spin-offs such as Lycos and Genentech are founded to exploit university intellectual property. They serve to transform technological breakthroughs from university research, which would probably remain unexploited otherwise. Therefore, policy makers have become very interested in university spin-offs as a means for technology transfer and economic growth. However, creating university spin-offs is not easy. Some universities generate more spin-offs than others (e.g., Di Gregorio and Shane, 2003; Klofsten and Jones-Evans, 2000; Kondo, 2004). Furthermore, university spin-off activity creates several difficulties, such as the potential conflict of interest between commercial and academic work and the risk to university reputation if founders of spin-offs act inappropriately (Bird, Hayward, and Allen, 1993; Shane, 2004; Slaughter and Rhoades, 2004). On the other hand, academic entrepreneurs feel sometimes that their behaviour is not welcomed by the university, or that the university procedures hinder the development of their venture. Thus, the main research question in this stream of research is: how can a university organization be designed that fosters the creation and development of university spin-offs?

This research was motivated by the observation that quite some knowledge has been accumulated about university spin-off creation and entrepreneurship in general, but that it is difficult to connect this wisdom with practices at universities. Therefore, a science-based design approach was adopted to connect the scholarly knowledge base with these practices (Denyer, Tranfield, and Van Aken, 2008; Romme, 2003; Romme and Endenburg, 2006; Van Aken, 2004). This resulted in five design principles, which are grounded in both theory and practice. The results of this study are published in van Burg et al. (2008). This publication focuses on the university level. Another publication from this research, Gilsing et al. (2010), focuses on the regional policy level and does also takes into account the design of policy to foster the creation and success of corporate spin-offs.

In the endeavor of developing design principles to advise these practitioners and to provide scientists with a framework to assess the state-of-the-art of the scientific knowledge, we identified a number of areas that needed further investigation. Therefore, we performed a study to explore the strategies that designers employ to use knowledge in the design process and to analyze the contribution of these strategies to the performance of the design process. We found that organization designers employ three strategies: off-line reasoning and planning, feedback-driven learning, and associative reasoning by way of analogies (cf. Broadbent, 1973; Tsoukas, 2005). Contextual conditions influence the use of these strategies and affect the associated effectiveness and efficiency of the design process (cf. Farjoun, 2008; Gavetti, Levinthal, and Rivkin, 2008; Simon, 1996). The design strategy of associative reasoning serves to acknowledge differences between the situation at hand and the associated case, which tends to result in design processes with high performance. As such, an analogy can function as a powerful vision to integrate design principles, to avoid lock-in in the current situation and to justify the design solution. In this respect, this study underscores earlier theoretical claims that designers in moderately complex and novel settings preferably engage in associative reasoning by way of analogies (Farjoun, 2008; Gavetti et al., 2008; Gavetti, Levinthal, and Rivkin, 2005; Gavetti and Rivkin, 2007). Moreover, feedback-driven learning is in particular instrumental in adapting given design principles and design solutions to the context. In addition, this design strategy serves to anchor design solutions in the organization and is necessary for the effectiveness of the design process (cf. Perrow, 1972; Weick, 1976). Finally, the execution of the design process, as such, appears to be largely influenced by the experience of agent-designers.

Another group of studies focuses on similar new venturing processes, but now in a corporate context. This research is mainly executed by Sjoerd de Jager (graduate student), Isabelle Reymen, Myriam Cloodt, and Elco van Burg. Large, mature organizations are often capable of exploiting existing products efficiently, but are typically less effective in being innovative. Financial systems and bureaucratic procedures adopted to control processes in the mainstream business of large organizations tend to be hostile toward innovative ideas, proposals and initiatives (Dess et al., 2003). One of the solutions to this problem is to structurally separate exploitation tasks and innovative exploration activities (Ambos, Mäkelä, Birkinshaw, and D'Este, 2008; Tushman and O'Reilly, 1996). Although there is quite some dispersed knowledge of the phenomenon, there is a need for guidelines how to properly transfer a corporate venture into the mainstream business realm, and thereby complement the vast amount of knowledge on corporate venturing processes. Here, our studies adopt a design science method to develop design principles grounded in the body of research evidence and meant to increase both the understanding of these kinds of transition processes as well as to support corporate management in the organization of these activities. Seven design principles were developed, following a similar approach as with the university spin-off design principles. The results of this study are being prepared for publication at this moment. Moreover, we explore some in-depth design issues regarding the corporate venturing process.

Design and development of business models

Several recent projects in our group focus on the design and development of business models. A business model is seen as a set of assumptions of how a company can create and appropriate value for its stakeholders. Many types and frameworks of business models have been developed, but it is still unclear how to "design" a business model, i.e. where to start, on which dimensions to focus, how to deal with the specific context operating in, etc. Also the development of business models over time is interesting to study; hereby a link can also be made with effectuation theory, e.g. experimenting with several business models in parallel. Graduate student Paul Zuurbier (2008) focused on effectual business concept development and business model innovation, linking business model development with effectuation theory. Business model ideation is currently the topic of graduate student Frank Elbers (2010). He is developing (part of) a creativity method for designing business models. Four other projects (on bachelor, master and PhD. level) are started recently on business model design and development topics. Finally, a project was performed in the creative industry focussing on the design of business models for collaboration between heterogeneous partners (like big companies and small firms or independent without personnel (ZZP)); this project will also be continued in a larger research project.

Design science methodology

Members of the ITEM group have worldwide recognition in the management and organization field for their design oriented approach. A number of recent principal and highly cited papers regarding design science methodology have founded this reputation. For example, the paper by Romme (2003) was the first to (re)introduce the design science perspective to organization science. Moreover, Romme and Van Aken have served as the "*original pioneers who brought the design sciences to organization studies*" (Paul Bate in: Journal of Applied Behavioural Science, vol. 43, 2007, pp. 10). In this respect, googlescholar.com reports more than 100 resp. 200 citations to their publications in Organization Science (Romme, 2003) and Journal of Management Studies (Van Aken, 2004). The approach presented in these papers has developed over several decades in the School of Industrial Engineering. Driving force of the design science research development in management science is the utilization problem or rigor-relevance dilemma. "*Management theory is either scientifically proven, but then too reductionistic and hence too broad or too trivial to be of much practical relevance, or relevant to practice, but then lacking sufficient rigorous justification*" (Van Aken, 2004, pp. 221). A number of the seminal papers are discussed below.

Romme (2003) argues that in view of the persistent relevance gap between theory and practice, organization studies should be broadened to include design as one of its primary modes of engaging in research. Design is here typified by its aim to find a solution, guided by broader purposes and ideal target systems. Moreover, design develops, and can draw on, design propositions that are tested in pragmatic experiments and grounded in organization science. This study first explores the main differences and synergies between science and design, and explores how and why the design discipline has largely moved away from academia to other sites in the economy. The argument then turns to the genealogy of design methodologies in organization and management studies. Subsequently, this paper explores the circular design methodology that serves to illustrate the nature of design research. Finally, Romme proposes a framework to guide the interplay between design and science modes.

Van Aken (2004) argues similarly that academic management research has a serious utilization problem. In this field mainstream research tends to be description-driven, based on the paradigm of the ‘explanatory sciences,’ like physics and sociology, and resulting in what may be called ‘organization theory.’ This article argues that the relevance problem can be mitigated if such research were to be complemented with prescription-driven research, based on the paradigm of the ‘design sciences,’ like Medicine and Engineering, and resulting in what may be called ‘management theory.’ The typical research products in Management Theory would be ‘field-tested and grounded technological rules.’ The nature of such rules is discussed as well as the research strategies producing them.

Romme and Endenburg (2006) further detail the design science methodology, and propose science-based organization design that uses construction principles and design rules to guide practitioner-academic projects. Organization science implies construction principles for creating and implementing designs. These principles serve to construct design rules that are instrumental in developing organization designs. Testing and implementing designs require pragmatic experimentation in complex, dynamic settings. The authors explore a circular design process as an example of science-based organization design.

Denyer, Tranfield and Van Aken (2008) refine the methodology to develop science based design principles. These design propositions follow the so-called ‘CIMO-logic.’ This logic involves a combination of a problematic Context, for which the design proposition suggests a certain Intervention type, to produce, through specified generative Mechanisms, the intended Outcome(s). They discuss how design-oriented research synthesis provides a vehicle for addressing fragmentation and increasing the chances of application. Moreover, this study explores how the development of design propositions can result from synthesizing previously published research and illustrate this with the design of high-reliability organizations (HROs).

Van Burg, Romme, Gilsing and Reymen (2008) also develop and illustrate a part of the methodology, especially regarding the actual interplay between practice and research. In the context of entrepreneurship and innovation, design processes tend to be as much emergent as deliberate in nature (Hargadon and Douglas, 2001). The framework in Figure 1 suggests there are ample opportunities for experimentation (practice) to drive the creation of, for example, design solutions and principles. This more emergent design process arises from what Schön (1987) calls reflection-in-action: that is, the rethinking that leads to on the spot experiments as well as the further thinking “*that affects what we do – in the situation at hand and perhaps also in others we shall see as similar to it*” (Schön, 1987: 29). This emergent quality of the research-design-development cycle in Figure 1 is likely to prevail when design principles are non-existent, underdeveloped, or unknown to practitioners. In a more mature discipline, this cycle is as much emergent as it is deliberate: the emergent dimension serves to respond to and account for the unique and dynamic nature of the local setting, whereas the deliberate dimension serves to build a body of knowledge that cuts across multiple settings. These two faces of design also reflect the need to decontextualize and contextualize design principles and solutions.

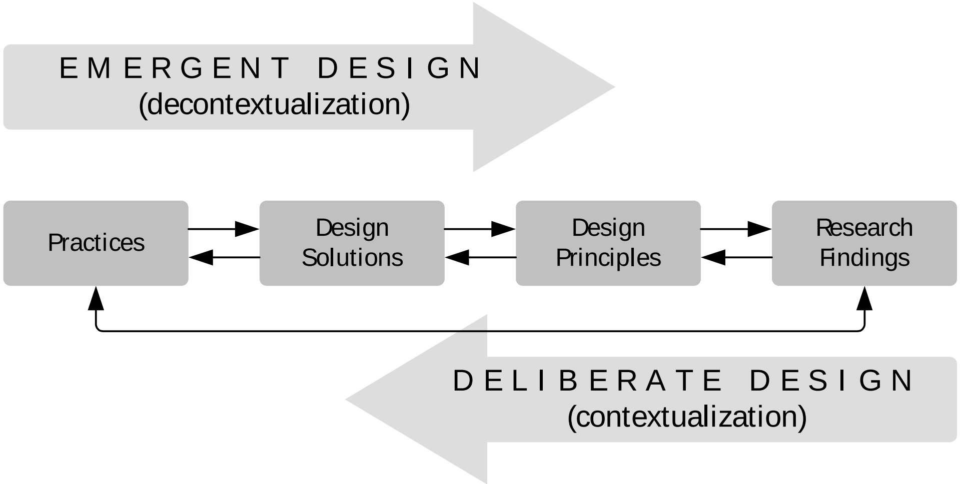

Figure 1: The research-design-development cycle from a science-based design perspective.

Other recent studies from the ITEM group that have a methodological component regarding design science are the following: Dunbar, Romme, and Starbuck, 2008; Huff, Tranfield, and Van Aken, 2006; Jelinek, Romme, and Boland, 2008; Romme and Damen, 2007; Van Aken, 2005; Van Aken, 2007; Van Aken and Romme, 2009.

Education and broader exposure

Design science methodology is not just an academic method, but is also used to teach students how to design organizations. For bachelor students, our design approach has been codified in a methodological handbook for business problem solving (Van Aken, Berends, and Van der Bij 2007). For master students, a more in-depth course on 'Design Science Methodology' is offered at the School of Industrial Engineering. Moreover, the current redesign of the education program of the School of Industrial Engineering also follows a number of insights from this methodology. Moreover, a group of PhD students gathers every month to discuss the development of design science based dissertations. The name of this group is the 'Design Science Research Group', and one of the group's members has also launched a wiki-page about the approach (http://en.wikipedia.org/wiki/Design_Science_Research).

Presence of the ITEM group in the design community

The ITEM group is present in the design community in several ways. First of all, several people of the ITEM group are member of professional organizations affiliated with design, like PDMA (Product Development & Management Association) and DMI (Design Management Institute).

Next, there are memberships of editorial boards of journals, focusing on designing. Georges Romme is for the journal Organization Studies responsible for the design related papers. George Romme and Isabelle Reymen are also editorial board members of the new International Journal of Organizational Design and Engineering (IJODE) (since 2009). IJODE is a scholarly journal aiming at the development of organizational design and engineering (ODE), defined as the application of social science, design science and computer science research and practice to the study and implementation of new organizational designs, including the integrated structuring, modelling, development and deployment of IS/IT and social processes. Georges and Isabelle are also member of the program committee of the related International Workshop of Organizational Design and Engineering (IWODE).

Isabelle Reymen was also associate editor of the design track of the European Conference on Information Systems in 2008 and 2009 and Joan van Aken of the International conference on Information Systems.

Hans Berends, Georges Romme and Jennifer Whyte organized a track on "Exploring the Interface Between Organization Design and the Humanities" at the European Group of Organization Studies (EGOS) Colloquium held in Amsterdam in 2008. Georges Romme co-organized with Sabine Junginger a Personal Development Workshop (PDW) on Design Research at the Academy of Management (AoM) Annual Meeting in 2009, which will be continued at AoM in 2010.

Finally, we review for journals like Research in Engineering Design, Organization Studies, Design Studies, Co-Design and several design related conferences.

Conclusions and further directions

Our group has contributed to developing a design mindset among (management and entrepreneurship) scholars as well as students. We created an improved linkage between science and design practice via the development of design principles. This work on *design science methodology* will be continued in the future via organizing workshops, editing special issues and publishing about the topic. Furthermore, given the increasing importance of entrepreneurship in the design and management field, the linkages between *designing and entrepreneurship* will be reinforced by studying design processes in the context of new business development. Finally, we will continue working from the more bottom-up, participative, reflective practice like approaches to design processes and their ability to deal with *flexibility in the design process*; the trend for more flexibility is widespread, given the increasing uncertainty and the continuously changing (business) environment.

A FRAMEWORK TO DEVELOP SUPPORT FOR PRODUCT-SERVICE COMBINATIONS FOR BASE OF THE PYRAMID

ICT supported healthcare in rural China

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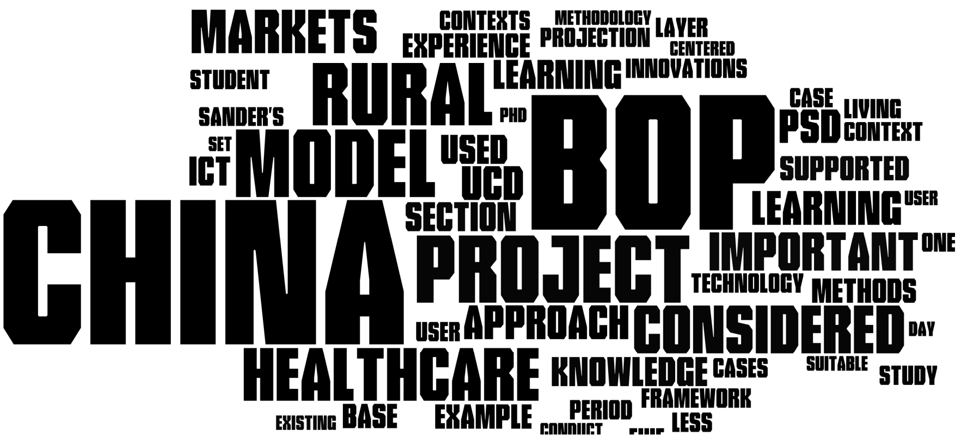

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Definition and rationale

According to the Prahalad (2002), there are 4 billion people living on an income less than US$3 per day and 1 billion living on less than even US$1 per day. These people are often called "Base-of-the-Pyramid" (BoP). Most of the BoP are living in developing countries, such as India, China and Brazil, and so on. BoP is a special consumer target group in product design. Prahalad and Hart's (2002) work about BOP suggests that there is a fortune to be made for entrepreneurs in BoP initiatives, while offering great opportunities for the world's poor to escape from poverty.

Our previous empirical research (Jiang and Kandachar, 2009), based on student design projects, showed that the state of the art in design for BoP always covers a great deal of design knowledge including the management of emerging markets (London and Hart, 2004), technology transfer (Simanis and Hart, 2008) and disruptive innovation driven approaches (Christensen, 2006).

Kandachar (Kandachar and Helme, 2008) proposed and validated a "User-centered Design (UCD)" strategy for BoP: it states that 1) the needs of the users should be considered as a starting point for BoP product and innovations, 2) several innovative methods could be considered as an effective approach to serve the unmet needs of the BoP-community. On the user's side the following aspects could be considered: ethnographic tools, cultural probes, business innovations such as hybrid business models, corporate responsibility, technological innovations like disruptive innovations, open source designs, etc.

Information and Communication technology (ICT) based products and services are considered as important solutions in solving historical health problems in rural China. (Dummer etc, 2006).

Problem statement and objective

Research (Kandachar and Helme, 2008) and personal experience (Jiang and Kandachar, 2009) illustrates that a User-Centered-Design (UCD) approach could be used in Product-Service combined Design (PSD) for Base of the pyramid (BoP). However, after observation of existing student projects and conducting interviews with professional and student designers in China and the Netherlands, we found that they still need to learn how to conduct UCD for BoP. Both have requirements in this issue. For example, most Chinese designers lack systemic UCD education and training. They follow a Product-Centered-Design approach; Dutch designers who would design for the Chinese rural market are always annoyed with the differences in the design cultures of their own and their Chinese design team members. Thus, the aim of this PhD project is to develop a design framework and guide for designers and we limited the contexts within "ICT supported healthcare in rural China."

Research question

Following from the above, the main research question of this project is: "how can designers quickly increase their knowledge of how to conduct User-centered Design in their targeting of rural China ICT supported healthcare markets."

Methodologies

As a PhD project, several different methodologies are being used, such as case studies and design inclusive research. The whole process of framework development will be conducted in three periods:

1. Literature review and case study: this period explored constraints for designers in Product-Design Design for BoP.
2. Contents development: in this period detail knowledge was developed that is useful for designers, e.g. the Chinese design culture will be studied via interviews.
3. Framework development: the last period will result in a systemic knowledge framework for designers about ICT supported healthcare design in rural China. This period will be carried out during the coming year.

Conclusions from steps initially

Step 1

- Designers suffer from two constraint categories in Product/Service Design (PSD) for Base of the pyramid (BoP): learning about design contexts and projection of BoP design projects (Jiang, 2009). "learning" means that the designer must set up a complete information category, analyze it and choose suitable methods; "projection" means that the designer must collect a variety of sources and set up a platform to achieve design goals.
- Both learning and projection can be optimized in the early stages of Product/Service Design (PSD) for Base of the pyramid (BoP) if designers are able to realize the importance of "learning" and "projection" – experience from design cases in China (Jiang, 2009).

Step 2

- The "learning" model is composed of five elements: design culture, mindset, methodology, method, and tool. This model originates from a co-creation model about user experience (Sanders, 2009) and adaption and adoption are needed in this project – the result of observation from 24 BoP cases.
- The "projection" model of BoP markets relies on stakeholders, which is a less important issue in high-end markets. For example in ICT supported healthcare projects in rural China, local academic partners play important roles and local (central) government could be considered as the preferred customer – experience from design cases in China.

"Learning model" based on Sander's model

In this section, we would like to introduce one aspect of the research work entitled "learning model" as an example to describe how we set up a model step by step. As mentioned above, we discovered that learning about BoP design contexts is a big barrier for designers, while here learning includes a variety of elements such as cultural effects on rural Chinese healthcare. To minimise the scope of our interest, we chose Sander's co-creation model (Sanders, 2009) as the starting point and developed the "learning model."

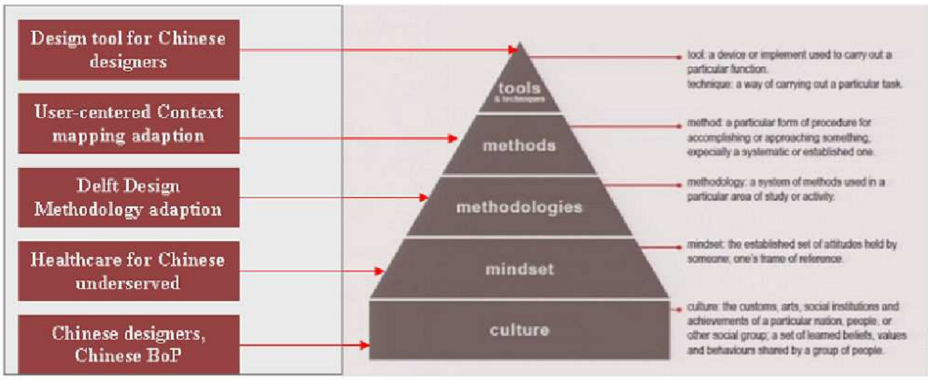

Figure 2: Sander's model, the first stage of our learning model in BoP design projects.

In Figure 2, Sander's model identified five layers that designers should focus on when they plan to carry out UCD research in design projects. These five layers might also be useful in BoP, however, specific BoP context questions should be answered in this project like:

- What is the design culture in rural Chinese healthcare?
- What are important design factors on rural Chinese healthcare?
- Are existing design methodologies (such as Delft Design Methodology (DDM)) suitable for BoP and how should these be modified?
- What kinds of UCD methods could be used to conduct user experience research?
- What are suitable design tools and techniques in rural China?

Thus we conducted five sub research projects and concentrate our interests on them. As a result, Table 1 illustrates descriptions, conclusions and outputs up to the present.

TABLE 1: Learning part of dissertation (unfinished).

Layer	**Dissertation chapters**	**Initial conclusion**	**Research Method**
Cultural layer	This section will explore the position of a designer in the PSD for BoP. The study in this part includes the exploration of Chinese design education system and designers'	Working styles between design schools and companies in China and Netherlands are different; in China, schools are not considered as knowledge exporters but potential	Initial workshop and interviews with Chinese professors and The approach in this part is the Involvement of

	knowledge, the situation of design activities and relationships between design institutes and industrial companies.	employee factories; the contact between SME and schools are rare.	Chinese University student designers both at TU Delft and at China.
Mindset layer	This section will discuss several design factors, which are related to PSD for BoP, a new mindset context map will present the relationships and differences between BoP markets and high-end markets.	(1) Chinese design contexts are composed of user, community, product and environment. Political factor is one important factor for environment. (2) Four aspects should be considered: society, market, technology and management.	Interview and case study (Jiang and Kandachar, 2009).
Methodology layer	This section will teach the designers about appropriate design methodologies, Delft Design Methodology is considered as a starting point for the model.	“Four domain models” could be used here. Designers should pay attention to reality, mind, production and realization.	Case study (Jiang and Kandachar, 2009).
Methods layer	The aim of this section is to provide indications for designers to accurately adapt existing methods with their own approaches. An example design case is “healthcare design opportunities identification in rural China” will illustrate that approach.	Methods from context mapping (Visser, 2009) can be used for user contexts in PSD for BoP in China. However, adaptation of methods by designers is advisable.	Design inclusive research (Jiang and Freudenthal etc, 2010).
Tool Layer	In this section, we demonstrate which tools can be used and advised for rural China healthcare. The data is collected from cases.	Communication skills and private networks are very important.	Observation, interview and experience.

Conclusion

We are half way into the project now. Several initial conclusions can already be given. Product-Service combined Design (PSD) for Base of the Pyramid (BoP) is one of the activities in design for emerging markets, in which BoP means an income less than US$3 per day living in developing countries such as China and India. Compared with other mainstream markets, designers meet many obstacles when striving for success in BoP markets. UCD was found to be one design approach that should be considered to create the values and impacts of design for BoP people; other important approaches include an innovation driven approach, technology driven etc. This PhD project focuses on how to help designers learn how to achieve User-centered Design for Base of the Pyramid within the context of rural Chinese healthcare. Alongside the investigation, a manual can be designed to guide designers. Some initial conclusions have already been achieved, for example, designers are suffering from constraints on “learning” and “projection” so that both are considered as important components in the framework.

INTELLIGENT HEALTHCARE

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Introduction

ICT based technologies have revolutionized healthcare. The information provided and the hardware support enable minimally invasive therapies, allow premature babies to survive, and raise the maximum life span of humans. Much more is still possible, and technologists are continuing development, e.g., nanotechnologies distributed into human bodies, treating cancer.

Technologists work together with medical partners to develop and to introduce more innovations to improve quality and safety of healthcare. At the same time the limits of patient safety are reached by increased complexity of the work situation and the technology. There are various technologies available, which could potentially offer increased patient safety in other application areas. However, actually making them available for use is blocked by usability problems or other limitations, e.g. legislation, standards, lack of knowledge about the workflow, or lack of insights into which information is actually needed by the medical professionals.

Cognitive ergonomics and structured information design in the medical domain is scattered, immature and often even totally lacking. Introducing methods from other domains (e.g., usability design for consumers or information design from aviation) cannot be conducted straight forward, because the context in which the ICT products are being used and being developed is not comparable to the established industrial design or ergonomics areas. The medical domain has many different products used in parallel, produced by different manufacturers, different protocols of usage and different user types, responsibilities and training levels, while the human body treated is a biological system with many unpredictabilities. Hospitals are (to some extent) ‘learning organizations,’ which means that treatments change and training methods change, based on evidence based medicine, incident analysis, etc.

The ICT-developers from R&D departments or academics (via consortia), are mostly engineers and scientifically trained personnel. Ideally, they need to involve users in all aspects of development, early functionality definition, user testing, implementations and next innovation rounds (next releases, product upgrades). However, often there is no connection to users in one or more of these stages: e.g. in post market surveillance of infusion pumps only two out of ten manufacturers actually conducted active data gathering, according to a Dutch survey by RIVM (Roszek et al. 2008). Other proper ergonomic approaches regarding usage, maintenance and incidents analysis are also often lacking.

An important current industry-user relation is based on interaction with leading medical users to define functionalities and conduct tests. Often presented information is defined with help of the user, but more often the manual is designed completely disconnected and certification of use of equipment is mostly lacking. Innovations in technology aim at restricted functionalities, not at optimizing the daily workflow and the larger safety system. There is no systems approach anticipating human work in context. Although presented information is often defined with the user, theories from information design and cognitive ergonomics are hardly used. This results in situations where the moment of information provision, information location and modality (e.g., sound/ visual) are not appropriate, or where handling the parallel tasks is difficult or even dangerous. One typical example is the neonatal intensive care unit: At this time there are so many alarm sounds that some propose that premature babies should sleep with ear silencers, thereby reducing possible disturbed brain development because of the noise. The frequent and loud sounds disturb cognitive work and alarms are ignored by nurses, in order to be able to conduct their daily tasks and handle (other) safety events.

Aim

The design research program 'intelligent healthcare' should contribute in changing this situation. Human cognition should be considered in ICT designs, as well as the complete work situation. Industry and ICT-based medical technology developers should communicate with medical users in a structured, complete manner, focusing on all relevant aspects of the system. Medical users should feed the lessons learned about technology back to industry (comparable to aviation incidents analysis to improve especially usability). Innovations in technology should be matched by innovations in organization or work procedures. Co-development of technology and organization is needed.

The program consists of three areas, with (design) research questions: 1) Information design: which cognitive ergonomics and information and interface design approaches can be applied (from various domains, e.g. aviation)? How should the methods be applied or changed? 2) Co-design: which factors in co-design influence quality of design, and influence patient safety in the total outcome? How do different domains learn to work together and how can this be stimulated? From the findings co-design methods are being devised and improved. 3) Prototyping: what are the requirements for prototypes meant for testing with users in iterative design cycles? Are there off-the shelf tools for that, or should new prototyping tools be developed? If so, new prototyping platforms are developed, following the new requirements.

Approach and research group

To answer the research questions multiple design cases are conducted. In the design cases detail methods and overarching methods (cognitive ergonomics, information analysis, and co-design) are adapted, applied and developed for the medical domain. This is done with several parties: medical, industrial and technology, see Figure 3.

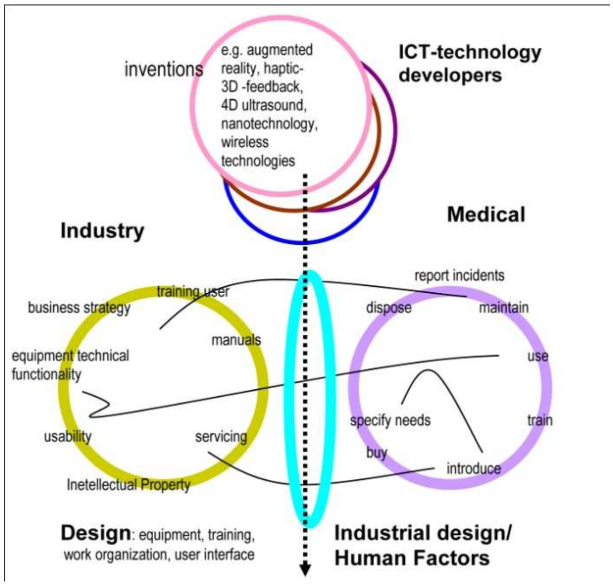

Figure 3: The parties in all design cases. Companies and hospitals should have relationships on all relevant topics. Already existing relations between companies vary. Common current relations are about providing training and co-developing system functionalities.

The Intelligent Healthcare Group is represented as the thin oval in the middle. It is situated in the Faculty of Industrial Design Engineering and led from the Human Information Communication Design group. Two researchers are from another group (Applied Ergonomics and Design) and department (Design Engineering). All researchers are in Medisign, which is in a matrix through the Faculty. The program and group was initiated and is led by the author with one PhD student and soon several student researchers. In 2009 the group consisted of six researchers and five MSc. graduation researchers.

All research is design case-based. Central in the approach is the establishment of communication between technology developers and the medical field while feeding in industrial design methods, and in particular information design and cognitive ergonomics. Co-design methodologies are being developed as well as training of the design team, because co-design needs to be learned. Co-design includes not only technology and user interface, but also the work organization. The two need to be developed in parallel for optimal fit. All projects (PhD, postdoc or graduation) produce interactive prototypes and user testing in the iterative design rounds to facilitate communication between developer and medical user.

When we started the methods to collaborate with a medical partner were immature – in particular because understanding about co-design was only at our side, and it had to become two ways. Important was to first raise awareness, to show demonstrators and communicate with the field. Reaching the final goal, to be able to co-design with all the parties in medical and industrial reality can only be accomplished in several carefully planned steps, which require several years.

Design research methods

There are several ‘schools’ of design research. The well known ‘design studies activities area,’ investigates how people design, the methods and processes used, and the outcome in terms of artefacts (classification by Cross 1999). In this approach the researcher takes an observer’s perspective. We use literature from this type of investigations to learn about possible methods to apply, to adapt the methods and to check our findings against other cases.

This perspective is, however, rarely taken in our own case analysis: we (from TUD and our partners) are involved in all our cases as design team member, as industrial designer, medical expert, or technologist designer. TUD leads the design research activities, but the other partners are involved also. The dominant approach we follow is ‘first-person perspectives’: the design-researcher is part of the design team and allows experiences as team member and as professional to influence the conclusions. The results are not totally objective, but the benefit, according to Fallman (2008) is that more and deeper insights are possible. An example method we developed for analysis is ‘retrospective participant observation.’ Several designers from the team analyze the process and design outcome together, and study literature to connect their findings to. Objectivity is sought in using as much as possible external judgments. For example, a ‘good’ design project (to study in depth) is defined as a project which is rated highly by the stakeholders or end users, not by us.

Design methods from one case are applied again in another context and validated, adapted, and improved. The whole process is a combination of grounded theory – identifying hypothesis, and finding support of these hypothesis in next rounds, while also looking for new insights.

Phase 1 - Raising awareness in the medical field

The early projects (2001- 2006) were mainly for raising awareness in the medical field. The prime focus was on communication with the medical field, developing co-design with medical and demonstrating what is possible through user-centered design. Main medical partner was University Medical Centre Groningen, department of nursing affairs.

Main case: in the ICU information overload and at the same time the information lack are reducing patient safety. To demonstrate alternatives, the ‘ICU of the future’ was developed, consisting of six graduation projects and a PhD study, by ir. M. Melles.

Some main findings: 1) Nursing informatics applications should cope with the three different roles in ICU nursing; i.e. practitioner, scholar, and human (Melles et al., to be published). 2) Usability problems can remain the same, even after two years of use. Alternative learning support is needed. 3) Demonstrators are effective means to communicate the power of user-centered design to other disciplines.

Figure 4: Nurses inspecting and giving feedback about the ‘ICU of the future’ at day of patient safety, 2006, at UMCG, Groningen. The six demonstrators from graduation students were tried by the nurses: distributed interfaces, e-learning, and personalized embedded help for infusion pumps; a personalized team trainer for a respiratory device; a concept for alarms in the ICU, with information via visual, tactile and sound.

Example Research Question 3: Prototyping

Building demonstrators or prototypes is crucial to validate research and design hypothesis and to explore aspects of user behaviour and evaluate proposed system in context. Various commercial prototyping systems are used in the projects. But often they do not fit the needs of the design team very well. In particular investigating ergonomics, requiring frequent and fast changes, preferably with the user even present, is poorly supported by current prototyping tools.

Research questions: what are the requirements for prototypes meant for testing with users in iterative design cycles? Are there off-the shelf tools for that, or should new prototyping tools be developed? Is so, new prototyping platforms are developed, following the new requirements.

Method and outcome: two TU Delft prototyping platforms were developed, tailored to the demands from industrial design. For this computer scientists are in our team. One aims at modelling 3D navigation supports, by dr. ir. E. Varga. The other is Quint pro builder (QPB), researcher: ir. M. de Hoogh (Freudenthal et al. 2004). QPB was developed to provide a simple coding platform for ‘laymen’ (designers). It was used in education for three years to investigate emotional reactions to revalidation services (meant to motivate to do boring things) and other user experiences. QPB can process data from sensors (e.g. through Max/MSP from Cycling ‘74) by means of an easy to use scripting language, link it with user and session data to produce output for the user interface (e.g. implemented in Flash from Adobe).

The student designs were rich and user experience testing could be performed well. The platform indeed supported rapid prototyping efficiently. However, understanding the possibilities of product intelligence at higher levels (e.g., system reactions to trends in user behaviour) is difficult for many design students, often resulting in relative simple - direct response - scripts. To design advanced functionalities multidisciplinary teams with designers and computer scientists would be beneficial.

Phase 2 - Industrial design meets complex multi technologies

Phase 2 ran from 2005-2009. The aim was to link industrial design, including human factors, to medical and to technology developers focussing on novel technologies (e.g., technical inventions for minimally invasive surgery).

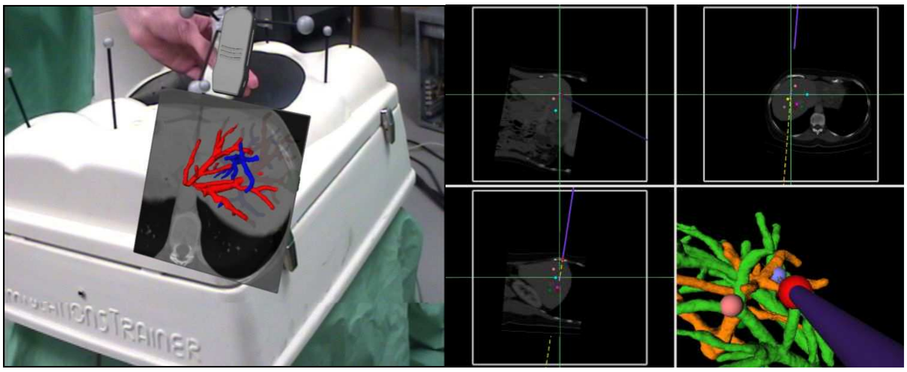

Figure 5: Left: Abdominal phantom with prototype of the ARIS*ER Radiofrequency Ablation system (Kalkofen et al. 2007), demo on website. The scene is viewed through the head mounted display in 3D. *Right:* Second iteration of the user interface design, with three orthogonal views though the needle and a 3D view, both versions show segmented out vessels and tumour in the liver (Stüdeli et al 2008).

Main cases and some key findings: 1) silent alarms to solve the sound problems in the intensive care unit: multimodal signalling is likely to better support cognitive tasks, reduce human errors and to reduce stress on worker and baby (Freudenthal et al. 2005). A concept was designed and feasibility study conducted. 2) The transfer and adaptation of knowledge from user-involved industrial design from the developed countries to developing counties. Cases are ICT for rural healthcare in China, researcher: J. Jiang MSc. and healthcare communication aids for the Deaf in South Africa (project leader: Prof. Blake, UCT). 3) ARIS*ER augmented reality in surgery, EU research training network (eight institutional partners).

Our share in the ARIS*ER plans was written in close collaboration with strategic medical partner (Prof. Pattynama, Erasmus MC). The aim was to enhance quality and safety of minimally invasive surgery by applying user-centered design. The technologies are: next generation novel imaging guidance (augmented reality based on medical images) and cross linked robotic systems (automatic control loops guided by sensed data from the patient). The chosen applications were: percutaneous radiofrequency ablation of liver tumours, laparoscopic liver resection, and endoscopic heart surgery. The hired researchers were: thirteen technology developers, one industrial designer (dr. A. Jalote-Parmar, M.Des.), one ergonomist (dr. T. Stüdeli Eur Erg), and one surgeon. These hired researchers collaborated with external partners and staff, to develop the new technologies. These were combined in demonstrators and tested with users (in the last round on phantoms, animals and patients) (Lamata et al. 2010). In Figure 5 two iterations of user interfaces to guide a needle treatment are shown.

Some main findings concern: multidisciplinary design, e.g., how to blend concurrent engineering with co-design; co-design methodologies, e.g., facilitation of communication between the disciplines, had to be supported by new methods (Jalote-Parmar et al., 2007); co-design has to be learned and trained; ergonomics can bring in structured requirements generation and evaluation driven design; interface design (e.g., for 3D navigation guidance in the human body), see Figure 5 and (Furtado et al., to be published). Other design methods (e.g., how to use technology assessment as design tool); design for learning by surgeons and their mental models (Freudenthal and Pattynama 2007).

Example Research question 2: Co-design methods

‘Co-design’ has various definitions and there are many methods available. There are, however, also many methods lacking. For example, there were no earlier projects – and therefore no actual methods, to co-design with all parties (multiple technologies/ medical/ industrial design/ ergonomics) – methods had to be developed from scratch.

Research questions: in all projects the questions are: which factors in co-design influence quality of design, and influence patient safety in the total outcome? How do different domains learn to work together and how can this be stimulated? From the findings co-design methods are being devised and improved.

Method and outcome: the roles and tasks of the different collaborating parties were not clear and developed during the cases and as part of the cases. In Figure 6 the co-design methodology in ARIS*ER in the later stage of the project is shown.

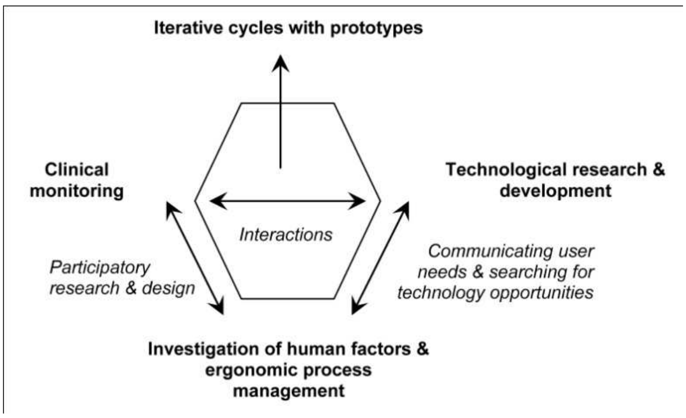

Figure 6: The co-design methodology in ARIS*ER in the later stage of the project. Working together had to be learned (Lamata et al., 2010).

Phase 3 – Completing co-design towards reality

In the current projects our aim is to link industrial design to medical, to technical and to industry (including other aspects, such as business) as indicated in Figure 3. In the previous phase we worked with academic and industrial technical research partners (fundamental research). Now we bring industrial reality into the projects: A: industrial quality improvement cycles; B: software development suited to industrial needs, taking into account easy translation to production; C: medical researchers follow the same multiple cycles of analysis, intervention in context and rigorous evaluation (also called action research), focussing on improved procedures for medical treatment quality. Here we combine technology driven action research and medical driven action research. Usability research and medical research will be done with the same prototypes, and often need to be done in combined tests. In ARIS*ER (in the previous phase) this combination also existed, but now the systems will be placed in the actual context of work, with real patients and in treatment chains, e.g., in home care. High level safety requirements are posed on the prototypes, on the testing protocols, and all investigations have to meet even more strict ethical requirements. Design research investigations also focus on the methods required for these conditions.

Rationale: Methods for co-design and user-centered design are validated for a range of contexts, and extended to include industrial needs. Human cognition is universal between domains; therefore cross fertilization is being exploited. The two main projects will be introduced and initial results.

Coupling the quality circle in medical to the quality circle in industry (CQMQI)

The organization of the projects is shown in Figure 3. Companies and hospitals already have relationships, e.g. in providing training and in co-developing system functionalities. Which actual relations are established varies between companies, domains and devices. We intend to establish ‘complete’ relations, focusing on all relevant aspects of the system.

The role of industrial design/ human factors (also called ergonomics) is to initialize or enhance these communications and improve their effectiveness. Secondly, the aim is to introduce information design and cognitive ergonomics. Thirdly, other industrial design methods are used to improve the design process. The idea is to actually link the quality circle in medical to the quality circle in industry. This part is conducted with our second strategic medical partner Prof. J. Klein, anaesthesiologist and Chair patient safety, Institute of Health Policy and Management (iBMG).

Various cases will be executed in various medical domains. At this time we are focussing on respiratory devices with Dräger, Erasmus MC and iBMG, Rotterdam. In fact a user interface researcher (ir. J. van der Peijl, PDEng) from Dräger is detached part time for a year to our group to establish close collaboration. Field studies are foreseen in Rotterdam. The second topic is Radiotherapy: Nucletron and Catharina Hospital Eindhoven. A pilot investigation is ongoing.

The interventional cockpit

The second project has the same high level aim, but the program focuses heavily on certain type of user-system interactions: STW granted the project ‘4D ultrasound for improved image guidance in minimally invasive needle interventions: the interventional cockpit,’ with medical partner Prof. Pattynama, vascular and interventional radiology (Erasmus MC) and imaging technology partner Prof. Niessen and dr. ir. T. van Walsum (Biomedical Imaging Group Rotterdam, Erasmus MC); Philips Healthcare is industrial partner. The goal is to make 4D ultrasound available to the interventionist. This means the interventionist will get a better view of the actual position of tissues and lesions in the body during needle interventions. Demonstrators will be implemented in the intervention lab and tested with patients.

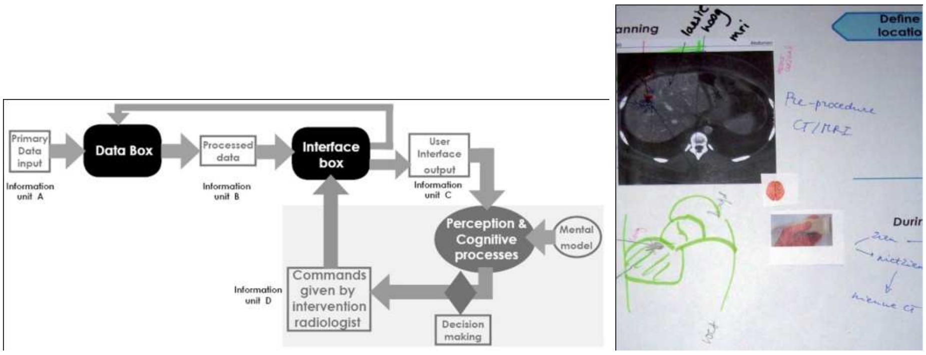

Figure 7: The information framework from preparation for ‘the interventional cockpit’ and the data from an adapted generative tool technique (for one participant at a time) used to understand cognitive processing as to define the information requirements (Meijs et al., 2008).

Example Research Question 1: Cognitive ergonomics and information design

Information design is closely linked to cognitive ergonomics. Cognitive ergonomics is a human factors discipline, while information design is a design discipline. Therefore information design (should) include(s) cognitive ergonomics, but information design is also concerned with technological implementation, graphical aesthetics, sensory ergonomics, etc. Ergonomics skills and knowledge are different from industrial design skills and knowledge.

Research question: which cognitive ergonomics and information and interface design approaches can be applied (from various domains, e.g. aviation)? How should the methods be applied or changed?

*Result*s: an example from the preparation phase of ‘the interventional cockpit’ is shown in Figure 7. An information framework was developed, identifying the need for user-centered requirements for primary data, processed data, commands by user, and user interface output. These requirements can be gathered by various methods of workflow analysis. But up till now there has been little attention on how to combine this workflow with cognitive processing and mental model interaction. An existing design research method, generative tools, was adapted, and applied; see Figure 7 and Meijs et al. (2008).

Key references from research group

Table 2 shows an overview of the key references from the research group.

TABLE 2: Key references from research group (four plus authors: indicated as et al.)

Author(s)	Year	Title
Melles, Freudenthal, Bouwman et al.	To be published	Coping with different roles in intensive care nursing: design implications for nursing informatics applications.

Freudenthal, de Hoogh, Keyson	2004	Intelligent Product Builder: a rapid prototyping environment for software in context aware hardware products.
Kalkofen, Milko, Massoptier et al.	2007	http://www.ariser.info/projects/rfa_demo.php [5-2-2010]
Stüdeli, Kalkofen, Risholm et al.	2008	Visualization tool for improved accuracy in needle placement during percutaneous radio-frequency ablation of liver tumors.
Freudenthal, Melles, Pijl et al.	2005	A contextual vision on alarms in the intensive care unit.
Lamata, Ali, Cano et al.	2010	Augmented Reality for minimally invasive surgery: overview and some recent advances.
Jalote-Parmar, Pattynama, de Ridder et al.	2007	Surgical workflow analysis: identifying user requirements for surgical information systems.
Furtado, Stüdeli, Sette et al.	To be published	Endoclamp balloon visualization and automatic placement system.
Freudenthal, Pattynama	2007	What's in a surgeon's mind? Learning for performing treatments and operating equipment.
Meijs, Freudenthal, van Walsum et al.	2008	Cognitive processing research as the starting point for designing image guidance in interventions.

Conclusions

In Intelligent Healthcare at TU Delft, the conditions for multidisciplinary collaboration were identified and implemented: 1) raising awareness, 2) training partners - on their request, and developing training programs with them, 3) developing co-design methods with them.

The role of industrial design in (large) multidisciplinary projects is to enhance communication between partners and also to apply industrial user-centered design and research methods. Similar to a contractor, designers conduct management tasks, as well as execution tasks. Depending on their specialism contractors work also as a bricklayer or as a carpenter. Designers apply management methods and human skills, but also execution methods: e.g., cognitive studies about users. If the carpenter misses a suitable tool he will buy it, adapt it or make a new one at the spot. In design this is not different. During the projects we adapted and developed many user-centered methods. Further development of "the carpenters' toolkit" for user-centered design is an important next aim.

In the next phase design reality is the aim: developing for actual industrial and medical context. Developed methods in the past five years will be validated and extended to achieve this. A main difference will be in the type of prototyping and testing and coupled medical investigations. The project will not only be user- and technology driven, but also company-, business driven and care-organization driven. Cognitive systems engineering methods will be deployed and improved, for systems design (organization safety) and for interaction details, such as orientation and navigation, decision support, eye-hand coordination, attention directing, and multitasking.

Acknowledgements

We would like to thank all the students, researchers, and partners who have worked with us over the years. ARIS*ER EU Marie Curie RTN network was funded under Marie Curie actions MRTN-CT-2004-512400; CQMQI is funded by Senter Novem; Communication access for Deaf People in South Africa is funded by NWO/SANPAD.

USE OF DESIGN ORIENTED SCENARIOS AND RELATED TOOLS IN RESEARCH BY DESIGN

Outcomes case 'Schiphol, the grounds' – integration of electric mobility into the built environment

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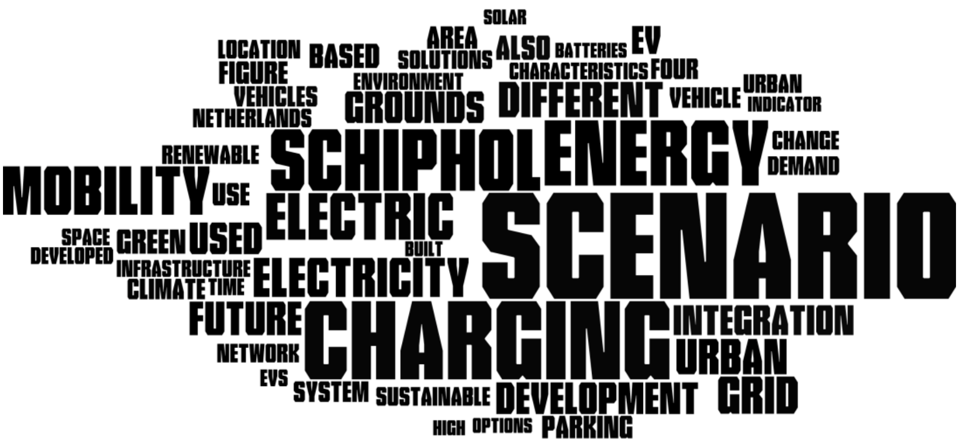

Word cloud of this chapter, created with http://www.wordle.net

Introduction

In this paper we present the main results of an integrated scenario development study for the introduction of electric vehicles at 'the Grounds' location at Schiphol in 2030. The scenario development study is part of a larger research project that has been executed by researchers of the Delft University of Technology and the Schiphol Group. This research project, called 'Diemigo,' is part of TRANSUMO; a national Dutch research program that aims to initiate and support a transition to a sustainable mobility system that supports an international competitive position of the Dutch economy ('profit'), that respects the environment ('planet'), and that offers high quality accessibility and mobility for people and the goods they need ('people'). This 'Diemigo' research project had two main objectives: to develop a preliminary methodology to select and design effective solutions for the implementation of large scale electric mobility and electric charging infrastructures into the built environment; and to develop and design a scenario specifically for 'the Grounds' locations at Schiphol (including electric mobility solutions, charging interfaces, power grid, urban design implications, and location choice). In this paper only the results of the scenario development and design efforts for the grounds are summarized.

The introduction of electric vehicles into Dutch society is one of the promising options to create a more sustainable mobility system for the future. Electric vehicles hold the promise to reduce local CO_2, NO_x and particle emissions in a major way. In addition, electric vehicles are silent, easy to service and have high 'well-to-wheel' energy efficiency. However, the transition to a partially electric mobility system also faces several significant challenges. Current electric vehicle technologies have limitations with respect to ease of use, driving range and time-to-charge, and are relatively expensive. Moreover, the use of electric vehicles requires an adequate charging and electric infrastructure, and also dedicated solutions to park and charge that are optimally integrated in urban design and built environment.

Schiphol is a pivotal point in mobility in the Netherlands with its central position in the Randstad and with a lot of public attention for all its actions and features. Schiphol considers e-mobility as a large opportunity for both its own fleet as well as for mobility streams towards Schiphol for reasons of sustainability, accelerating sustainable mobility, increasing its license to operate, and in time cost reduction.

For this purpose Schiphol is developing a roadmap that describes an ambitious but realistic implementation scenario for e-mobility (2008-2020) for the Schiphol fleet. Timing of introduction of particular types of electric vehicles in time are depicted, as well as necessary infrastructure; the latter may also be used by other fleet owners, thereby serving as an enabler for large scale e-mobility at the Schiphol premises.

Examples of large scale implementation of charging station infrastructure for e-mobility are scarce (e.g. La Rochelle), and necessary implications of the grid, interfaces with buildings and urban planning issues have hardly been addressed. Furthermore, limited experience exists regarding charging stations in terms of design, grid implications, location choices, and public use aspects.

The Schiphol Group has the ambition to develop its properties and business park areas in a more sustainable and socially responsible way. Electric mobility is one of the options to consider.

There are three major challenges within this research: ‘electric transportation as a system innovation,’ ‘adoption and diffusion of e-mobility’ with ‘user-driven approach,’ and ‘making decisions in an uncertain world.’ The methodology for identifying, selecting, and developing the right combination of EV concepts, urban and electric infrastructure solutions has to facilitate the three strategic challenges: (1) it has to be able to address interdependent elements and sub-systems of the mobility system, (2) it should align future mobility and user needs with technological solutions, and (3) it should be able to identify the infrastructure and mobility solutions that can accommodate a wide variety of EV options in the future.

The applied methodology is structured according the phases analysis (technology assessment, workshops, and identification of key factors and driving forces), scenario development, concept development, design prototyping, and evaluation. This paper will focus on the latter three.

Design scenarios

The main focus of the presented research lies in the integration of electric mobility in the built environment. Scenario building is especially useful in circumstances where it is important to take a long-term view of technological developments and related strategies of actors. It is also useful when there are a limited number of key factors influencing appropriate strategies, but also a high level of uncertainty about such influences. Scenario building tries to build plausible views of different possible futures for relevant actors based on groupings of certain key environmental influences and drivers of change. The result is a limited number of logically consistent yet different scenarios that can be considered alongside each other. Manzini (2006) makes the distinction between Policy-Orienting Scenarios (POS) and Design-Orienting Scenarios (DOS). Policy-oriented scenarios usually deal with the macro-scale of the socio-technical systems and present a variety of possible futures and facilitate political decisions. Design-oriented scenarios are conceived as tools to be used in design processes. These scenarios should propose a variety of comparable visions that have to be clearly motivated and enriched with visible and (potentially) feasible proposals. A Design-orienting scenario is supposed to create inspiration for ‘designers’ whether in industry, government, universities or NGOs, to design urban plan, products, services and social arrangements that might realize steps towards the realization of these scenarios (Green 2001). A DOS should contain the following elements:

- Various ‘proposals’ developed as concrete plans, products and/or services.
- A global ‘vision’ picturing the effect of the implementation of the ‘proposals’ and their possible impact.
- The essential characteristics explaining the main effects and benefits the DOS is expected to have in terms of sustainability, economics and user acceptance.
- A storyboard, describing ‘a day in the life…’ for the mobility user in 2030.

General background future development scenarios

The urban developments in and around Schiphol and ‘The Grounds’ location, focus within this research in particular, will be realized at a spread timescale throughout the coming decades. The planning – with the associated decisions on sustainability – does however find place on an early stage. For technological developments, a decade is a long time; products that are not economical attractive right now, might be competing within a few years. On top of that, the prices of conventional electricity generation and natural gas extraction are predicted to rise with a rapid pace due to scarcity, resulting in an increased economical feasibility on renewable energy sources. In order to give an insight in the feasibility of the proposed measures various scenarios will be used. For this research, the used scenarios are condensed to the predictions of technological performance, product price developments, energy pricing and climate change.

The energy prices are of great importance in the majority of the proposed techniques in the following sections. The current energy price, for example, for normal users in Holland is around the € 0,08 per kWh without taxes and €0,23 per kWh with taxing (Eneco, 2009). But history and all future models show that these prices will rise in the coming years. The causes for the change are among others the increasing coal and gas prices due to scarcity, the political problems in oil producing countries (geo-political instability), the probable inclusion of CO_2 in the electricity price, the increase of the energy demand due to economical growth, the market behaviour of the producers and the production of renewable energy. Summarized, the energy prices are dependant on multiple variables related to society. In an attempt to analyze these developments, the Netherlands Bureau for Economic Policy Analysis (CPB 2005) formulated four probable scenarios. Each scenario resembles a shift in the current society towards a combination of a few characteristics. The different variables that cause changes in topics as energy pricing, affluence, purchasing power or political influences are dedicated to one of these scenarios. With these figures, various complex models can predict what the future fluctuations will be in the four scenarios for Europe (‘Strong Europe,’ ‘Global Economy,’ ‘Regional Communities,’ and ‘Transatlantic Market’). According to the Netherlands Bureau for Economic Policy Analysis, each of the future scenarios for Europe has an equal probability of occurring. Subsequently these scenarios were used to predict the energy pricing in the Netherlands in the coming decades. The results were used in the predictions of the future economic feasibility of the techniques. Unfortunately, the calculations on the scenarios were based on the indexation of the values of 2002. Currently, in 2009, the energy prices have changed dramatically, which undermined the accuracy of the scenarios. For this research, the results were still used for calculations, but with small modifications to the current energy price levels. Instead of taking 2002 as a starting point, 2009 is taken and gradually extended towards the future. The percents of rise in price levels fit in with the results that are predicted by the Netherlands Bureau for Economic Policy Analysis.

The next model that has been used for the future predictions is that of climate change. The Dutch meteorological institute, the KNMI (Koninklijk Nederlandse Meteorologisch Instituut) developed different climate scenarios for the Netherlands. Like the scenarios mentioned earlier, they developed four different scenarios based on two characteristics. At first, there is a probability that the air circulation patterns change within the coming decades due to global climate change. The change in air circulation might have the effect that the weather in the Netherlands will shift from a maritime to a continental climate. According to the KNMI, this phenomenon has about 50% change of occurring. Second, it is known that the annual mean temperature will rise the coming decades. However, this can either be only one or more than two degrees Celsius. For the scenarios they take those two options as characteristics.

In Figure 8 the climate scenarios are schematically shown. From the characteristics of the scenarios, weather conditions such as perception rate, sun hours, wind speeds, temperature and humidity can be predicted.

For the following chapters, the most important outcomes will be the changes of the incoming solar and wind potential. These differences in climate change might have a serious effect on the performance of various techniques (Figure 9). Wind turbines, for example, have 15% difference in efficiency from best case [W+] and worst case [W] scenario. This has a major effect in the payback time and the carbon reduction of the technology.

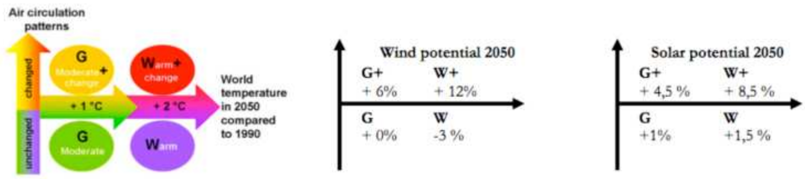

Figure 8: The four climate scenarios for the Netherlands; G+, W+, G, W (Hurk et al., 2006).

At the same time the technology itself will also develop. As for the climate change scenarios the W+ scenario was taken to be leading; this means a calculated rise in temperature in 2030 of at least one degree Celsius. Moreover to an increased wind potential in 2030 of approximately 6% (or 15% in generated electricity) and an increased sun potential in 2030 of 4,5%.

Urban Indicator

An assessment on the essential characteristics – sustainability, economics, and user acceptance – will lead to the selection of the most promising scenario. This scenario will form the context for the concept development. To quantify the effects of the different scenarios the impact for the urban development in terms of number of EVs and the pressure on the available space and amenities, an instrument called Urban Indicator has be developed and applied. The Urban Indicator uses the available area and projected urban program as input and several specifically defined variables. The main variables are based on the future use and users of the area: different groups of users with different purposes and different modal splits will use the area. For the modal split the following variables were considered: car alone, car passenger, car pooler, train, metro, bus, motorbike, and bike. Afterwards in every scenario the existence and profile of the groups was adapted to the scenario leading to a variation in mobility pattern and modal split.

In total seven groups of users of the area are considered. In the first level of the Urban Indicator model these seven groups of users result in a number of electrical cars including All Electric cars and Hybrid cars:

1. Employees working on the location (destination).
2. Schiphol Group employees (transit).
3. Other employees of Schiphol (transit).
4. Travellers using P long (transit).
5. Airside car fleet (destination).
6. Rental cars.
7. Commuters with destination Amsterdam: transferium / P&R (transit).

The second level of the Urban Indicator model is used as a tool to predict the charging requirements at the location. Therefore, a distinction is made for three aspects: *distance* (radius) of travel, *duration* (hours) of the parking and *time window* (day/night/full day). This information was essential for the DIEMIGO sub research by Faculty EWI. Every aspect consists of three classes:

- Distance: 0-15km (10km average); 15-30km (25km av.); > 30km (50km av.).
- Duration: 0-9hrs (day part); 2 days (business); 8 days (long travel).
- Time window: 0800-1800 (day time); 1800-0800 (night time); 0000-2400 (all day).

The third level of the Urban Indicator model is used to determine the land-use and forms the base for the design proposals. The projected urban functions and related parking program occupy the available space. But, the space for buildings is limited due to requirements of the buildings themselves and necessary space for infrastructure, water and green. The pressure on the space requires building in levels and piling up different functions, including parking. Unfortunately, the sky is the limit here as the height of buildings is restricted. The key variables are the average number of building layers (levels) leading to the built footprint, and the allocation of space for infrastructure, water and green. The required parking can be arranged on ground level, occupying space or in buildings enlarging the gross square area. The distribution of the functions in the area results in four indicators:

1. Gross square area: the total square meters of (projected) urban program.
2. Floor-Space Index (FSI): the gross square area divided by the available space.
3. Ground-Space Index (GSI): the built footprint divided by the available space.
4. Open-Space Ratio (OSR): the not-built area divided by the gross square area.

Based on the information three sets of diagrams have been made to visualise the location profile:

1. Occupation (built, parking, infrastructure, water, green, undefined).
2. Functions (business/offices, housing, commercial, leisure, culture, parking).
3. Indicators (FSI, GSI, OSR).

As the focus within the research elaboration is based on innovative integration of electric mobility with possible surplus effects for both the location itself as for Schiphol, it was concluded that high amounts of electric cars need to be attracted to the area to be able to visualize optimally the consequences and possibilities of electric mobility in an urban setting. With the help of the Urban Indicator, numbers of future amounts of electric vehicles and spatial consequences were calculated. Next the four different design scenarios developed are used to extract all data related to Schiphol and the ‘Elzenhof the Grounds’ location necessary to complete the Urban Indicator outcomes.

Scenarios Schiphol ‘The Grounds’ 2030 and concept development

On the basis of desired improved sustainability and frontline positioning of Schiphol ‘Elzenhof the Grounds’ with respect to EV integrating facilities, four different future design scenarios have been elaborated. They can roughly be characterized as: (1) economical involution, (2) economical prosperity, (3) green decentralization, and (4) deep green development with vehicle to grid & grid to vehicle exchange (Figure 9). These scenarios were given special names for identification. The first design scenario ‘*Time to eat the dog*’ shows existing opportunities as for Schiphol ‘Elzenhof the

Grounds' development to include sustainability based EV integration in the built environment even in case of economical involution.

The second design scenario '*As good as it gets*' shows additional opportunities based on introduction of new public transportation connections and improved EV integration and attached renewable energy supply in higher densities. The third design scenario '*Footprints on the water*' shows excellent improvements as for outdoor climate and comfort as a result of EV integration in the built environment and self-sufficiency aiming strategies based on green decentralization with compact clustering.

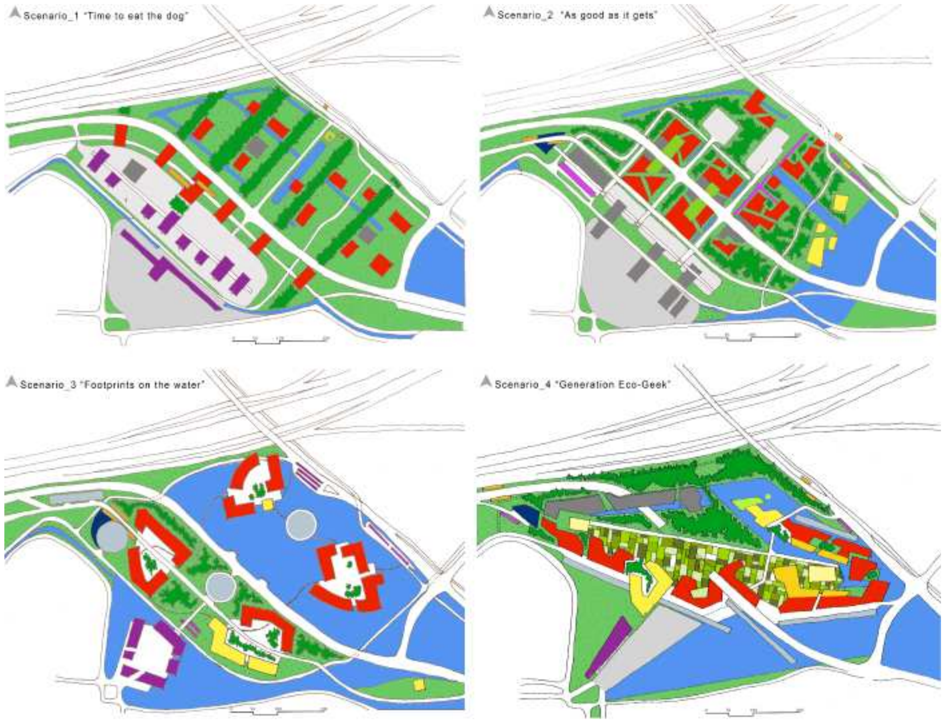

Figure 9: Urban lay-out of the four different future design scenarios.

The fourth design scenario '*Generation Eco-Geek*' shows additional opportunities for urban comfort at larger scales (more than outdoor climate near buildings alone), EV charging with integrated renewable sources and smart use and exchange of V2G (vehicle to grid) and G2V (grid to vehicle) for both economical and sustainable backup.

Within the focus of this paper the exact elaborations with belonging details and characteristics of the four future design scenarios are less important, and therefore will not be addressed. Next phase in the research was to evaluate the four scenarios using a comprehensive set of criteria: urban design, climate adaptation, flexibility, parking, public transport, and environmental impact. This paper will not explain all different outcomes of the assessment. After the evaluation of the four design scenarios, the overall score of design scenario 4 'Generation Eco-Geek' resulted to be highest. Apart from this, the same scenario also contained most innovations for both integration of EVs and related charging options. Finally, the attached conceptual design offers excellent opportunities to elaborate environmental technologies and positive consequences of EV integration as for urban climate and urban comfort best. Therefore it was chosen to elaborate this scenario further in detail, in calculations/dimensions as well as design and potential innovative concepts.

During the concept development phase in parallel different options for urban plans, mobility concepts and electric infrastructures are being developed. One of the important instruments to be used in fostering the richness of the generated options is the morphological chart. A morphological chart is a visual way to capture the necessary product functionality and explore alternative means and combinations of achieving that functionality. For each element of product function, there may be a number of possible solutions. The chart enables these solutions to be expressed and provides a structure for considering alternative combinations.

Design prototyping: future scenario Schiphol 'the Grounds' 2030

The design prototyping shows potentially demonstrable elements of the scenarios in the near future or solutions that can already be applied are important in order to show the potential of the transition towards electric mobility for Schiphol AirportCity. Visuals of the urban development, the mobility concepts, the e-infrastructure and e-charging solutions are important deliverables of this phase of the project. In the research report the strategy of implementation also is addressed to, with emphasis on the roadmap and essential steps to be taken now.

Schiphol 'the Grounds' 2030 scenario describes a world in which rapid technologic development, green living and minimalistic design principles play a key role. It marks a sea change in consumer behaviour, as people exhibit a clear preference for value-based products and attention to detail. Members of the society described in this scenario have a long-term perspective, which is manifested in their interest in education, collaboration, and innovation.

At Schiphol 'the Grounds' all building structures are organised around a high-quality, deep green inner garden (Figure 10). The model of the 'short-cycles city' forms the basis for this elaboration. It is a further development of the principle of decentralized concentration. Apart from the relatively small diameter, or compactness, the main line of approach is the integration of ecological and environmental-technical principles.

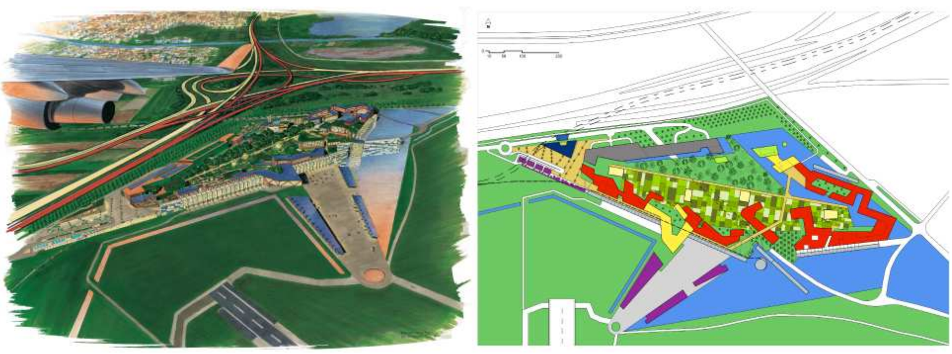

Figure 10: Final elaboration (urban plan) design scenario 4: 'Generation Eco-Geek.'

As it turned out, small-scale autonomous entities based on regenerative systems have come within reach because of recent technological improvements. This also holds for connected small-scale “semi”-autonomous or autarkic entities, which will be able to absorb the continuous transformations better, on account of their non-isolated character. It is part of a system based on a geographically clustered network of nodes that aim at autonomy and offers possibilities for timely anticipation of changes that originate from technique, society or market conditions. This network geometry starts from the creation of “cells” that form a spatial, social, economic or ecological (strong) network, in a hierarchic relationship or otherwise (Saxenian, 1984; Timmeren, 2006). In this approach energy is replaced primarily by incoming solar radiation, while materials are replaced by recycling and reuse. Because of its prime location, the Grounds is also used as a transfer point or transferium – departing travellers park their EVs in the long-term parking facilities and visitors to the Netherlands pick up their tailor-made e-rentals, which enable them to move throughout the country in style and comfort. The park also serves the airport’s airside needs, providing a portion of the facilities that enable the airport’s characteristically smooth operation.

Final outcomes and process evaluation

Several pioneering forms of e-mobility and supporting infrastructural networks have been elaborated closely in research and were integrated into the design proposal for Schiphol’s real estate, resulting in innovative, comfortable, silent, and green urban environments (Figure 11). Schiphol’s workers use several modes of public and private transport, which come in a variety of shapes and sizes. For example, many employees use ultra-light electric vehicles as an extension of public transport for the final kilometers until reaching their destination. Employees and travellers alike are encouraged to make use of the ‘e-rope,’ a personal rapid transit system that brings passengers from one end of Schiphol to the other within the privacy of their own cabin. It takes just minutes to travel from the customs area on the airport to the grounds via the developed high-frequent and flexible ‘e-rope.’

The electricity grid network must cope with an increasing number of decentralized electricity producers supplying various amounts of electricity to the national grid network. The integration of these decentralized producers demands that the electrical grid be restructured. This provides the unique opportunity to take strategic measures accommodate electric mobility. At Schiphol ‘the Grounds’ this has been investigated both for e-grid lay-out and integration, focussing on potentials for connection to renewable energy supply, potential economic benefits, design integration and innovation.

The future energy demands of ‘the Grounds’ including the daily charging of over 9000 EVs can be produced locally to a large extent. Nevertheless, connections with the municipal electricity grids resulted to remain important, since green electricity is not produced equally divided over the year. The main share of the green electricity in the calculations is produced by solar cells, which generate in summer over five times more energy than in winter times. Here the Vehicle-to-Grid (V2G) system is introduced. V2G systems are systems in which batteries are used as ancillary storage for the electricity network. Vehicle batteries may be loaded from or discharged to the grid network depending on the fluctuations in energy demand. V2G systems support the use of intelligent charging protocols, which may be necessary for mass deployment of electric vehicles.

Figure 11: Images of the developed characteristics (left, right) and EV+ service concepts (middle) based on assemblage on demand according to a variety of user specified options.

Figure 12: The Park & Charge long term parking garage with V2G/G2V based e-system.

V2G systems may aid in the integration of renewable energy sources into the grid network. The harvest of energy from renewable sources, such as wind and solar energy cannot be scheduled in the same way as a coal-powered energy plant. In order to compensate for this, vehicle batteries can absorb excess electricity at times when renewable production is high, and contribute needed electricity at times when demand for electricity is greater than supply.

At Schiphol 'the Grounds' the elaboration concerns a connection with a smart grid. In general the cars will be charged when (more than) sufficient sustainable electricity is available and/or the total demand of electricity in the Netherlands is low. The latter implies that charging occurs at night-time when the total energy demand is lowest, during daytime when solar power is available, and during weekends when the business park needs less electricity. So, the batteries of parked EVs will temporarily become a part of Schiphol's sustainable energy system. The EVs batteries are connected to the grid by means of a bi-directional charging device and can be used by Schiphol for 'peak shaving' in expensive times of peak demand. Smart management by network operators could enable charging during periods of low demand, resulting in a levelling off of the grid demand profile, instead of an amplification of the peak. In this way, Schiphol can economically benefit from this battery capacity but also the EV owners, who allow Schiphol to make use of their battery capacity by parking in the garage. The performance of the battery and therefore the EV is highly dependant on the manner in which the battery is charged and discharged. The battery charger replenishes the energy in an electric vehicle in a similar manner to refilling a fuel tank with gasoline. The difference is that the charger offers different possibilities to charge the vehicle, such as over night at home or parking place instead of refueling at a gasoline station. The battery charger is a device that converts the alternating current distributed by the grid to the direct current needed to recharge the battery. There are many methods to charge EV batteries according to their different charging characteristics. Conductive charging technology is currently the most favoured, as it allows for the connection of EVs to an existing power supply with high efficiency, without the need for extra infrastructure. Different charging modes have been described (standard charging, semi-fast and fast charging).

Schiphol's EV fleet is fully charged with solar power. At the airside of 'the Grounds,' approximately 250 vehicles that are all electric are charged here and connected to the solar roofs of the parking spaces along the platform. This roof provides enough electricity to charge the whole fleet during the year. There is enough electricity in wintertime: the Park & Charge garage uses the excess electricity during summer time.

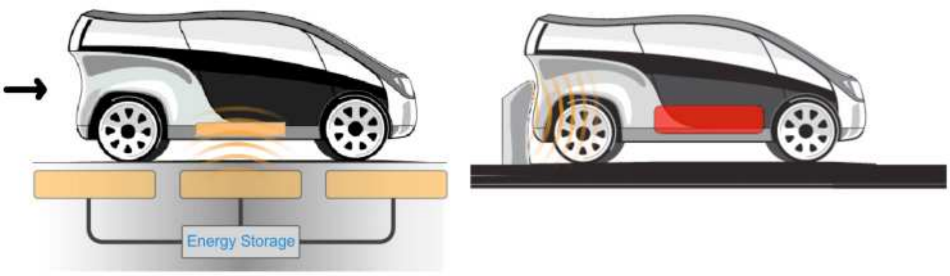

Figure 13: Scheme of dynamic contactless energy transfer charges, or dynamic inductive charging (left) and static inductive charging (right), as used in the Park & Charge.

Another integrated innovation in the design elaboration concerns inductive charging. Induction charging is different from other forms of EV charging because it does not require a physical connection between the vehicle and the charging unit. Instead, induction charging utilizes magnetic inductive coupling, which enables the transfer of power across a small air gap between the inductor source (located on the charging unit) and the receptor (located on the vehicle). Inductive charging may take place by means of static charging, which describes the act of charging while the vehicle is parked, or dynamic charging, which describes the act of charging while driving by means of in-road induction charging devices (Figure 13). Schiphol provides inductive charging lanes. These lanes are in general not used to fully charge the batteries; the speed of charging is limited and the efficiency of charging is not as high as during standard charging. Nevertheless, these lanes can extend the ranges of the vehicles that drive on them. The charging lanes can be provided of electricity by local small electricity storages that are connected to solar cells that are incorporated in the sides of the roads. Within the Park & Charge garage, but also in other EV parking places the 'static' variant of inductive charging is being introduced. The batteries of these EVs are charged from the grid when there is plenty of renewable energy available and discharged to supply the grid at times of peak energy demand. In this way, the sustainable energy system provides economic benefit to the owners of the garage, as well as to those of the EVs. This bi-directional charging system is connected to various types of locally generated renewable energy. In this way Schiphol is a prime example of decentralized energy production and use of the national energy grid network:

The research presented demonstrates the need to include interdisciplinary approaches to the integration of strategies for raising public awareness, for marketing the different qualities of essential flows, especially energy (exergy/cascading), and establishing a service business for building and integrated electric mobility on the basis of operating more decentralised installations. In addition to the issue of sustainable energy generation, with the introduction of electricity-based mobility both new possibilities and problems become visible, especially as for its interconnection with, and integration in the built environment.

Around the world several concepts for EV charging and EV/Building interfaces have been developed, or are under development. In general however integrated smart grid concepts, comfortable charging or user focused services and innovative charging are still lacking and mostly based on the principle of relatively simple “technical fixes” and do not address to problems to be solved in case of large scale introduction of electric mobility. Moreover, integration in the built environment is poor and full of potential pitfalls, especially as for security of supply when implemented at large numbers.

The outcomes of this research show that a high penetration of electric mobility into the built environment can be achieved generating little environmental impact, resulting in full integration within innovative and comfortable green urban areas. Through the development of the Grounds Business-Science Park and mobility transfer hub, Schiphol possibly plays a key role in the roadmap to green mobility. With the implementation of new transport technologies, unique services, and advanced sustainable energy production and management systems, Schiphol builds on the values of a progressive society to offer a innovate and inspiring environment for work and travel.

DESIGN SYSTEMS GROUP
Knowledge models for design and engineering (2005-2010)

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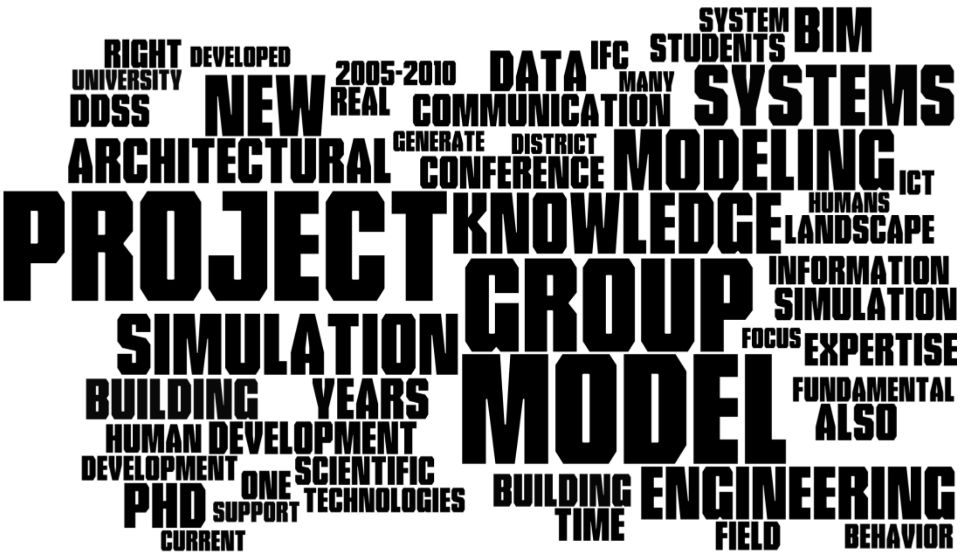


Word cloud of this chapter, created with http://www.wordle.net

Abstract

The Design Systems chair of the Eindhoven University of Technology has two main lines of research, namely: (1) product and process modelling and (2) simulation of human behaviour in the built environment. In the period 2005 – 2010 three PhD's defended their thesis and eleven students received their Masters title within the chair. Seventeen journal papers were published in scientific journals and many projects were undertaken in collaboration with industry. The Designs Systems group's expertise has focused on knowledge modelling as a common ground for design and engineering research. The most frequent applications of knowledge models are: simulation and communication.

Introduction

Design research is a very broad research field. For an academic research group like the Design Systems group at the Eindhoven University of Technology it is necessary to focus on specific research topics. The use of information and communication technology (ICT) in the context of architectural and urban design is the foundation of the group. ICT however is also a research field in its own. Developments in ICT research trigger new developments in design research and sometimes also the other way around. Nevertheless a long term focus is necessary in our own field to be able to contribute substantially to the scientific knowledge. In case of the Designs Systems group these are:

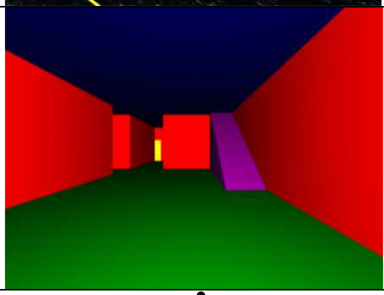
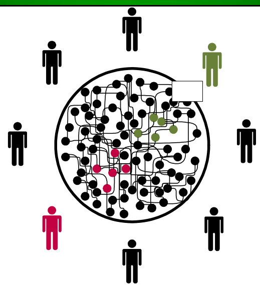
1. Product and process modelling.
2. Simulation of human behaviour in the built environment.

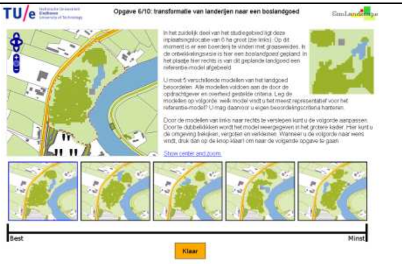
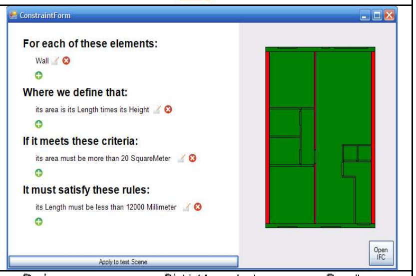
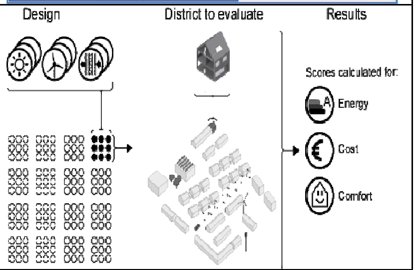
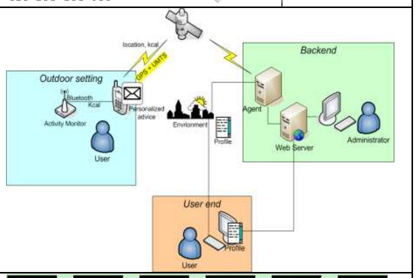
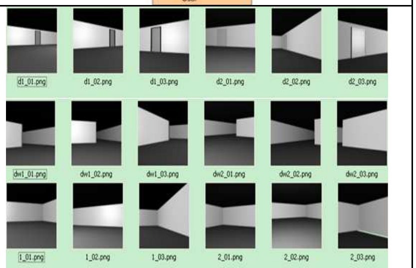
Product and process modelling research is considered fundamental to almost any other research in architecture and planning. Studying the complexity of architectural design and making abstractions into data structures and flow diagrams is basic to understanding what design is. Moreover once described using formal languages, this design knowledge can be re-used and extended for different purposes. Lately Building Information Modelling (BIM) has gained a lot of attention which came more or less as a surprise. Our group has advocated BIM for more than twenty years. For a long time this was a continuing progress through international research without any awareness of these developments in design and engineering practice. When presenting the latest results to practitioners the most common remark was that they would come back when it was all finished. Since about two years the situation has changed dramatically. The most obvious reasons for this are the maturity of the IFC standard and the improved support from CAD packages for 3D modelling. Right now there is a huge demand for BIM expertise. A serious danger is that the expectations of BIM are over estimated. Building Information Modelling is very complex and still a lot of research remains before communication is possible without any loss of information. In the Design Systems group right now we look ahead of current standardization initiatives for more powerful and flexible way of information modelling.

Approximately five years ago we started a new line of research named behaviour simulation. Simulation in general is a powerful tool for academic research applied in many disciplines like structural engineering, building physics, etc. In architectural design facilitating human activities is a fundamental objective. It was felt that in order to be able to analyze architectural design performance, a simulation model was needed of human behaviour. Of course we realize that such a model is very ambitious if not impossible. Trying to mimic real human behaviour assumes that we have a complete understanding of human cognition, whereas especially in this field relatively little is known. Our research has some overlaps with cognitive science, but also large dissimilarities. Cognitive scientists usually try to explain interaction between external stimuli and humans, but they do not develop models for simulation purposes. Although ambitious, we feel that modelling the interaction between architectural space and humans is fundamental to architectural design and engineering

PhD research projects

TABLE 3: PhD projects in the Design Systems group (2005-2010)

Name	Year	Title	Picture
Vincent Tabak	2004-2009	User simulation of space utilization: system for office building usage simulation.	
Chengyu Sun	2005-2009	Architectural cue model in evacuation simulation for underground space design.	
Jakob Beetz	2004-2009	Facilitating distributed collaboration in the AEC/FM sector using semantic web technologies.	

Kymo Slager	2005-2010	Development of the landscape generator; a method to generate plausible cartographic landscape configurations for collaborative spatial planning.	
Remco Niemeijer	2006-2011	Computer interpretable language for expression of design and engineering constraints.	
Rona Vreenegoor	2008-2012	Energy model for district design and evaluation.	
Yuzhong Lin	2008-2012	Guided user behaviour: technology development and simulation.	
Qunli Chen	2008-2012	Visual perception computing and interpretation using a virtual building model.	

Jakob Beetz and Remco Niemeijer fit within the tradition of product and process modelling research. Jakob devoted his PhD to semantic web technologies. Whereas current AEC industries are still struggling with the implementation of the newly developed IFC standards, scientific researchers are working on new technologies.

Standardization has lead to complex inflexible and hard to manage information models. The next move is not to standardize the information objects but the information modelling methods. This new research direction is a response to current problems with implementation of standards in design and engineering applications. Semantic differences between the internal representations of the design and engineering programs and the communication standard are very hard to bridge. Standardization of data structures in the end will not suffice. Thus reasoning is necessary to overcome semantic differences. Such reasoning mechanisms can only be developed by researchers with domain expertise. Remco Niemeijer is developing a language interpreter that can take text as input and translate these into formalized constraints. His research touches upon natural language processing but with a demarcation to design constraints. Once interpreted successfully design constraints can be imposed upon the Building Information Model to ensure that changes or refinements do not conflict with building codes or the designer's intent. Critical issue in this research is to cope with natural language constructions that are sometimes ambiguous but nevertheless accepted in real life.

Vincent Tabak, Chengyu Sun and Qunli Chen are the first series of PhD's working on human behaviour simulation in the built environment. As a first step we decided in Vincent's case to reduce behaviour to movement. In the Design and Decision Support Systems (DDSS) research programme in which the Design System group participates a substantial body of knowledge was available on activity-based modelling. Vincent adapted this principle which basically consists of an agenda for each person stating activity time and location. He developed an algorithm to construct an agenda for every virtual human (or agent) in the simulation using organizational data as input. Running the simulation generated data on a person's location in the layout of a building at any time of the simulation period (e.g. one day or one week). From these data the space utilization can be calculated or the data can be used as input for e.g. indoor climate calculations. The simulation model is not a proper behaviour model, but a movement model because it does not include vision, sound, or haptics. Chengyu made a step forward by adding visual cues to the agent model. He focused on evacuation in underground stations and researched the effect of architectural attributes (distance, width, height, etc.) of the main cues (exit, doorway, stairs) on the preferred movement direction. With his simulation model he proved that movement trajectories can be simulated reliably. Interestingly he collected his preference data through experiments with real humans in virtual environments. With Qunli's research we extend this model with more realistic machine vision and with a memory model. Vision research touches upon computer vision research but yet is very different, because it is not only our aim to recognize objects through some smart image processing algorithm, but to recognize them like real humans do. Therefore, again we will rely on experiments with real humans to collect data and include human limitations in navigation through space.

Yuzhong Lin is a PhD that established collaboration between the chair of Design Systems and the chair of Urban Planning. Both chairs felt that mobile computing will have a major effect on how persons behave in space. An empirical research project was started by Yuzhong investigating the mobile technologies and simulation methods. The project was narrowed down to use mobile computing as a motivator for improving health and well-being. Preliminary experiments show that people prefer personalized messages that don't conflict with their own planning. Ultimately our goal is to develop a system that sends messages at the right time and at the right location. What is right can only be confirmed through experiments with real users.

While the above mentioned PhD's are performing fundamental research that does usually not immediately generate practical results, we also run PhD project s with a short term goal, often funded by national funds on specific topics. Kymo's research is such an example, funded by the Ruimte for Geoinformatie (RGI) programme. In this project one other research institute participated (Alterra), one governmental institute (Kadaster) and one commercial company (Nieuwland). In this project we aimed at the development of a system named Simlandscape. As the name suggests, it should support landscape designers in generating landscape design in a participatory setting. Two components were implemented, namely a sketch table and the landscape generator. The last component was developed by Kymo based on evolutionary design principles. The main research question was to prove that his landscape generator could generate plausible designs. A survey among professional landscape designers proved that in most cases they could not tell the difference between computationally generated designs and professionally created designs.

A growing category of PhD researchers are persons that are employed by companies, but seek possibilities for further knowledge development. Rona Vreenegoor is such a person who spends two days per week on her PhD research. Obviously there must be a match between the companies business and the PhD research project. From her company and from literature we noticed a lack of models for energy simulations on a district level. Most energy models work on the level of spaces or at best buildings, but not for whole districts. However, the existing building stock is probably best renovated not on the individual housing level but on the district level, because on the district level new possibilities are available. Rona is working on a Multi Agent System that can handle a variety of energy production and consumption components. Through simulation we hope to find an optimal solution for different cost models. Next to that we will investigate the habitant's opinion on the renovation possibilities and compare these outcomes with the computed optimum. With this model we hope to get a better understanding of the current stand-still in energy reduction programs.

Graduation projects

TABLE 4: Graduation projects in the Design Systems group (2005-2010)

Name	Year	Title
Martin Klein	2005	IFC compatible agent-based egress simulation (ICARES).
Erik van der Feesten	2005	Confection for the masses in a parametric design of a modular favela structure.
Glenco Janssen	2005	RFID: communiceren met prefab betonnen heipalen.
Remco Niemeijer	2006	User-oriented dwelling design.
Sjef Horsch	2006	Een genetisch woningbouw ontwerptool.
Jaap van de Bosch	2006	Onder-bewust.
Paul Bos	2007	8:30 AM sterdam; design & communication by visual interaction.
Marc Obbens	2009	Van virtuele planvorming naar effectieve besluitvoering.

Jeroen Witteman	2009	Calculeren met BIM.
Detlev van Loenhout	2009	Unplanned encounter simulation.
Jeffrey Kuling	2010	Methodological generation and validation of structural design.
Joop van de Tillaart	(2010)	Generating 3D visualizations from 2D digital plans.
Stefan Rink	(2010)	Bouwen aan integraal offreren.
Tom Wolters	(2010)	Prototype of an architectural dynamic building.
Petra Driessen	(2010)	Participatory architectural design through 3D city models.

Graduation projects are usually linked to on-going research projects. Consequently, the same topics are found here as in the PhD projects, namely: building information modelling, behaviour simulation, design generation, and participatory design. On average three students graduate per year on a topic related to design research. Fortunately these students find jobs very easily even in time of economic crises. This confirms that our research topics are not only scientifically sound but also relevant for industry.

Additionally to the traditional graduation programme, two initiatives were made: a dual master track and focus on BIM.

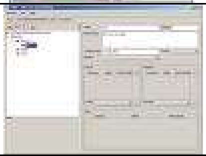
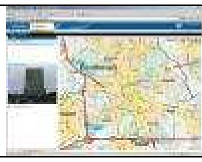
The DDSS Master track can be followed in conjunction with another track at the cost of one semester additional study load for the student. Currently two dual tracks with DDSS are available, namely DDSS with Architecture (ARCH) and DDSS with Urban Design and Planning (UDP). Recently three students started in de DDSS+ARCH track. We think this is an excellent opportunity for architecture students to obtain more computing skills and thus a better position on the labour market.

As stated above, Building Information Modelling was a research topic over twenty years, but now has established itself also in education. Instead of developing a new BIM course, we decided to adopt BIM in existing courses on computer aided design, collaborative design, system development, free form design, etc. It is now possible to teach BIM because a variety of commercial tools are available that support the BIM modelling and communication concept. However, true uncomplicated communication between design and engineering partners in a building project is still a long shot. Thus, students will face this reality and learn how to cope with the current state-of-the-art. We envision a shiny future for those students that have the knowledge to act as the BIM manager in building projects. For this new role a combination of architectural design knowledge and information technology knowledge is required.

Research and development projects

TABLE 5: Research and development projects by Design Systems (2005-2010)

Name	Description	Period	Picture
3D modelleren en visualiseren: pilot project Overamstel	Teaching methods and techniques in 3D modelling and data management.	2009-2010	

Gebiedsprogrammeer systeem	Development of an interactive website for presentation of transitions in urban districts.	2007-2008	
ProClient	Research on system requirements for client oriented applications.	2007-2008	
COINS praktijkprojecten	Testing 3D modelling and management principles in real-life construction projects.	2006-2007	
Lights on Eindhoven	Development of a website with routing along points of interest.	2006-2006	
CROW-OB	Scientific expert review of a library with infrastructure components.	2006-2006	
Belevingskaarten	Survey in a district in Eindhoven to measure the citizen’s perceptions of the neighborhood.	2006-2007	
Harmonization of the Industry Foundation Classes (IFC) and the STABU LexiCon taxonomy	Research on the implications of the integration of IFC and STABU Lexicon.	2006-2006	
Sense of the City	Development of a mobile tracking system for collecting citizens impressions.	2006-2007	
IFC to OWL Transformer to Facilitate Business Object Generation	Research on the implications of converting IFC models to OWL models.	2006-2006	
Virtual Maquette	Development of an interactive VR system to present the university campus to visitors.	2005-2005	

COINS Scenario	A case study of 3D model based design and engineering.	2005-2006	
e-Dormer - Web application for applying for building permits	Development of a web-based system for automated building code checking of dormers.	2004-2005	

Table 5 provides on overview of the projects that were executed in the period 2005-2010. These projects are mostly small scale projects running at most two years and funded by industry. Although the Design Systems group does not advertise its expertise, we are regularly approached by companies and governmental institutes with research questions. These research questions often are not very well defined which means that many discussions are necessary with the client before we can actually start. Obviously in all cases the projects should relate with our research expertise and it should generate new knowledge. Sometimes we conclude that we are not the right partner, for instance when the project consists of routine work.

Industry projects provide an excellent opportunity to promote scientific expertise and to learn about real world problems. Real world problems are often not just technical problems but also financial, managerial, juridical, political, etc. problems. When innovations get stuck because of these issues, developing a prototype (or demonstrator) can help. At relatively low cost the technical feasibility is studied, and the prototype is used to investigate the introduction of a new technique or method in the existing organization. Sometimes it takes many years before a company or institute is ready to pick up innovations.

Key publications

The number of journals for publication of our design research results is very limited. The only journal that focuses on design as such is Design Studies. From the perspective of the Design Systems group ICT related researchers are also a relevant forum. However since we don't contribute to the field of computing science, most very narrow focused ICT journals will not accept our publications. The strength of the Designs System group is the research on new models for capturing and exchanging design and engineering knowledge. Knowledge modelling is a very young research field and by this time typically covered by Artificial Intelligence researchers with a mathematical or philosophical background. The strange situation here is that although many people advocate multidisciplinary research, this type of research is not recognized in its own right. Ultimately all scientific research should fit with one of the (long) existing journals for fundamental research. For applied researchers like us it means that we successfully divide our research over these different forums, but we are not sure if we always reach the right group of fellow researchers.

TABLE 6: Key publications of Design Systems in the period 2005-2010

Author(s)	Year	Title of publication
Tabak, de Vries	2010	Methods for the prediction of intermediate activities by office occupants.
de Vries, Sun	2009	Human choice extraction for evacuation route prediction.
Achten	2009	Experimental design methods – a review.
Beetz, van Leeuwen, de Vries	2009	IfcOWL: A case of transforming EXPRESS schemas into ontologies.
Hoes, Hensen, Loomans, de Vries, Bourgeois	2009	User behaviour in whole building simulation.
de Vries, Steijns	2008	Assessing working conditions using Fuzzy Logic.
Orzechowski, de Vries	2007	Eliciting user preferences through a guided design personalization process.
de Vries, Harink	2007	Generation of a construction planning from a 3D CAD model.
de Vries, Buma, Jessurun	2006	An intuitive interface for building management and planning.
Tan, Timmermans, de Vries	2006	Route knowledge in complex environments: an analysis of pedestrian recall using stereoscopic panoramic interactive navigation.
Achten	2006	Towards real-time design drawing recognition.
Tan, de Vries, Timmermans	2006	Using a stereo panoramic interactive navigation system to measure pedestrian activity scheduling behaviour: a test of validity.
van Leeuwen, van der Zee	2005	Distributed object models for collaboration in the construction industry.
Segers, de Vries, Achten	2005	Do word graphs stimulate design?
de Vries, Tabak, Achten	2005	Interactive urban design using integrated planning requirements control.
Pranovich, Achten, de Vries, van Wijk	2005	Structural Sketcher: representing and applying well-structured graphic representations in early design.
de Vries, Jessurun, Segers, Achten	2005	Word graphs in architectural design.

Special events

Our faculty and our group specifically celebrated the honorary doctorate of John Habraken in 2005. For the Eindhoven University of Technology it was the first time that a professor from the faculty of Architecture, Building and Planning was granted the honorary doctorate. The Design Methodology Group in the faculty continued research on the principles developed by Habraken after he left for MIT. When the Design Methodology group and the Building Informatics group merged approximately 10 years ago the new Design Systems group was established. Therefore the Design Systems group still holds the legacy of this expertise. The last person with a PhD in the field of

Design Methodology is Henri Achten who will leave our group in 2010 and continue his work at the faculty of Architecture of the Czech Technical University in Prague.

In 2006 we hosted the Design Cognition and Computing conference. This conference was formerly known as Artificial Intelligence in Design. The conference attracts researchers not only from the architectural design domain but from various disciplines. Although John Gero who founded this conference retired from his professorship at Sydney University, the conference series is continued. The role of cognitive science is increasing in traditional design and engineering fields. Research methods and theoretical models are adopted but differences are also apparent. In cognitive science the research comprises usually data collection and analyses, whereas in design and engineering this is followed up by a modelling phase.

The Design Systems group organizes the bi-annual DDSS conference together with their fellow researchers from the Urban Planning group. The DDSS conference attracts researchers from all over the world from the design and planning domain with a focus on decision support. This year it celebrates its 10^{th} anniversary. These days the conferences to choose from are numerous which makes it sometimes hard to judge their scientific quality. That is the downside of being rated in scientific assessments by the number of publications. Over these years the group of researchers visiting the DDSS conference is not extremely big but remarkably constant.

Conclusion

Our DRN 2005 paper was titled ‘Understanding design through design support tools.’ At that time the Designs Systems group was focused on tool development for designers. As can be observed from this paper we shifted away from tool development to knowledge modelling. This change in attitude is not a surprise because five years ago technologies were relatively new and rapidly changing. Technologies were looking for application areas. We researched how new technologies could support designers. Now that we have a better insight on the possibilities and drawbacks of design technologies we come back to the more fundamental question what the objective is of all these new tools. In our case we concluded that knowledge capturing and transfer is the common ground. Consequently knowledge modelling has become our main focus, but always in the context of design and engineering. The most frequent applications of knowledge models are: simulation and communication. Knowledge modelling is not application domain specific thus we expect to exchange expertise with other domains.

Meanwhile the research approach has not changed. In PhD research projects we typically first develop a new theoretical model, next we implement this in a prototype with the help of ICT and then we test the model through experiment with the prototype. This research approach has proven to be very successful and therefore we continue with that another five years.

THE ID-STUDIOLAB 2005-2010
Further developing a creative research environment

Aadjan van der Helm, Pieter Jan Stappers, David Keyson, Paul Hekkert

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Introduction

ID-StudioLab is a design research community at the Faculty of Industrial Design Engineering at Delft University of Technology. It was established in 1999, as a creative design research environment for researchers, university staff and master graduate students. Each member works on his/her own project but in a collaborative and multidisciplinary setting. At the time it was a unique initiative that through the years has gained a wider acceptance nationally as well as internationally.

This paper presents the ID-StudioLab research approach and organization, discusses the research themes and illustrates this with example projects. Then we will discuss the future directions for the research within ID-StudioLab.

Research approach and organisation

ID-StudioLab promotes a tight fit between design and research: researchers become actively involved in the design process, but also designing as an activity becomes an integral and equal part of the research process ('research through design') (Hekkert, Keyson et al., 2000; Pasman, Stappers et al., 2005).

ID-StudioLab started as a design research community with the purpose of joining researchers, students, and educators in the department ID, whose work was 'user-centered and design-driven.' Its active membership has hovered between 20 and 40 people, half of whom had their primary desk in the studio. On purpose it was set up to cross boundaries between groups in the department. Part of its vision was to adopt the mentality and ways of working of a design studio, rather than an academic monastery with isolated scholars in silent and separated rooms.

As a consequence, the lab facilities (Figure 14) should bring together people working on different projects and from different perspectives in a single space with rich opportunities for seeing, demoing, participating in, discussing, fertilizing and questioning each others' ongoing work. This requires an integration of office space and workshops, and originally started with a single room full of people and a workshop room for tinkering and messy tasks. With the move to a new building, ID-StudioLab was housed in a block of five adjacent spaces: *StudioMingle* for people's desk work, *StudioMake* for electronics, *StudioDo* for tinkering, *StudioSay* for presentations and workshops and *StudioTalk* for data analysis and quick meetings. Over the years the makeup of the ID-StudioLab spaces was enhanced from the original white standard university office rooms into a visually stimulating environment of a design studio, with lively colours, full-wall metal whiteboards and projection areas, and diverse opportunities to display work in progress; as the community grew, the corridor outside the studios was included in the workspace as *StudioHallway*. The ID-StudioLab facilities themselves served subject of our research on design, expressivity, communication and interactive technologies.

The research through design approach has remained the predominant approach for projects in the ID-StudioLab (Hekkert, Keyson et al., 2000; Pasman, Stappers et al., 2005). Design researchers actively engage with their topics by designing, building and testing product concepts. Generating knowledge from the building process, the product prototypes and the use of the prototypes in context by users. The infrastructure of the ID-StudioLab has been further developed to support this approach. Facilities like *StudioTalk*, for data analysis of rich contextual data, *StudioMake* and *StudioDo*, for quickly building product prototypes and taking these to a level of refinement suitable for real world use. Applications to start new projects in the ID-StudioLab spaces are carefully weighed as to maintain the research through design character, and the benefits they can bring to and gain from the day-to-day contact with other projects.

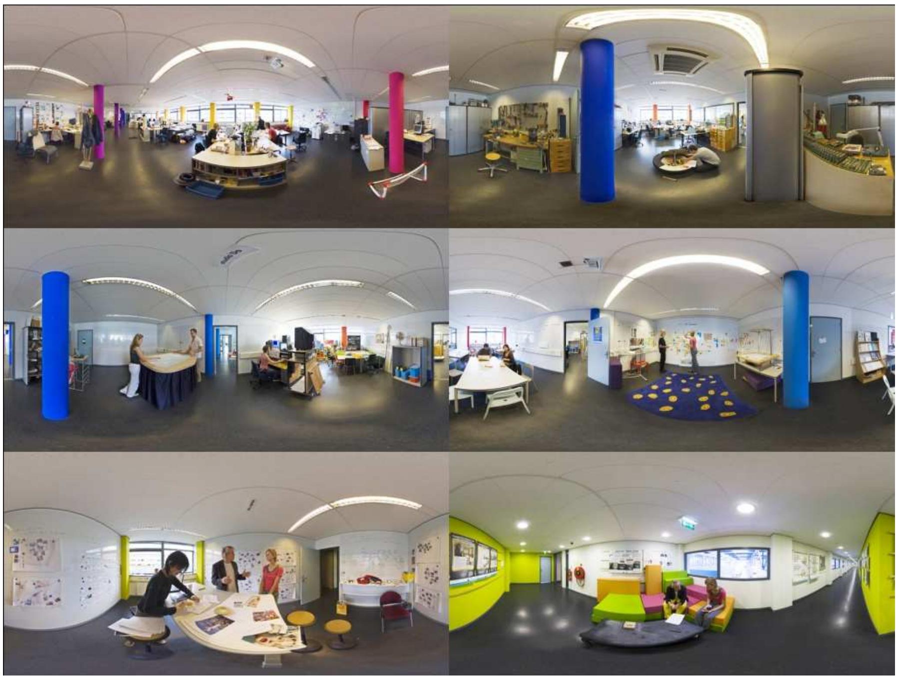

Figure 14: Panorama-photos give an artistic impression of the StudioLab spaces (spaces left-to-right, top-to-bottom in order they are mentioned in the text).

Research developments 2005-2010

In accord with a general restructuring of the research of the Faculty, research in the ID-StudioLab has gravitated to fit the new portfolio (Hekkert, Vergeest et al. 2008). This portfolio introduced a matrix structure for the research (see Figure 15), with three foundational columns (strategic design, user experience, and technology transformation) crossed by three applied rows (healthcare, personal mobility, and living/working). Research projects at the faculty take place in one of the columns or row-column combinations.

Most of the work at ID-StudioLab fits in the User Experience (UX) column, with a substantial part in the Living/Working (LW) row. The matrix structure enables various forms of collaborations.

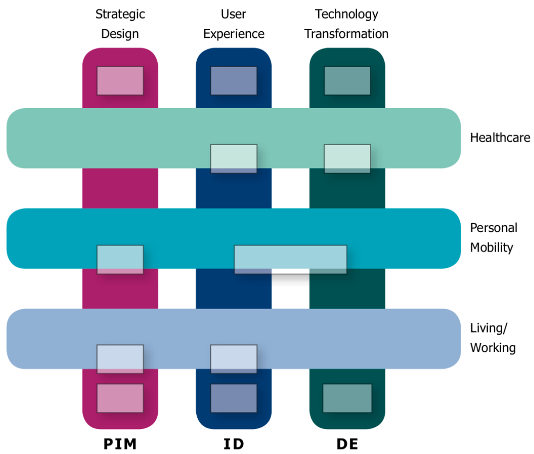

Figure 15: IDE Research portfolio structure.

The character of the ID-StudioLab is inherently informal (i.e., it is not 'owned' by any of the groups or particular projects in the ID department) which makes it a highly dynamic environment capable of adjusting quickly to interesting developments. With this knowledge, the five themes mentioned below should not be seen as written in stone, impossible to deviate from. The themes rather present an overview of where the currently ongoing ID-StudioLab projects fit in the portfolio. In the next section we present a selection of those projects.

TABLE 7: Some project in ID-Studiolab 2005-2010

Subprogram	Short description	People involved
Sensory & cognitive fluency	Investigating how the sensory and cognitive system works (together) in human product interaction. It seeks to expand the capabilities of products and overcome limitations in the design of new technological systems.	Geke Ludden, Reinier Jansen.
Faces of user experience: aesthetics meaning & emotion	Investigating user or product experience by studying the aesthetic experience, the experience of meaning and the emotional experience. In an integrative approach as well as studying separate experiences in isolation. It seeks to support students and industry to design authentic experiences.	Nazli Cila, Erdem Demir.
Contexts around us(e): culture, situation & sociability	Investigating how contextual factors, models, methods and techniques from relevant disciplines can be integrated or adapted for design. It seeks to give designers understanding of the context of product use and to provide the means to make that knowledge operational.	Froukje Sleeswijk Visser, Helma van Rijn, Nynke Tromp.

Usage, comfort and safety	Investigating user activities, physical and other conditions that influence comfort and the risk involved with product use. It seeks to develop tools and insights to address the situatedness of product usage and to provide inspiration in designing.	Stella Boess.
Living/work	Investigates how to design for maintaining and enhancing the quality of live over time as related to environmental, socio-economic and individual life styles. An integral approach is chosen whereby the environment, product role and human behaviour are taken into account.	Martijn Vastenburg, Miguel Bruns Alonso.

ID-StudioLab projects

A continuous stream of asynchronous projects is in progress: PhD projects, commercially funded research projects, MSc graduation projects and a diverse range of collaborative project with students. In this section we provide examples of projects.

Bringing the everyday life of people into design: Froukje Sleeswijk Visser

This PhD project (Sleeswijk-Visser, 2009) investigated how rich experience information can be communicated in the design process of design practice. In the last ten years many new methods and tools have been developed for generating user data to be used in the fuzzy front end of the design process. First, we have developed a procedure based on user research methods to inform and inspire the design process. This procedure is called contextmapping (Sleeswijk Visser, Stappers et al., 2005) and based on cultural probes and generative techniques. Second, we have investigated how the results of such user research methods can be effectively used in design practice. Contextmapping studies deliver a large and varied set of data and insights, which should inform and inspire not only the researchers who conducted the study, but also other stakeholders (designers, researchers, managers, marketers). In eight different case studies, most of these in collaboration with industrial practice, we have explored several new ways of communicating the data, to inspire designers, let them empathise with users, and engage stakeholders with the data. This iterative process in which new communication tools were designed and evaluated in real practice led to practice-based knowledge which is represented in a theoretical framework (aimed at other design researchers), and concludes a chapter with guidelines, tips and tricks (to serve practitioners) with the knowledge gained during this project.

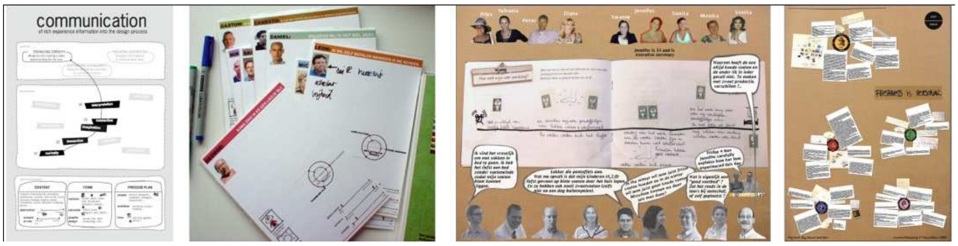

Figure 16: Left to right: user experience communication model, distinguishing three layers of goals, mechanisms, and means. Three communication tools: the personal cardset, web sensitizing tool to engage design team, and action posters for workshop sessions.

Design tools to interact with difficult-to-reach users: Helma van Rijn

Designers need to get closer to the lives and experiences of their users to design products that better fit these users' needs. Especially, when the lives and experiences of users are very different from that of the designer, this need is even more important. For example, it is difficult to imagine the experiential world of people with cognitive disabilities. Reason is that you have never been (and cannot be) in their situation.

This PhD research focuses on direct contact with these 'difficult-to-reach' user groups, and children with autism in particular. Designers need to put more effort in understanding these people's lives, experiences, needs, and preferences. Standard techniques to learn from direct contact with users, such as interviews, observation studies, and generative techniques won't work. For example, many young children with autism cannot talk and are difficult to engage in social interactions. Moreover, they can react strongly to new situations or events. A designer can feel uncomfortable in this situation, especially when he does not have any prior experience with these users. In this case, a designer has to find new ways to overcome these issues by learning from second hand information from caregivers or interacting with these users in different ways.

Aim of this research is to develop tools and techniques to enhance a designer in interacting with children with autism and their caregivers, and thereby bring knowledge about the user group. As a first step, a set of toys was designed, which brought out specific behaviours of children with autism and were tested with M.Sc. design students in an elective course (H. van Rijn, F. Sleeswijk Visser et al., 2009). These toys (or tools) should provide a handhold to structure the interactions and explore the possibilities in interacting with the children. In a next step, these toys shall be redesigned and evaluated with designers.

Implication Design – artefacts with an intended effect on society: Nynke Tromp

When reflecting on the way we currently live our lives, it is hard to think of an activity in which we do not make use of artefacts. We clearly live in a man-made world. Designers, being the creators of this man-made world, therefore evidently have a big, although underestimated, influence on the way we live our lives (Verbeek 2005). A microwave, for example, clearly functions different than comparable means to prepare a meal, such as a stove. Logically this difference in functioning changes the cooking process. But what is more striking is that since the coming of the microwave, families appear to share fewer dinners together. Artefacts intervene in social systems, which means they can have a far-reaching effect on social behaviour. Being aware of this influence opens up possibilities to start designing this influence. This PhD project aims to gain knowledge that is needed to design these far-reaching social implications. As this activity is especially relevant when dealing with issues of social kind, the design cases within this PhD project deal with such issues.

Three design projects have been carried out to explore the possibilities for designers to intervene in issues of social kind. Respectively these projects dealt with social cohesion (Tromp 2007), feminism (Borgonjen 2009), and social safety (Tromp 2010). Figure 16 shows that all three projects used a systemic representation to understand the relationships within their domain and the possible role of the product. Based on these projects, the 'Vision in Product Design' approach and additional insights from systems thinking, an initial design method has been developed. Currently four students are testing this method within their graduation project. These students focus on a so-called 'socially weak' area in the Netherlands and aim to develop an artefact with an intended social implication. In doing so various design strategies will be tested that have been defined in an earlier study to existing products with an effect on user behaviour. The development of experiential prototypes will allow evaluation of the intended implication, and hence the success of the method.

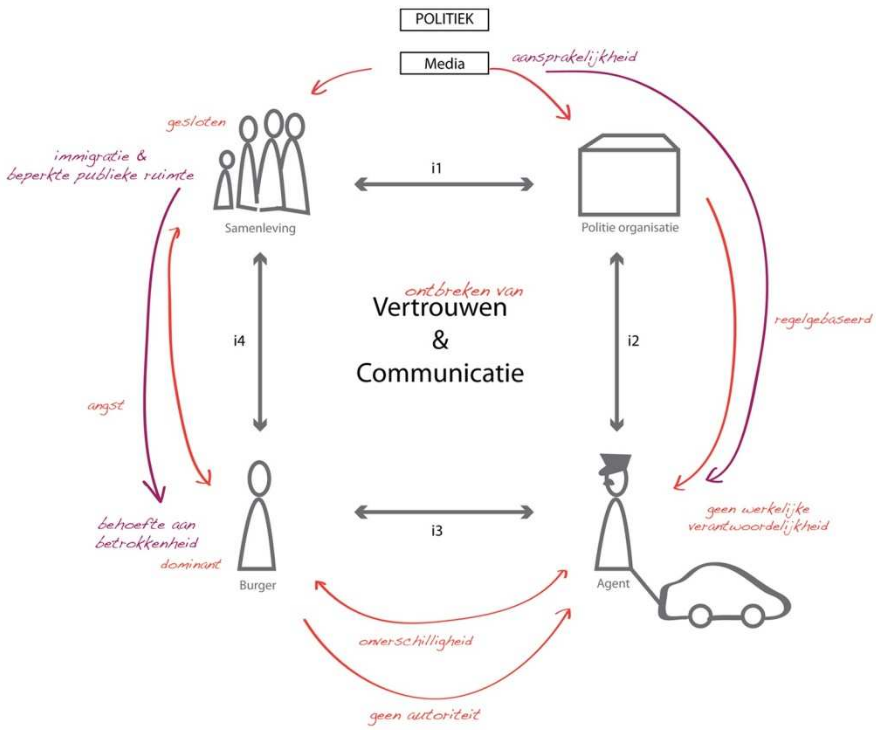

Figure 17: An example of how designers visualize social systems that allow them to understand how products can create social implications.

Metaphor generation and experience in product design: Nazli Cila

Metaphors are effective tools for communication in design, which are used for expressing and enhancing the meaning of products. They can be used as a means to make abstract ideas concrete and thus turn a complex product into a comprehensible one (e.g. Windows desktop), or they can lead to pleasurable user-product interactions by emphasizing the function, social or cultural meaning, or personality of the product (e.g. Senseo coffee maker).

In order to provide a coherent overview on product metaphors, a framework was constituted gathering the variety of factors found in linguistics literature and adapting them to products through the analysis of various product metaphor samples (Figure 18). In this framework, metaphor is considered as a creative communication process between designer and user. These parties create the metaphorical meaning together since the product metaphor mediates between the intentions of the designer to generate the metaphor, and the experience (i.e. reception, comprehension, interaction, affective reaction, etc.) of the users. In this PhD project, the aim is to have a thorough understanding of these two processes. We will focus on different components of this framework by conducting three studies in which designers will be given several design tasks and the results of each study will be evaluated. Through understanding how designers generate metaphors and how people experience these, we aim to contribute to design knowledge by providing a means of creating pleasurable product experiences, and offer designers the necessary insights and inspiration for designing successful metaphors.

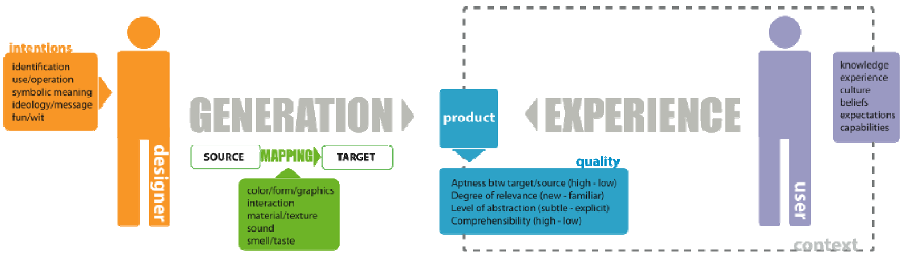

Figure 18: The “product metaphor” framework.

Understanding and designing for emotions: Erdem Demir

In the design practice and research domains, there is a growing interest for the emotional consequences of products and services. This can be observed clearly when we look at various conferences and books that focus on the emotional impact of products and at design firm mottos like “form follows emotion.” Despite the growing interest, the main issue of designing for a particular emotional consequence has largely remained uncovered. The raison d’être of this project is to develop theoretical knowledge to support designing to evoke or prevent particular emotions.

The project started with an investigation of how emotions are elicited. In this phase, appraisal theory was selected as the theoretical basis, as it focuses on the main question of interest. Appraisal theory states that emotions are elicited through automatic assessments of the personal meaning of a situation, i.e. appraisals. In this phase, the core issue was to make this body of knowledge operational for designing for emotions. To this end, a framework of appraisals underlying emotional experiences in human-product interaction was proposed.

In the second phase of the project, the focus was on the design for emotion process. The main idea was to explore ways to utilize the theoretical knowledge in the idea-generation process and to identify the needs of the designers in designing for emotions. The basic problem that was observed was the gap between the abstractness of the theory and the concreteness of the object of design. Based on this observation, a questionnaire that allows collecting examples of emotional stories was developed. This questionnaire aims to identify the causes of the collected emotional stories through a questioning sequence that was developed based on appraisal patterns of emotions. The questionnaire can be used for data collection to be used in different design projects, by asking the participants to recall particular emotions relating to those domains (e.g. driving experiences, airport experiences, in the office, lives of elderly) and provides examples pulling the theory to concrete grounds.

Independent@Home: supporting the elderly at home using aware systems: Martijn Vastenburg, Thomas Visser and David Keyson

With today's technology, elderly users can be supported in living independently in their own homes for a prolonged period of time. Commercially available products enable remote monitoring of the state of the user, enhance social networks, and even support elderly citizens in their everyday routines. Although technology seems to be in place to support elderly users, one might question the value of present solutions in terms of solving real user problems such as loneliness and self-efficacy. Furthermore, available products tend to be complex in use and do not relate to the reference framework of elderly users. Consequently, user acceptance of today's solutions tends to be low. Figure 19 shows three prototypes of case studies that have been conducted within the project. These three case studies are focused on context-aware products; the product behaviour is linked to the context of use. The products all aim to merge into the daily routines of the users, thus their effects can only be studied on a longitudinal basis. These field studies require high efforts of the researchers, both in terms of conducting the field study and in terms of developing a robust and functional prototype. With the Independent@Home research project, the ID-StudioLab aims to develop and provide the proper instruments and methodology to support designers. In the project, funded by SenterNovem IOP-MMI, ID-StudioLab collaborates with industry partners and home care service providers. These have participated in a series of design explorations, in which the design space and the user-centered design process have been explored. At the same time, a service platform has been developed (Vastenburg et al., 2009). This platform enables designers to make design iterations, even when time is limited and the technical requirements are complex. In Figure 19 some examples of developed prototypes are shown. Flowie is a virtual coach which stimulates elderly people to exercise more (Albaina et al., 2009). A field test showed that people appreciated the feedback by the display and they enjoyed the interaction with the virtual coach; the system could however be improved by linking the coach to weather conditions. ConnectAll shows a prototype which connects elderly and their informal caregivers. The product has been developed in close collaboration with the elderly and their caregivers. Rather than focusing on supporting the care giving process, the product emphasizes the peace-of-mind by showing day-to-day activities and by facilitating peripheral communication. Snowglobe is a social awareness display, which aims to improve the feeling of social connectedness of elderly people, and thereby contribute to wellbeing. In a field test, participants indicated that they enjoy using the system. It appears to be difficult, however, to measure changes in perceived social connectedness in a quantitative way.

Figure 6: Prototypes developed within the Independent@Home project (left: Flowie, middle: ConnectAll, right: SnowGlobe).

Bringing product use into designing: designer perspectives: Stella Boess

Intended users are often absent in design team meetings. We studied how designers can still engage with and be inspired by user data in such meetings. Previously, we and others found that information about product use should be presented to designers in a convincing, in-depth way, well-rooted in empirical work. Here, we focused on the ways that designers use user data. We compared a design meeting without user data to one in which we presented cards showing user situations and quotes. The design topic was visual reminders in people’s homes. We found that the designers used both their own experience and the participants’ situations in their designing. They used the photos and quotes from participants to reflect on their initial ideas from the first meeting and added new aspects based on the user data. They preferred to stick to their initial ideas rather than come up with new ones from the data. They did not use the presented materials as a self-explaining source of information, although they confirmed they had enough time to study them. Rather, they asked the researchers to explain and elaborate on the cards to understand the situation better. We conclude that data presentation alone does not enable designers to design empathically. Open conversation is also needed (de Jong, Boess et al., 2007). The participating designers were Froukje Sleeswijk Visser, Daniel Saakes and Jasper van Kuijk.

Sensory incongruity and surprise in product design: Geke Ludden

People continuously experience the world and the objects in it through all their senses. Product designers can influence the way people experience products by paying attention to the multiple sensory aspects of product design. Designing sensory experiences can be aimed at communicating a consistent message to all sensory channels, making this message a stronger one. The opposite approach, designing a product in a way that incongruent information is provided to different senses, can be used as a means to create surprising products.

In this research project, three types of sensory incongruities were studied: visual – tactual, visual – auditory and visual – olfactory. First results were described in (Pasman 2005). We found that when information from two or more sensory modalities conflicts, this can evoke a surprise reaction as well as feelings of amusement, interest, confusion or disappointment.

In one of our later studies (Ludden 2009), we argued that in concurrence to joke theory, people appreciate and enjoy appropriate incongruities that can be related back to the product, whereas they are confused by and have negative opinions towards inappropriate incongruities. To study this effect, products in two categories, (rubber duckies and deodorants) with (in)appropriate sensory incongruities of three types: visual – tactual, visual – olfactory and visual – auditory incongruities were designed and evaluated.

Both appropriate and inappropriate incongruities were evaluated as surprising and confusing. As expected, appropriate incongruities evoked more amusement and were liked better.

Affective tangible interaction: design of a pen that responds to stressful behaviour: Miguel Bruns Alonso

Previous research at the ID-StudioLab has investigated a tangibility approach to affective interaction, i.e. how people express emotions through interaction with an alarm clock (Wensveen 2002). Building on this research one may question how products should respond to affective input to influence emotions, which after measuring and interpreting affect, is the end goal in affective computing. Stress, which is considered as a subset of emotions, was selected as context for this research, and fidgeting behaviour with a pen was considered as a means to interpret stress. Two pen movements were found to be indicators of stress, rolling and rocking movements (Alonso, Varkevisser et al., 2007).

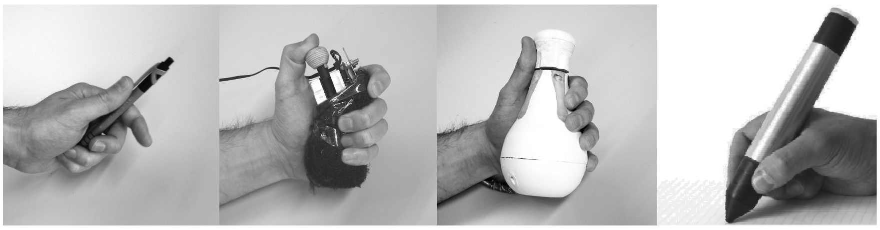

Figure 20: Left: Stressful behaviour while fidgeting with a pen. *Middle* two images: Various iterations of prototypes for measuring behaviour and giving feedback through actuators. *Right*: Final prototype of the research project (the RelaxPen).

Through a process of research through design, a method frequently applied in ID-StudioLab projects, a design approach was evaluated for how a product could respond to fidgeting behaviour to influence stress. Haptic feedback was proposed as a means for product response to this behaviour since the modality of feedback is consistent with the input (Wensveen 2004). Thus a pen was developed that responds to stress by adapting its behaviour. The pen fixes or loosens the tip when a rolling movement is made, and it changes the freedom of movement of a ball when a rocking movement is made, providing a change in the perception of balance. Approaching stress from a designerly perspective has opened new and interesting fields for exploration in affective computing, looking at behaviour instead of physiology or facial expressions. On the other hand it provides designers with an insight on how to approach the design of responsive products.

Sketching product sounds: Reinier Jansen

In our daily lives we are surrounded by product sounds, whether it is the rattling of an electric toothbrush, or the whooshing sound of a washing machine. Contributing to the total user experience of a product (e.g., product functionality, identity, and satisfaction), it is important for designers to consider product sounds. A framework for product sound design related communication has been put forward by (Özcan and van Egmond 2006). This framework essentially states that product sound design should be incorporated from the very beginning of the product development process. Sounding sketches have been proposed as communication method during the conceptual design phase. However, designers currently lack a tool that facilitates sketching of product sounds. Existing tools are focused on musical sounds, and designers are often faced with their limited sound vocabulary when using tools that rely on semantics.

Therefore, a concept for a Product Sound Sketching Tool (PSST) was developed as objective for a master's thesis (Jansen 2009). PSST consists of a dedicated product sound synthesizer, a collection of playful objects, and a table with a web-cam to track the objects on it. Through their visual and tactile designs, these objects serve as physical representations of the synthesizer's virtual sound parameters. For example: the speed of periodic volume fluctuations found at, e.g., washing machines is controlled by adjusting the length of a sine-like leather belt wrapped around two cylinders. In this way, product sound design is made tangible.

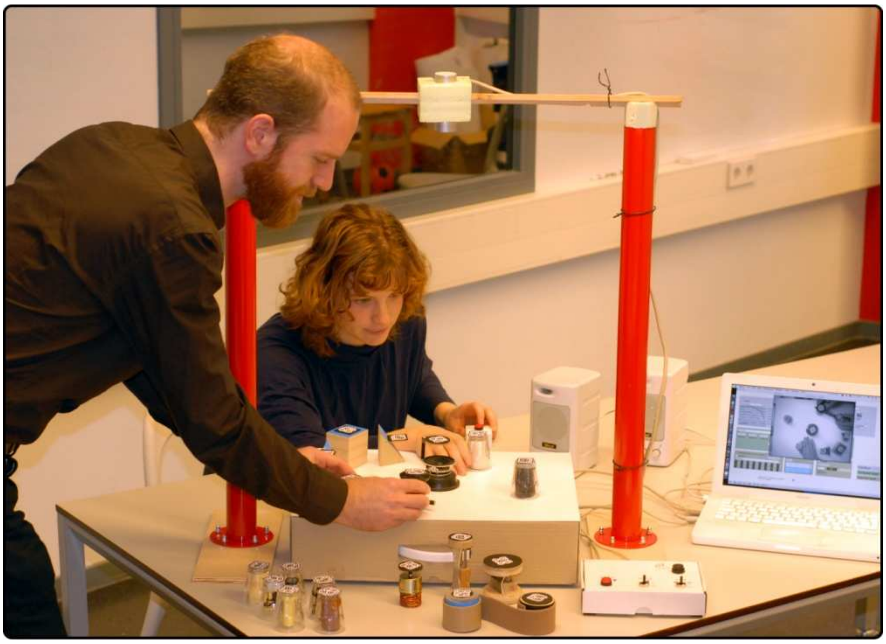

Figure 21: A design session with Product Sound Sketching Tool (PSST).

Discussion

The presented projects show the multifaceted nature of ongoing design research at ID-StudioLab. Although ID-StudioLab members are mainly involved with their own specific projects, sharing the facilities of the ID-StudioLab makes cross-fertilization easy – one could say ‘intentionally unavoidable.’ On a small scale, the “coffee-fetching discussions” contribute, on a larger scale the regularly organized LabTalks, weekopenings, visits by international guests provide a rich environment that continues to inspire members to improve each others work and create new synergies between research strands.

An important partner to the research projects in the ID-StudioLab is the Design for Interaction (DfI) master program of the Faculty. DfI is a 4 semester master programme that aims to educate designers specialized in analyzing and conceptualizing of and in designing for human product interactions in relation to the physical, cultural, technological and societal context in which the product is used (Stappers, Hekkert et al. 2007). Because the education programme and the ID-Studiolab research agenda are closely coupled, this means that a yearly influx of ca. 100 MSc students is confronted with, and get the chance to participate in, the research.

ID-StudioLab members are instrumental in shaping courses and assignments to arrive at interesting work for students. In return, the student work provides interesting cases, inspiration for the ongoing research projects, direct application to designing, and an effective channel to make research findings reach Dutch industry. The MSc. project PSST, mentioned in the section with example projects makes an excellent case of the benefit of tightly coupling education and research. The course Exploring Interactions in which students learn to conceptualize for interactive products and the course Interactive Technology Design in which students learn to design interactive concepts by making experiential prototypes (van der Helm, 2008), are just two examples of education providing inspiration to research and vice versa. Deepening courses allow students to practice their skills at the combination of research and industry, e.g., in the RichViz! elective students can train in contextmapping techniques in close collaboration with companies (Stappers, van der Lugt et al. 2007). In recent years we have collaborated in teaching the design of interactive installations with the Hyperbody group of the Architecture faculty of TUDelft, combining the architectural viewpoint with the product designers’ viewpoint. The resulting installations have been exhibited at the Science Center of TUDelft and at the Industrial Design Engineering Faculty.

Conclusions

Design research is inherently multifaceted and multi- or cross-disciplinary. Therefore crossovers and learning across projects is essential to effectively and simultaneously create situated and generalized knowledge on a cross-disciplinary playing field. Cross-overs should happen in different stages of research: serendipity in contacts, sharing and learning from each others’ skills and perspectives. For the next five years, we envisage that the maturing of the new research portfolio and connections this offers, both within the Faculty of Industrial Design Engineering, and with the growing network of academic and industrial partners, but mostly also that it accommodates the research and education passions of those who participate. After ten years of “a design research community: user-centered, design driven," we intend to continue the course of combining people and technology, with products and services, for education and practice.

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SOLVING AN UNRESOLVABLE PUZZLE?

How to support the designer in context

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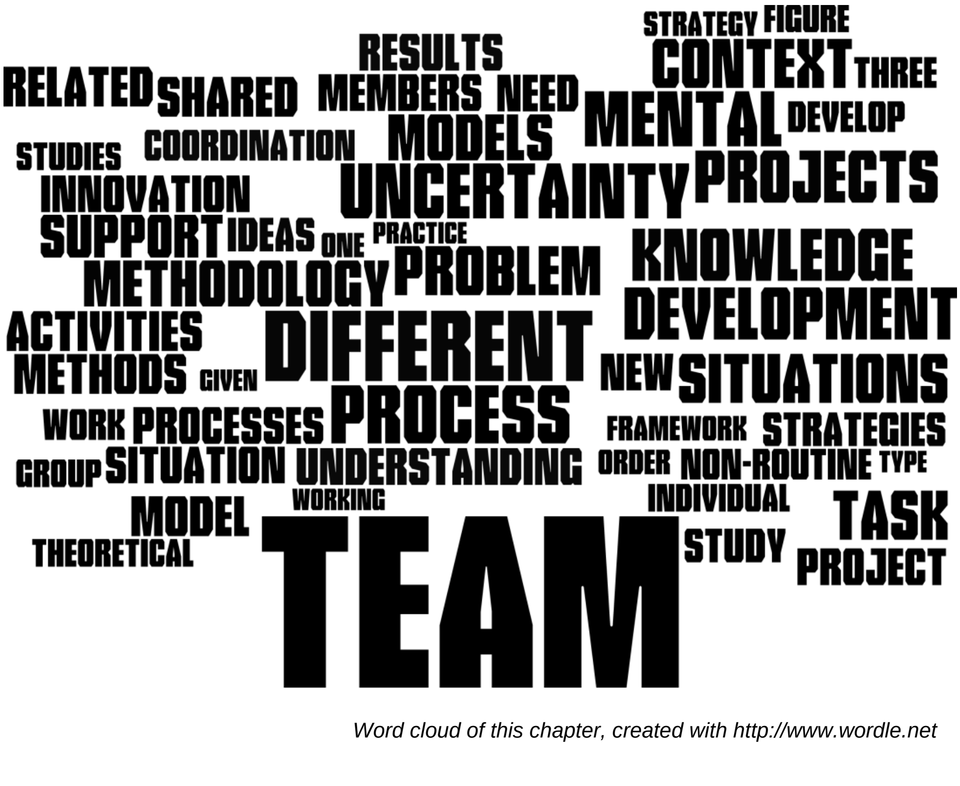

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Introduction

The aim of scientific conferences is usually twofold, first, conferences should bring together leading researchers in an environment that stimulates the exchange of ideas and views; second, conferences provide a platform for the latest research and progress in the field, and thus are at the heart of newest developments. However, the current conference is somewhat different: although the first and second aim might be important, too, this symposium – hold every five years – furthermore pursues to provide the scientific community with achieved and planned results, with finalised research projects and with research visions, with past and future. The five years interval of the conference ‘Design Research in the Netherlands symposium’ allows the participants to gain better insights into planning, implementation and results in terms of the research framework, and thus they are able to understand and follow the development of research plans of different research teams and/ or projects on a bigger scale.

This is also what we try to provide within the current paper. The research framework of the Design Theory and Methodology group (the section consists of one full professor, two associated professors, one assistant professor, and eight PhD students) at the Faculty of Industrial Design Engineering at TU Delft presented in 2005 was conceptualized as a general framework addressing the need to further assess cognitive, social and organizational determinants of designing in order to be able to understand the ‘methodological needs’ of the designer. In this paper we will first briefly present the research framework of our group and then portray three research projects which were conducted to gain knowledge about these different influences on the design process.

In the following we present selected results of the research of the last five years which provide further information about the needs of supporting the designer to perform in a successful way. Thus, these results also contribute to the different fields of influencing factors of the research framework (Badke-Schaub et al., 2005). The presentations of the projects do not entail literature reviews because the emphasis here is on the conceptualisation of projects and their results, done by our DTM group.

Design theory and methodology

Is experience a critical factor for creative design processes? What kind of strategy may help to cope with fixation during idea generation? Which selection strategy is more appropriate than others? If design methodology wants to support designers these and many further questions need to be answered, a theoretical background has to be taken into account.

Based on the assumption that designing is not a purely intuitive artistic activity but one that can be taught and learned, knowledge is needed about how to steer different design problems throughout the process of designing. Design theory is the body of knowledge which delivers an understanding of the principles, practices and procedures of design. That knowledge leads to hypotheses on how designers should work, and these hypotheses are the basis for building methods which should support the designer. Accordingly two different views on design methodology can be drawn, the descriptive and the prescriptive view. No doubt that design methodology should offer methods which 'align' with the needs of the users, here the designers.

But designers are different in terms of knowledge, experience and skills; also the task is different in terms of complexity, uncertainty, resolution level etc., and so is the organizational context. The process the designer should follow may be explicitly prescribed in a given method, however the characteristics of the individual designer which influences the choice as well as the use of methods are not considered. This is also true for characteristics of the specific task and project context such as the organizational environment, time constraints, financial constraints, and constraints associated with multiple projects that must be treated simultaneously. These are elements, which contribute to an increase of uncertainty in design practice and need to be addressed by design methodology. Furthermore the designer must feel the need to use the particular method; therefore the benefit must be recognized very quickly to convince the designer that the method will not add more uncertainty. Thus, designer-centered methodology should focus on the designer by reducing motivational resistance on the one hand and uncertainty on the other. We argue that if design methodology is to support designers appropriately, it must allow the designer to choose an appropriate method in a particular situation given a set of characteristics specific to that interaction between the designer and the situation.

This integrative view aims to overcome the most important limitation of design methodology, the missing link to the 'human' characteristics of designing, neglecting the designer's needs in his design situation, with a specific task, seeking to solve the problem at hand. Based on the fact that the basic principles of design methodology offer essential support for designers we build upon this knowledge but integrate the human aspect. By understanding designing as a complex problem solving process, steered by the human cognitive and motivational system, we get a deeper insight in the way designers work. Ultimately, this may help to develop supportive methods and tools for the designer. Thus, this program addressed a substantial new dimension: the designer as human being and a pleading for a 'designer'-centered methodology.

Research program

In 2005 we started to define the research program for the following years (Badke-Schaub, Lloyd, van der Lugt & Roozenburg, 2005). The research strategy was guided by the goal to find out which aspects determine designers' work and why is design methodology not broadly accepted by designers in their daily work. Thus, to summarise the aim of the research was solving the unsolvable puzzle, how to support the designer in his/her context.

The general framework is depicted in Figure 22; it sketches the designing as a complex problem solving process in an environment with numerous influences which are interconnected. Of course, this general model does not provide any answer about the kind of variables in the different fields and their interrelations. It is a starting point for investigating how design is – to enhance the descriptive knowledge about designing, to 'identify' this network of designing. From these results the prescriptive knowledge, the development of support for the designer, can be applied.

Thus, the primary aim is to gain more insights into this network in order to understand the needs of the designer. Furthermore, in order to understand designing and to come up with fruitful support, there needs to be a theoretical background which provides the appropriate context of explanation.

Hence design research has to borrow from other disciplines such as psychology, anthropology, etc. That means design research has to encompass the important fields of influencing factors:

- 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 22) of this interplay.

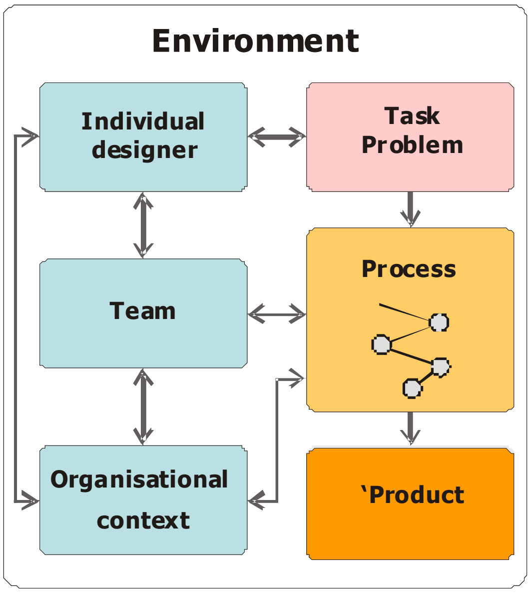

Figure 22: Network of designing.

In our outline of the planned research for the following years from 2005 to 2010 (Badke-Schaub et al., 2005) we also presented a framework how to gain and integrate empirical knowledge about designing. This integrated approach is based on three interrelated columns as depicted in Figure 23.

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 (Andreaasen and Hein 1987; Hubka and Eder 1992; Roozenburg 2002a, 200b) naturalistic decision making (Zsambok 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 validated by empirical data.

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.

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.

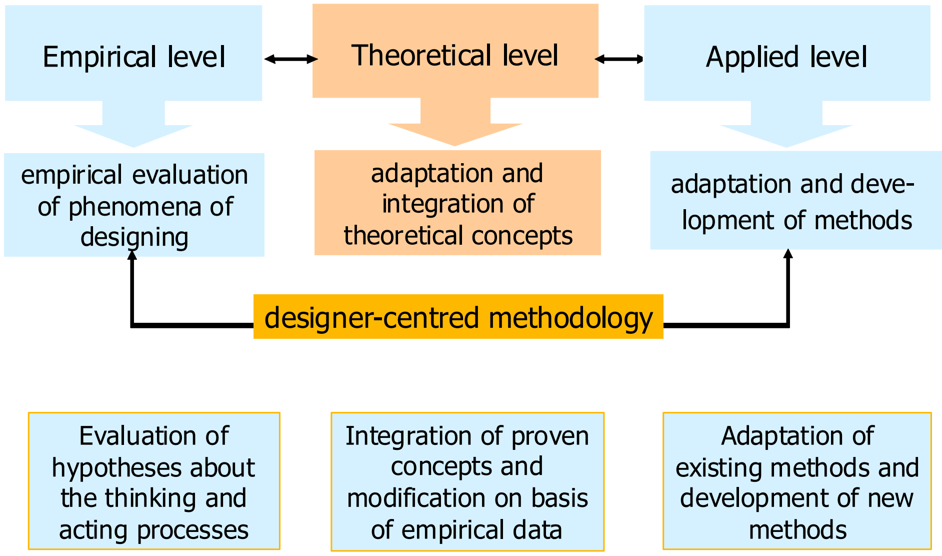

Figure 23: An integrated research approach: synchronisation of theory development, empirical studies and application in design research.

Research projects

In this chapter we will describe three research projects which were aimed to answer questions about interdependencies of factors in the main fields *individual*, *team*, *organisation*, thus referring to cognitive, social and organizational determinants related to the process of designing and the result.

Task – designer – process: uncertainty as determining characteristics of design problems guide designers' strategies

Designing is the development of products, services, and experiences; the most challenging part of designing is the development of new and innovative solutions. Because the outcomes of innovation processes are supposed to be new, they can not be predicted during the design process. For this reason a fundamental element in design is uncertainty. Uncertainty emerges when the situation, the possible measures and /or outcomes are not known, and no probabilities can be calculated. To be able to deal with this inherent uncertainty, designers have to rely on knowledge of previous processes that seem to have some communality with the current process. To be able to proceed, they need to have a clearer picture of the problem, and to better understand the problem, they have to proceed. These situations are non-routine situations in the sense that in this situation the designer does not know obviously how to proceed. As a consequence the designer has to reflect on the situation and may have to develop or introduce new strategies or procedures.

As part of a PhD project, Daalhuizen (Daalhuizen et al., 2009) did an interview study with sixteen design practitioners from six different design companies, located in the USA and the Netherlands. This study focused on non-routine situations that designers encounter in practice and the ways they deal with those uncertainties. The two main questions of this study were: “what kind of situations do designers consider as situations of high uncertainty?” and “how do designers respond in order to deal with these uncertainties?”

The different sources of uncertainty associated with non-routine situations identified by the designers were related to one of the following categories: (1) uncertainty related to the own person, (2) uncertainty related to the social context, or (3) uncertainty related to the task. All three types of uncertainties contribute to a general level of uncertainty that either lead design practitioners to get stuck and be ‘paralyzed by hesitation’ or to reflect on the situation and develop or introduce an appropriate strategy or method in order to proceed with the project.

Analyzing the frequency of occurrence of non-routine situations it turned out that designers encounter a variety of situations that can be categorized according to the three sources of uncertainty as shown in Figure 23. The data revealed that 48 % (n = 54) of the non-routine situations were related to the task and that 44 % were related to the social context. This means that, according to the perception of the designers, only 8 % of the situations related to their own ability or behaviour.

According to Figure 23 the participants perceived most non-routine situations as a result of the task, e.g. most uncertainty occurred because of a changing understanding of the problem during the design process. Due to the change in understanding, it was not appropriate to continue with the same course of action. The designer’s view of the task shifted and therefore needed to develop or introduce a new way of approaching the problem. Very close to the changing problem understanding is also the aspect of ‘getting counter-intuitive information’ which again causes the designer to reframe the problem and to reconsider former decisions.

Uncertainty was also caused because the designer was operating on a strategic level that required the analysis of strategic issues and development of strategic propositions in addition to working on the design of the product itself. In these cases different knowledge needed to be analyzed, and results needed to be translated in a language appropriate for a strategic level.

Designers attributed significantly fewer causes of uncertainty in non-routine situations to their own person or behaviour compared to the task or social context. Uncertainty caused by the own person (the individual), was perceived due to problems with the transition from analysis to synthesis during the design process, or as consequence of an escalation of commitment to a sub-optimal solution or uncertainty occurred as a consequence of an improper framing of the assignment.

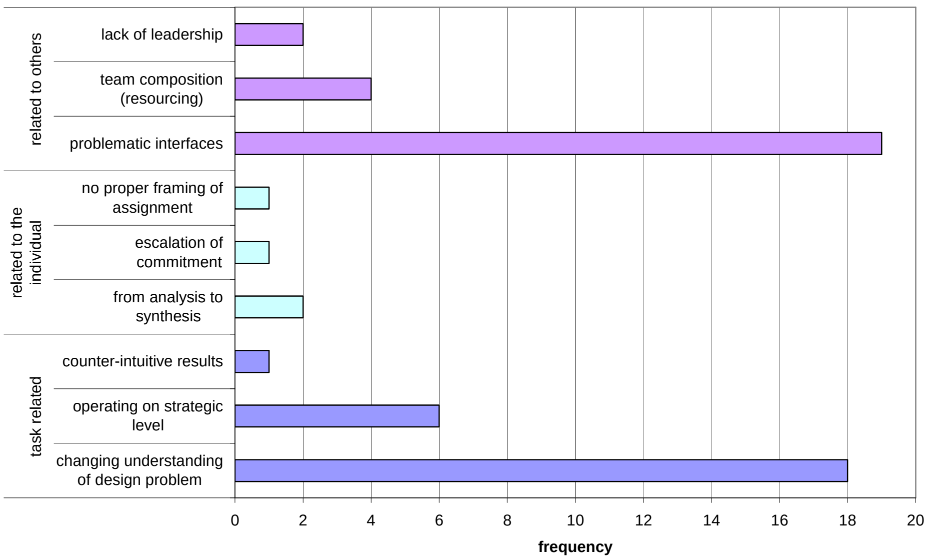

Figure 24: Frequency of types of non-routine situations related to the three sources of uncertainty (n=54).

The question of how the designers deal with those non-routine situations can be answered by the results depicted in Table 8. The interviews indicate that designers have a broad set of activities at their disposal. The sixteen participants mentioned 71 single activities that were part of their strategic repertoire. The self-reported activities were grouped into nine different categories and these are summarized under three different strategies. Strategy 1 is closely related to the problem at hand: these activities are mainly focusing on the current problem as it is, not going beyond the given situation. Framing the problem, visualization and also the articulation of the business value are activities which can be clearly described and supported by existing methods. Activities subsumed under strategy 2 are outward directed, searching for different kinds of support in the environment and in the organization whereas strategy 3 describes more general heurism, such as ‘keep on going’ which are more or less useful in different situations and environments.

TABLE 8: Frequency of different types of strategy (n=71)

Strategy type 1	**f**	**Strategy type 2**	**f**	**Strategy type 3**	**f**
frame the problem	8	involve stakeholders	17	keep going	11
visualize information	2	create open communication culture	11	use intuition	2
articulate business value	11	go multi-disciplinary	7	take project ownership	2
Sum	**21**		**35**		**15**

Relating these chosen strategies to the question in how far methods support the selection and application of these strategies it turns out that only about mainly strategies type 1, that is one third (n=21) of the strategies mentioned by the designers, can be supported by design methods. Especially for the strategies type 2 there is no methodology available – especially not related to the design discipline, and strategies type 3 are in essence no strategies and thus methodological not supportable.

Designer – team – processs: shared mental models in design teams are the result of explicit verbal coordination and joint sketching activities

In any situation of communication the sender and the recipient have to align their ways of thinking in so far that they are able to understand each other. In any situation of cooperation where the knowledge and skills should be used most efficiently, it is necessary for all people involved to develop a shared understanding. It is assumed that each individual develops and holds mental models about the situation around him/her; these mental models may be similar or different to those of others.

The term 'team mental model' refers to members of a team sharing their individual mental models. According to the definition of Klimoski & Mohammed (1994) team mental models can be thought of as knowledge or belief structures about key elements of the teams environment that allow team members to anticipate one another's actions and to coordinate their behaviours. Developing a team mental model is therefore essential to help individual designers coordinate their ideas and activities.

The research in this area was executed in a PhD project by Andre Neumann investigating how do design teams arrive at a common mental model, what influences the development of mental models and how can we measure it:

a) How do design teams establish common mental models?
b) When and how do design teams modify mental models?
c) How can we measure the development of common mental models in design?

As mental models are constructs and as such can not be observed directly, the problem occurs how to study this type of 'unobservable thing,' how to elicit the content of someone's mental model. Obviously, the analysis of externalizations is one important way to get insights into the person's head. The main externalisations of human beings are words and sketches (Goldschmidt, 1991). Thus, in a first experiment team settings were chosen, where verbal communication provides a natural angle into the mental models of the team members. Our approach was therefore to observe the interaction in design teams without interrupting the process. In a second study the influence of (Neumann, Badke-Schaub and Lauche, 2009) investigates how joint sketching in teams affects the idea generation process in early concept generation.

The first study was an experiment with 33 industrial design engineering students (fourth year) working with three persons in a team. Thus eleven teams a design task of two hours had been given which was divided into three phases. First, the participants developed ideas and concepts individually, in the next phase they should discuss these ideas with other participants in a team of three members and in the last step the group should come up with a final group design which had to be presented to a simulated customer.

In order to draw conclusions about the sharedness from overt behaviour a theoretical model has been developed. During group interaction, groups can coordinate their actions implicitly, based on expectations, or explicitly, based on formal agreements and plans that are verbally expressed (Wittenbaum, Vaughan, & Stasser, 1998). In order to be more efficient, groups have a natural tendency to coordinate their action tacitly rather than explicitly based on their knowledge about each other and the task. Teams, after a start-up time, develop sharedness and, as a consequence, need less explicit coordination.

On the basis of data gathered in a single case study (Badke-Schaub, Lauche, Neumann & Ahmed, 2009) a theoretical model (see Figure 25) of the development of sharedness and coordination in teams has been derived. The model depicts two different processes related to the development over time:

1. the process of developing shared understanding, and
2. the results of shared understanding on the following coordination activities.

Groups that have achieved shared understanding continue to employ the same cognitive processes, yet the frequency of certain activities decreases once shared knowledge on how to collaborate on the task and within the team has been acquired. The task model refers to information exchange that is related to the problem definition and evaluation, and to the solution space including the generation, analysis and evaluation of an idea. The process model refers to the approach and methods of how the task is with which the team solves a task.

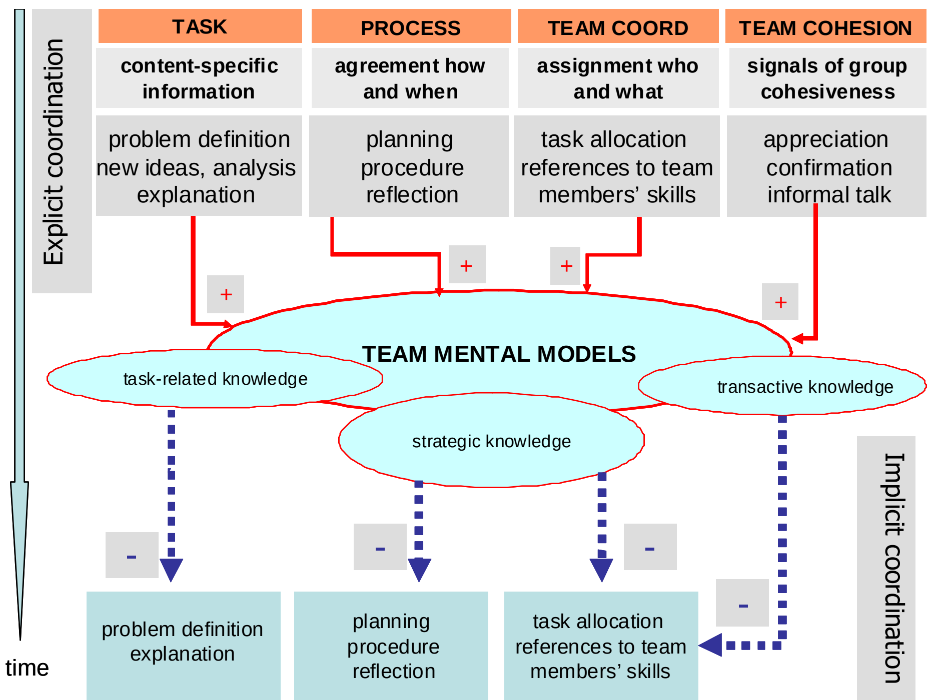

Figure 25: Development of implicit coordination in teams as basic element of shared team mental models.

At the beginning of their collaborative process, team members need to explicitly coordinate their action. Once a common understanding has been achieved about how and when to do what, only minor adaptations should be necessary and, in turn, implicit coordination will suffice. The team coordination model refers to roles and responsibilities and is based on the awareness of other team members' knowledge, skills, and experience. Team cohesion refers to the team climate and the preference of the members to be part of the team. As the team stabilizes over time, team members are expected to put less effort into keeping the team together. This should lead to a decrease in team cohesion utterances.

As team members gain more sharedness in time, it is assumed that they need less explicit coordination since they can synchronize their mental models implicitly. In turn, they should talk less about these aspects. In order to test these theoretical assumptions, design teams were observed under experimental conditions.

A second study analyzed the influence of sketching as externalization on the development of shared mental models in design teams. 36 Teams of three design students were given a design task in which they were asked to come up with visualized ideas. In the control groups, team members sketched on an individual sheet of paper while working in a team. As a result it could be shown that the teams where the team members were sketching individually produced more in total and more diverse ideas. No difference was found between the quality and innovativeness of the ideas. Also according to the hypotheses, individually sketching teams elaborated less on their ideas but explained their own ideas more. The teams did not differ in terms of satisfaction with the final result. The results suggest that common sketching did serve as a common ground in the group that leads to shared views and ideas. This, however, goes along with less productivity of ideas.

Designer – process – organisation: designers in practice need to do more than solve design problems – they need to 'sell' their innovation to managers and clients, and often also innovate the organisation

This third field of research focuses on the organisational context in which designing occurs. It addresses the fact that as a professional practice, designing does not occur in isolation: the designers work in or for a company, they need to relate to clients and other disciplines and their activities form part of the new product development processes of the organisation. Therefore the research in this field is carried out as longitudinal case studies in the field, following innovation projects as they develop over time. Exemplar research questions are: What strategies do design teams use to convince their management of the need of their innovation project? How do companies pursue innovation implementation and how do different groups within an organisation adopt and appropriate innovation? How do teams that span organisational boundaries find a common way of working? For each question, an example project will be briefly introduced.

Strategies of design teams were investigated in a longitudinal field study of seven new product development projects (Lauche & Erez, 2010). The research resulted in a model of new product development from the perspective of the innovators as 'expansive innovating,' i.e. moves to actively influence an organization's strategy bottom-up through shaping the scope of innovation projects. The model of expansive innovating integrates the literature on design methodology, on creative team processes, on innovation management and on organisational change.

We identified organisational context factors and actions of innovators that shaped the course of innovating. In successful projects, innovators engaged in extensive goal clarification, explicit management of team processes, and ‘issue selling’ in their organization. Protracted projects were associated with limited organisational support and understanding of innovation, a high involvement of externals for core tasks, and team practices of collective moaning, which did not translate into proactive issue selling activities. In projects terminated early, innovators were disconnected from the organization and failed to strategically align their project.

For innovation implementation, we studied how information and communication technologies impacted on how distributed teams coordinated their activities and processes and how different system designs influenced this process (Bayerl and Lauche, in print). This longitudinal multi-case study was conducted in an organisation that has a history of working remotely on highly interdependent tasks on an ongoing basis. Based on 78 semi-structured interviews and observations over a period of twelve months, we identified coordination requirements for primary team activities, as well as the effects of changing media capabilities to overcome difficulties of ongoing distribution. Most theories and models on technology implementation and adoption focus either on the individual user or the organization as a whole. An important conclusion from our research has been to identify group-level variables such as team characteristics and intra-team dynamics will likely influence the success of implementations.

For analyzing inter-organizational collaborative design projects, a new project has started that will explore how team members develop shared work practices and a partially shared object. As products become more complex, the development of new product often spans organizational boundaries. The current research on inter-organizational networks has focused on structural properties or the formation of such networks, largely ignoring the actual work practices of designing across organizational boundaries. This project takes a practice theory and activity theory approach to explore how the potpourri of various work practices evolves. The premise of our research is that inconsistencies and disruptions can lead to work practice innovation and new collectively shared competencies can be developed (Deken and Lauche, 2010). We propose that the coordination of inter-organizational designing can be studied from the perspective of the shared object formation. Particularly in product innovation, the object leaves multiple traces in the form of physical artefacts that can be analyzed for form and content and serve as a prompt during interviews to elicit further information about authorship and use.

In another project Jalote-Parmar (2009) investigated how the designer can develop supporting methods by taking a comprehensive analysis of the workspace, in this case the surgical workspace.

Further projects aiming to enhance the knowledge of the designer in context are empirical studies of interrelations in the big network, such as quasi- experimental studies investigating cognitive aspects of designing (fixation) (Cardoso et al., 2009), field studies investigating lean processes in different disciplines of design (da Silva Vieira et al., 2009), theoretical conceptualizing and field studies on the analysis of service design (Secomandi et al., 2008) and the development of a system which supports designer in using methods in non-routine situations (Daalhuizen et al., 2009).

Conclusions

What all these studies reveal so far goes beyond the mere question what kind of methodological support is relevant for the designer; these studies provide a better understanding of the designer in context and by this develop theories of designing. Although this attempt seems to be too ambitious in the light of the complexity of this issue the attempts are fruitful regarding the results the research revealed so far. However, the reported projects of our group also refer to an even increasing complexity of the designer's world, given that more and more social and organisational issues determinate the design context. If we arrive at a stage where theories cannot only explain the designer's behaviour but also predict the main threads of his actions, the still unsolved puzzle how to support the designer is solved and we are able to support the designer with a designer-centered methodology.

A DESIGN APPROACH TO RESEARCH AND A LANDSCAPE APPROACH TO DESIGN

A Wageningen experience

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Word cloud of this chapter, created with http://www.wordle.net

Introduction

Integration of art with science is one of the common characteristics of landscape architecture, architecture and urban design, and perhaps for the design disciplines in general. Yet when the integration of design with research is pursued, given its demand and value, we need to be more specific about what kind of design or research we are talking about. I often find that design is understood in shallow terms (such as surface design, experimental design, or a concept sketch) by scientists or planners, and that research is frequently understood within the field of design as merely information gathering (such as site-analysis, programming criteria, and case or precedent studies). We need to have a deeper understanding of research and design - to understand design as designers mean it, and research as researchers do. Just as there are many different types of research there are many different types of design. It is precisely these differences that warrant a differentiated approach to design research integration. The question is: how? Clearly, one measure does not fit all, thus variations must be studied.

Product design and building design approaches can not be applied to the design of process, experience and place, all of which are important in landscape design. Design types (in terms of product and procedure) also need to be differentiated in terms of their closedness or openness, i.e. closed design or open design. We can call the former ‘operational design’ prior to construction, and the latter ‘strategic,’ leading to various adaptations as the situation unfolds. Research too, can be empirical, theoretical and even explorative where a problem or hypothesis is loosely defined and solution-seeking or verification is done in an iterative mode rather than a linear one. Not all sciences are analytic: theory building, for example, is creative and imaginative. Likewise, not all designs are creative, particularly not those that follow existing paradigm, typology and style.

This paper is based on my recent experiences at Wageningen University as Chair Professor of landscape architecture, positioned within an environmental science department (we have about 250 scientists working in the Landscape Center – *Centrum Landschap* – and have direct connection with Alterra, a renowned Green World Research Center). The Wageningen landscape architecture group has traditionally pursued regional-scale landscape design with a rural focus. During my tenure we expanded our attention to include urban issues. We also tried to differentiate a “landscape approach to design,” theoretically as well as methodologically, from both an architectural approach and an ecological approach to design (Koh, 2008). At the same time we tried to differentiate design from planning, a task that of course, is not always easy given the nature of landscape, that is, its openness, sliding scales, and nested hierarchy.

In this paper I argue the following points: (1) design research integration must vary according to type of design and research; (2) a landscape approach to design is emerging as an effective approach to environmental design on a large scale (architecture, urban and regional design), for sustainability, regeneration, health and place identity; (3) most of the current “landscape approaches” (as in landscape urbanism or Lassus’ kinesthetic design) are more practice-based operations, short on theoretical clarification, and built upon diverse conceptions of landscape (landscape as material process or landscape as a spatial or aesthetic concept); (4) digging deep into the ontology of landscape (landscape as what) is necessary to theoretically legitimate a method, in this case called a landscape approach to design, be it a critical, evaluative, descriptive and even prescriptive method (landscape as how); and (5) clear understanding and communication of the nature of landscape design and landscape design methods opens the way for effective design research integration in landscape architecture, as well as transdisciplinary collaboration, particularly at the regional scale.

To advance these arguments, I will discuss: (1) the meaning of landscape that guides our design research, (2) the design research typology in landscape architecture, (3) a landscape approach to design, and (4) the method of sustainable landscape design at regional scale that integrates research. I will then elaborate on three design research projects to which we applied a design approach to research: energy landscape, climate landscape, and microclimate experience in urban space.

The meaning of landscape

The English dictionary provides two meanings of landscape: one as a painting, a ‘picture representing a view of natural scenery,’ and the other, landscape as territory (Webster’s, 1979). This definition already implies the double domain of landscape as art and geography. One can say that landscape started as an artistic concept in Renaissance Italy but became a scientific concept when A. von Humboldt used this term for a unit of geographic study in mid 19th Century. Landscape however means more than that. Cultural geographer John B. Jackson defines it as ‘an area of the earth’s land surface that has been modified by human activity’ (Murphy, p. 11), The European Convention of Landscape as ‘art of the land, as perceived by local people or visitors, which evolves through time as a result of being acted upon by natural forces and human being.’ Some landscape ecologists in their own way recognize the problems associated with the multiplicity of meanings and implications associated with this term and call for a shared ontology of the term for effective collaboration within the community of their scientific practice (Lepczyk, 2008; Palka,1995). Landscape is also used as a reference to the environment. This is particularly clear in the ECLAS definition of landscape architecture ECLAS Handbook).

It is also important to note at this point the fact that landscape architecture as a discipline, by definition, covers design, planning and management. It is in the nature of landscape that design, planning and management cannot be separated. This being the case, one has to understand how such interrelatedness affects theory and methods of landscape architecture. In this interrelatedness lies the uniqueness of a landscape approach to design and planning. I see significance in the emergence of landscape as an integrative and unifying concept, underlying the broad spectrum of art, science, humanity, nature, and culture, and replacing, as a core concept, those other core concepts such as place (1980s-90s), environment (1970s-80s), space (1950s-70s), and form (1930s-70s). And, of course with the founding of the European Landscape Convention in 2000, landscape assumed a policy dimension, and legal and political cloud.

The nature of landscape

Landscape as an idea and practice is culturally grounded. Landscape is one of few English words that have their root in Dutch. The key to this Dutch word *landschap* is 'schap,' a reference to region, and the board governing the region. It is at once a spatial, regional concept and an organizational, management and housekeeping concept. In European context, landscape (as in the Germanic languages) has a different connotation from that of Paysage (of Latin and Mediterranean culture and region). The former refers more to territory, the latter to appearance, scenery and poetics (Lorzing, 2001). Likewise the East Asian concepts of landscape, *San-sui* or *Feng-sui*, are not the same as the Western concept of landscape, simply because East Asian cosmology and epistemology are different from those of the West. Yet, *San-sui* is a more artistic and poetic concept, and *Feng-sui* more ecological and geographical.

A landscape approach to design

The design approach in landscape architecture during the modern period has been heavily influenced by an architectural approach (Treib, 1993). The discipline of landscape architecture was barely establishing itself away from the landscape garden, horticulture and rural planning tradition, thus lacking its own theoretical and methodological basis for design. Modernist landscape designers were closely interacting with architects and urbanists before and right after World War II (as in the case of Mien Ruijs in the Netherlands, and Garret Eckbo, Thomas Church, Dan Kiley and others in the U.S.A.). Yet, even though these landscape architects followed architecture, they at the same time were aware that they were dealing with living systems, ecology.

It is important for the purpose of this discussion to clarify some important points in the nature of landscape that have direct bearings on the landscape approach to design, differentiated from *architectural* and *ecological* approaches. In the end, the fundamental idea in landscape architecture is the recognition of landscape as noun and landscape as verb. As factors that can influence the design methods of landscape architecture we can list the following as reference points of our discussion.

Landscape is: (1) open and without borders; (2) land and people interaction, that is at once nature and culture; (3) a living and self-organizing system; (4) nested hierarchy in the scales of space and time; (5) dynamic and changing: unpredictable, fluid, and Ki-filled field; (6) complex; (7) regional scale, encompassing both urban and rural regions; (8) material as well as poetic, visible as well as invisible, space as well as process; (9) rhythmic, pulsating with life-cycles: non-linear; (10) metaphor for home, body, and community, thus source of cultural and spiritual identity, Genius Loci; (11) heterogeneity in the horizontal surface reflective of vertical layer composition; (12) complementarity of creation and conservation, change and continuity, new and old; (13) unique and idiosyncratic.

It is these and other characteristics in the nature of landscape which legitimate that the design and planning of landscape should be approached differently than from an architectural, spatial planning, civil engineering or even an ecological approach. Whereas an architectural approach in the Roman, classical, as well as Modernist practice, is inherently colonial, assertive, entropic, and bounded, a landscape approach is not. Planning deals with space, decision, and policy. A landscape approach deals with process as well as space. A landscape approach is scientific as well as poetic, designing for change and continuity. It differs from an ecological approach in that it recognizes landscape not only as ecological, material and system process, but also as aesthetic, experiential, symbolic and cultural (Koh, 2008b). In the case of cultural landscapes humans become important agents for change, disruption as well as organization.

As sustainability can only be realized by focusing on environment, energy and economy as well as culture and aesthetics, landscape ecology, compared to ecology, becomes increasingly perceived as inclusive of both natural and cultural processes (Nassauer, 2008). Landscape ecology also combines the spatial thinking of geography and process thinking of ecology. Theoretically, a landscape approach to design is then built upon the conception of landscape as an eco-poetic entity. It is therefore natural that among today's landscape architects we observe a growing attention to the necessary integration between ecology and design on the one hand and ecology and aesthetics on the other (Gobster, 2007; Koh, 1988; Lovell et. al., 2009; Meyer, 2008; Musacchio, 2009b). How then can we make ecological design more acceptable to the community and society? By aesthetic engineering (Saito, 2007), more appropriate 'landscape language' (Spirn, 1998), 'sustaining aesthetic' (Meyer, 2008), or by eco-revelatory design? How can ecologists and landscape designers work together, so that design can become action research and researchers can secure their relevance and effectiveness? The questions that landscape architects have to address are many and most of them refer to global problems. They include climate adaptation, energy harvest and cascade, urban food production as well as urban health and sustainability, urban and industrial site regeneration and restructuring, landscape access for the urban poor, habitat protection for biodiversity, landscape as cultural heritage and identity, and urban-rural integration not only in terms of space and human experience but also material process of production, consumption and recycling of material, energy and wasted materials and land.

This landscape approach has already appeared in architecture, both in terms of integrative and sustainable design, making it one of the reasons why Dutch architects and urban designers have risen to prominence in the last two decades. Over the last ten to fifteen years we have also witnessed the rise of a landscape approach to urbanism, in the name of landscape urbanism, ecological urbanism or even infrastructural urbanism, in this case landscape being the primary infrastructure (Handel, 2009). Landscape urbanism, however, is still in the early phase of its development. It is still more a practical approach and an operational response, not supported by the empirical sciences of coherent theory. It is the architects' search for an alternative to an architectural or social science approach to urbanism after experiencing the dead-end of policy-based planning, a form-based modernist approach. This is just another reason to call for an articulation of the landscape approach (Koh, 2009). On the other hand, there are now quite substantial numbers of sustainable designs at an urban scale as well as a community and site scale, such as Ecolonia and EVA-Lanxmeer in the Netherlands. The apparent knowledge gap is in sustainable design at a regional scale. Would the landscape approach prove to be more effective at this scale than an architectural or spatial planning approach? Our answer is yes, and the following are examples support our judgment.

A design approach to research

Can there be a design approach to research in landscape science and architecture? Can the designers contribute to research and join the collective effort in the community of scientific (as well as design) practice? Can the designers forgo their ego distinction in the invisible process? Can they understand and integrate scientific concepts into artistic and aesthetic ones? I think they can, and need to, learn. The challenges and rewards are there as we all know (Forman, 2002). By coupling design with research we can make research more relevant to the questions raised by the designers, and make design more credible and persuasive. Of course this is common for design research in other fields as well.

There are, however, several forms of research and design relationships: Research for design (such as programming, user needs and site investigation), research of/into design (such as case study of designs or design processes), or research by/through design (such as design driven by research questions rather than abstract ideas). It is this last type, research with and by design, which is as yet unclear and under-developed. Research with and by design is where designers are engaging in research out of necessity when dealing with new types of problems and questions. In this area designers are looking for substantial information from and with scientists. To gain this new information, the designers' understanding of the research process and method is important (as in the case of case study and design experiments), just as is the scientists' understanding of the design process, and how the processes interact with each other. In this regard we may call this "design (as) research." Laurel gives a good differentiation of design and design as research (Laurel 2003, pp. 82):

"*All designers engage in creative exploration in the process of designing, but difference between design that is simply design and design that serves as research has to do with goals and outcomes of each. Designers who are conducting research through their creative practice create work that is intended to address both particular design itself and a larger set of questions at the same time. In most cases, the inquiry is sustained over a long period of time and the designers create a body of work in response—projects and practices that serve experiments through which they interrogate their ideas, test their hypothesis and pose new questions. Critical reflection is a necessary component of design research practice. Designers must be able to articulate their questions and conclusions.*"

The fact is that scientists also design their models and research methods in their fundamental as well as empirical research. Landscape ecologists recognize that they also need to engage in design to realize sustainability and habitat restoration. In such scientific research, landscape architects and architects can consider their design as a hypothesis, or experimental design followed by monitoring. This necessity of monitoring in large-scale landscape design is a result of the complexity, unpredictability and nonlinearity inherent in landscape performance. A unit of landscape or ecosystem is a 'field' of multiple material forces and species, inclusive of humans. It is an interaction. The outcome of this interaction is difficult to predict. Furthermore landscape itself is an intelligent and creative, resilient and adaptive, self-organizing and emergent system.

Drawings, models, and promotional renderings favour vision and final state, rather than embodied sensory experience and process simulation of performance and construction. These visual media and tools are not good enough for landscape architecture. There are additional reasons why design research integration is more necessary and requires more rigorous applications. To name a few, landscape interventions are required to deal with relatively high levels of uncertainty, indeterminacy and complexity, because landscape itself changes, is disturbed by unpredictability, and populated with diverse actors. Consequences of intervention can thus appear unexpectedly at some other time and place. This requires monitoring because landscape, by being open and subject to various impacts and vulnerable to damage, can have serious environmental health and safety consequences (Johnson and Hill, 2002). But, design research is less the concern of this paper than design research integration. My concern here is not so much revealing how design is made and how designers think as it is about how design is integrated with research.

Design research can be conducted on design products as well as design procedures. How to improve the product performance, that is, its effectiveness, is just as important as how to improve the efficiency of the design process to reduce its labour intensiveness, the mystification of the creative process, as well as its lack of validity.

The international Environmental Design Research Association (EDRA), founded in 1969, has now been active as design research interface for almost forty years. Design research goes back not only to the Bauhaus of the 1920s, or Leonardo DaVinci of the Renaissance, but even further to the alchemists of the Middle Ages. Mostly unpublished though, this research was not shared (Fara, 2009). Still, design research continues to be perceived as, and perhaps is, new territory, and remains poorly articulated further than by Laurel, "*Design research is a method of invention that sides with finding out rather than finding the already found…*" (Laurel, 2003, p.10). However, we can derive a typology of design research integration in the following models: (1) XY crossing model of design and research as separate activity with weak interaction; (2) reiterative model or spiral metaphor, incorporating behavioural sciences in programming and design evaluation (Lang, 1987; Zeisel, 1981); (3) reiterative model incorporating ecology into design process (Steinitz, 2002); (4) descriptive model of design and research weaving in landscape architecture (Milburn and Brown, 2003); (5) design research and designerly inquiry (de Jong and van der Voort, 2005, Rowe, 1987); (6) design research model in landscape ecology and planning (Nassauer and Opdam, 2008; Lovell and Johnston, 2009); and (7) context categorization of design desearch (Laurel, 2003).

Examples

We present three examples of a landscape approach to design for sustainability as well as a design approach to research: energy landscape, climate landscape, and climate adaptation of the urban outdoors. They are all ongoing research projects involving PhD. candidates, interacting with other disciplines and universities.

Energy landscape

This research is motivated by the awareness that there is little sustainable design research on the regional scale, and that for the future energy independence of the Netherlands, regional-scale sustainability must be explored. The research is funded by Senter-Novem and involves TU Delft (building physics), Groningen University (Spatial Planning), and Wageningen University (Urban Environmental Management and Landscape Architecture groups). Going beyond the end-of-pipeline thinking, and the improvement approach of existing pipeline-based infrastructural systems, we investigated how space and landscape can be used for energy assimilation, storage and close-looping, how urban energy waste can be harvested and cascaded. We explored how to use exergy rather than energy as the key concept to measure the efficiency of energy systems and the quality of energy to be recycled (that is, optimum use and matching of energy potential), and how to predict and evaluate consequences of energy measures on spatial, landscape, and spatial quality. Our group uses the ecosystem model as the most efficient energy system (since an ecosystem operates in exergy because it does not use non-renewable energy, and its embodied energy mass is locally recyclable), and selects relevant ecosystem strategies and principles that lead to an energy economy in terms of process and spatial structure.

The ecosystem is basically an exergy system since it is energy autarkic and does not transfer entropy to another system. In terms of planning method, we employed scenario-thinking to deal with uncertainty in the external context and participatory process by engaging local knowledge and stakeholders. The scenario approach is necessary considering the thirty year time-frame needed for energy transition. It is also compatible with a landscape approach, given the fact that landscape is open and adaptable, and that landscape cannot be produced or created but only changed and managed. For the successful management of transition to renewable energy, community engagement is indispensible. Besides, land and landscape itself by definition, as noted earlier, means land and people, or community. Our design of energy landscapes is therefore guided not just by the spatial allocation but also by calculating and appropriating the energy assimilation potential as well as energy needs. We simulate how the landscape would change in each scenario depending upon community decision, thus planning becomes communicative and interactive. This planning is also a landscape approach in that town and countryside were taken together, the former more as an energy sink, the latter more as a source. Additionally, we sought to optimize the connectivity and transportation distance between the two.

Climate landscape

How can we adapt our city and landscape to the specific environmental and health consequences of climate change in the Netherlands? Can we mitigate the meso-climate impact by changing land-use and spatial/formal and structural change of the city? Can "blue" and "green" networks be strategic tools for climate adaptation and mitigation? We have to design research in order to offer something in this regard. One example is the climate landscape research by Rob Roggema, using regional landscape structure as a tool for climate adaptation. Another is our Master program atelier where about fifteen students work intensely for two periods to study the projected impact of climate change in the city of Arnhem, and to explore adaptation and restructuring of the city in response, thus making climate response a part of the structural vision of Arnhem and its surrounding landscape.

This design research also demonstrated that the Master atelier can be a powerful laboratory for research-driven design, if its structure is prepared properly and made in an information rich context. Tedious calculation and quantification can sometimes prove to be a better use of time and learning experience than a search in the dark, waiting for ideas or inspiration. More importantly, it demonstrates that today's landscape architecture at Wageningen University is no longer engaged in beautification and amelioration work as it is in infrastructure landscape and urban regeneration and restructuring. The recognition of landscape as infrastructure also opens up new territory for landscape architects to engage in sustainable urbanization and urban management issues in developing countries, as we have done in Bangladesh (Fore, 2008; Hermens et.al., 2010; Loeck et.al., 2004). In this case, a landscape approach to infrastructure design proves its effectiveness above the industrial-age infrastructure, not only in terms of exergy efficiency but also in terms of local economy, culture and stewardship. Most of all, it is the multifunctional uses of landscapes such as bringing in thermal delight, sense of identity, opportunity for recreation, and even bringing a sense of ownership back to the community, that lead to actions of care for the landscape.

Climate adaptation of the urban outdoor

Given the Dutch climate and European urban lifestyles that call for urban sojourn, many Dutch urban outdoor places are poorly designed. Thus precious resources are wasted and the opportunity for “urbanism as a lifestyle” is lost. This research investigates the microclimatic and experiential performance of typical urban outdoor space through case studies of places in Eindhoven, Den Haag, and Groningen. Urban outdoor space designed with an architectural approach simply does not work. Too much attention is given to visual aspects, and too little to the invisible, in this case climatic comfort and atmospheric perception, and local knowledge of the places. The research analyzes the spatial and formal characteristics of these places, locates the comfort zone both by aerodynamic and shadow analysis, and explores effective adaptive means such as wind barriers, and shape, scale and proportion of outdoor places. Our research reveals that the problems of Modernism in urban design are mostly to do with the hegemony of vision and the visually-focused and ideologically-driven architectural approach. The research aims to generate design guidelines for microclimate comfort in urban places, and employs dynamic modelling techniques to evaluate the performance of design interventions such as shade trees, wind barrier trees or other wind screens. In the absence of an air tunnel, a computer simulation program was employed.

This empirical design research of actual cases of the Netherlands led to a theoretical reflection on wind, or the atmospheric, as the breath of earth. Thus we were dealing with the poetics of microclimate as a phenomenological aspect in our response to the environment. Whereas *Venustas*, one of Vitruvius’ triad, was equated to delight in both classical and Modern architecture, thermal comfort leads to a new aesthetic language, *gezelligheid* in Dutch, or a thermal delight.

The state of design research in landscape architecture

While these PhD researches show a designer’s approach to research for adaptive design and for landscape transformation, we also make design research integration one of the defining characteristics at Wageningen. At the Master level, which is comparatively more design than research oriented, research is a tool to inform design in terms of specific in-depth sciences, such as hydrology, biodiversity and energy flow. At the same time, the usefulness of scientific information is tested by the design process. Such integration is our way of integrating theory into design. Theory guides the design and particular theoretical positions (in regard to landscape language, or aesthetic theory, for example,) are self-consciously chosen. Thus the design studio becomes an information rich context. Again, most of our Master ateliers deal with strategic design for large-scale landscape with such thematic issues as landscape as water, food, or energy machines; urban agriculture; urban nature; and landscape/ecological infrastructure dealing with restructuring of coastal defences. These Master ateliers also maintain reciprocal relationships with on-going PhD. research.

Among the three sub-domains of the discipline of landscape architecture, that are landscape design, planning, and management, it is landscape planning that has engaged in relatively more research. Most of this research however tends to be substantial rather than procedural in content. Landscape planning, working more at regional scale, deals less with formal and experiential issues and thus less with creative imagination. Emerging global issues facing us also call for a design response at this regional and metropolitan scale. Re-shaping and regeneration of our built environment requires understanding of the ecological and poetic roles that our landscape plays, as well as of its role for climate mitigation and adaptation. Environmental scientists, by knowing what designers need to know and how designers think, imagine and evaluate, can contribute to this design research collaboration. Likewise, landscape architects with access to a quantifiable, thus testable, and dynamic model can better monitor the performance and environmental/ ecological consequences of their designs and adapt them, thus making design an act of ‘designing’. Never in human history have architecture and construction led to so much destruction on site as well as elsewhere, and spread their wastefulness both in terms of spatial and material consumption. A landscape approach to design recognizes the necessity for the integration of consumption with production (energy and space), development with conservation, and the need to find complementary relationships between material and sensory worlds.

For landscape architects to deal with new types of problems, with little existing knowledge and little time to wait for it, integrating design with research is the only sensible option. To do this, we have to bring a research-minded attitude and questioning skills into design education and practice. This is still difficult terrain, but the potential reward is high, because there is no other design profession more suited to our contemporary environmental and urban problems than landscape architecture. A landscape approach to design will work well where both ecology and poetics matter, and certainly better than an architectural, engineering or even a planning policy approach. A landscape approach, however, must also integrate design with planning and management as tools, and must avoid a close-minded ego and closed design if it is to help realize the vision of community. Given the fact that landscape implies open, publically accessible land, and requires community engagement for its stewardship, a landscape approach implies a community approach. It does so not only in terms of a community of practice, but also a community of design and management practice that is engaging and adaptive, and even inclusive of the larger community with other species and future generations.

As design is integrated with research, design is becoming designing, more process-directed than end- or goal-directed. That is good, and also natural for landscape architecture. In such cases, design is closely related with and reciprocal to, planning. Furthermore, landscape of a regional scale is not to be constructed but transformed and managed. Thus the aesthetics that guide design of such scale, or landscape, has to be an “aesthetic of transformation” rather than an aesthetic of form (Koh, 2008b). Design as a means of ordering then becomes ordering of change and evolution rather than ordering of form. Such aesthetics of transformation will embrace irregularity in regularity and unpredictability in predictability, because human regularity can be nature’s irregularity, and order now can be disorder in the future.

TRACING THE OBJECT

An activity theory perspective on inter-organisational designing

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Abstract

This PhD project aims to advance the current understanding of inter-organisational product design and develop guidelines for practitioners to support the coordination of such projects. We present a conceptualisation based on cultural historic activity theory. The main premise is that through disruptions induced by contradictions between the activity systems of the different organisations, there is a need to (partly) align work practices—potentially leading to work practice innovation—and practitioners need to (partly) integrate their different, fragmented perception of the design object—potentially leading to an expanded view of the object of design.

Introduction

Nowadays, design not only happens at intersects of functional disciplines, in for instance multi-disciplinary teams, but increasingly more at intersects of organisations. Many products require a range of knowledge and technical capabilities that a single company may not posses; therefore, companies increasingly form alliances and project consortia to integrate knowledge for realizing their product design goals (Gulati, 1998). Even though trends such as ‘open innovation’ (Chesbrough, 2003) initiated discussion amongst academics and practitioners, hitherto scant research focused on the functioning of inter-organisational product design and few methods are available that support an effective collaboration.

Compared to other complex tasks, e.g. flying an airplane, design has an indeterministic nature (Schön, 1984; Simon, 1969); what is needed to perform well is unknown a priori; rather, this understanding is constructed during a project. This makes product design difficult to coordinate in a single organisation, let alone between multiple organisations.

This PhD project aims to advance the current understanding of inter-organisational product design and develop guidelines for practitioners to support the coordination of such projects. However, given the poor understanding of inter-organisational designing to date, this paper focuses on conceptualising this phenomenon by providing a perspective for studying it and addressing the unique challenges that designing across organisational boundaries impose on designers. We argue that cultural historical activity theory provides a fruitful means for conceptualising inter-organisational designing and propose methodological implications.

Theoretical background: designing as an object-oriented activity

In this paper, we conceptualise inter-organisational designing as a social process (Bucciarelli, 1994). Cultural historic activity theory perceives ‘activity,’ such as designing, as a complex, collective endeavour. The activity system, the main unit of analysis, focuses on the complex interplay between subjects (the designers) and objects (the design), that is mediated through the other elements of an activity system: the instruments (the subject’s tools, symbols and representations), and the social mediators in the form of rules, community, and division of labour. Designers aim to develop a design concept that will form an instrument in a user's activity system, see Figure 26. Designers, therefore, constantly project their design concept into the (perceived) user's activity system to understand the implications of their design efforts.

The ability to re-enact 'designerly' ways of knowing (Cross, 1982), thinking, and acting is held by the individual designer but is constituted, defined, and changed by the community of designers. What is considered as appropriate design capabilities, is defined by the community of designers; therefore, to understand an activity, the historicity of the activity system must be investigated Mutanen (2008).

The object is a central element in activity theory. Objects are concerns to which people direct their attention. Through acting, people change and create adjusted or new objects (Engeström, Engeström and Vähääho, 1999). Objects are considered a moving target and cannot be reduced to short-term, conscious goals—it is the 'project under construction.'

Design is concerned with solving ill-defined problems (Simon, 1969). Through iteratively exploring the problem and solution space (Dorst and Cross, 2001) in the user's (future) activity system, the solution space is constrained. This process illustrates that the object is a 'moving target' and 'constantly under construction.' The development of creative outcomes is determined by the quality of the problem and solution analysis as well as by the exploration of redefining the problem and solutions space in new ways. Of particular interest here is that the object of design leaves a trace of intermediate artefacts that can help to study the process of design; it changes from initial objective statements, to product visions, early sketches, technical models, 3D CAD models, prototypes, to the launched product.

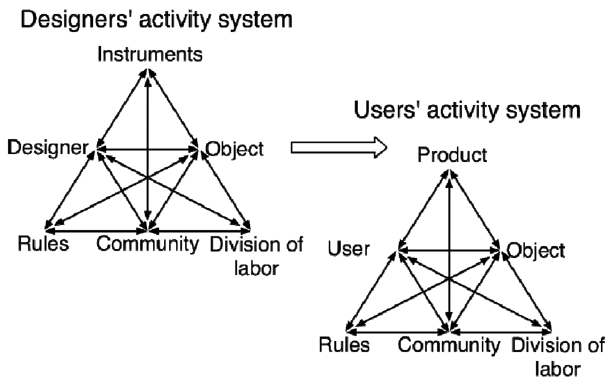

Figure 26: Designers' and users' activity systems (Kuutti, 2008; Lauche, 2004).

Conceptualising inter-organisational designing

We conceptualise inter-organisational designing as multiple activity systems working on a partially shared object (Puonti, 2004). The main premise is that through disruptions induced by contradictions between the activity systems of the different organisations, there is a need to (partly) align work practices—potentially leading to work practice innovation—and practitioners need to (partly) integrate their different, fragmented perception of the design object—potentially leading to an expanded view of the object, see Figure 27. Next, we will explain the model in more detail.

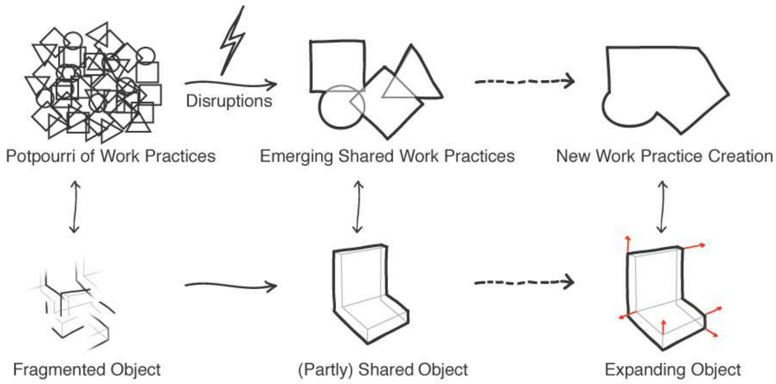

Figure 27: Relations between disruptions, expanding object, and work practice innovation.

From a potpourri of work practices to disruptions

When practitioners start designing in an inter-organisational setting, their work practices are like a potpourri; they are unlike, unorganised, and unaligned. The instruments, rules, and division of labour—the elements of an activity system—of the various consortium partners are heterogeneous as they have historically emerged in different communities and followed their own trajectory of changes. The various designers will, for instance, all have their own means for representing the design, specific design processes, and preferred ways of interacting with others—they all 'know' how to design, but in their very own ways. A former member of an inter-organisational project explained:

"[Our company] *is very much process-focused, with many checks to assure the appropriate product quality.* [Our partner] *is a marketing machine, it's all about speed, and time-to-market. Then we announced we needed to do more product tests, and many other things, taking another nine months. That is the time it takes for them to develop and market an entire new product line. There were just so many major differences in perceptions and experiences between us.*"

As Blackler reasoned: "*in order to function as a system, different organisational constituents require a means of interacting with each other sufficiently to produce strategic action*" (Blackler, 1993, p. 26). Therefore, for designers from different organisations to effectively design together, they need to develop forms of coordinated interacting to direct their behaviour towards a shared goal.

The inconsistencies that exist between the activity systems may lead to disruptions between the work practices of the various communities. People can no longer work 'as they are used to' because now they have to cooperate with people to whom what is 'normal' for themselves may be incomprehensible. This constitutes one of the main problems of inter-organisational product design. Weick and Roberts (1993), for instance, found that competent practitioners were suddenly unable to perform their skills in new circumstances. In inter-organisational designing, therefore, designers may be unable to design skilfully in the new context. Practitioners have to overcome this sudden inability; they need to do new sensemaking and reflect on their capabilities and experiences.

Integrating the fragmented object

At the start of an inter-organisational product design project, the design is of fragmented nature; no single person will hold a complete, integrative perception of the object (Puonti, 2004). Furthermore, the perceived object is likely to differ between the various activity systems. A prerequisite for effective cooperation is that actors should construct (partly) shared objects—all actors can have their own perspective, but their objects need to have some overlapping features (Puonti, 2004). However, the indeterministic nature of design makes it more difficult to construct such a shared object.

We propose that focusing on the object provides a useful angle to study how actors coordinate their design efforts across organisational boundaries. In design, the object leaves multiple traces in the form of physical artefacts that can be analyzed for form and content and serve as a prompt during interviews to elicit further information about authorship and use.

Integrating work practices

For effective inter-organisational cooperation, it is important to overcome the disruptions and establish work practices that enable members to align their various aims and cooperate in ill-defined interactions with unclear roles (Engeström et al., 1999). Since the ‘knowing how to design’ is viewed as inseparable from its practice—one cannot distinguish between the two—a ‘simple transfer of practices’ is impossible Barnes (2001).

Orlikowski and Yates (1994) identified two mechanisms for changing practices: through ‘inadvertent’ or ‘reflective agency’ change. The first refers to the accidental improvisation through slippage; the latter refers to the deliberate improvisation. Reflective agency can occur through trial-and-error experimentation, learning from others, or active searching for alternative practices. During inter-organisational design, part of the work practice integration could result from a trial-and-error approach, since the actors will try to resolve the disruptions through improvising. On the other hand, the theory predicts that through active searching and learning from each other, actors could also change and integrate work practices.

The expanding object and work practice innovation

One of activity theory’s main premises is that work practice innovation may arise from disruptions. Disruptions, therefore, are not only seen as obstacles, they also have a positive potential. This prediction resonates with research that showed that boundary interactions can hamper as well as enhance product design (Edmondson and Nembhard, 2009). At the boundaries of communities of practice, competences and experiences diverge and people are exposed to new experiences and new forms of cooperatively constructed competence (Wenger, 2000). A high divergence between competencies and experiences may lead to no or very little learning (Wenger, 2000). However, when focused on a shared task or goal, the disruptions may result in work practice innovation, i.e. the emergence of new work practices (Engeström et al., 1999). Disruptions, therefore, can be seen as a motor of change. When, for example, being confronted with the other organisation’s (alternative) means to organise product design, practitioners might try to adopt this means in their own organisation. This is illustrated by the following quote from a former manager who worked on the collaborative product development of a durable and a fast-moving consumer good producer:

"*Our organisation is highly centralized whereas* [the partner's organisation] *was highly decentralized. During the product commercialization, that mostly focused on profit responsibilities, this was in the different countries for* [the partner] *whereas in* [our organisation] *this was my responsibility. You saw that* [partner] *changed this, starting with* [this collaborative project], *where the partner also got the profit responsibility. So, you could see that a tension existed because the people had different responsibilities and authorizations*."

Additionally, after disruptions in an activity system occurred, the object may be viewed in an entirely new way—redefined and expanded. Through seeing how others view the object, novel views can be incorporated in the activity system. Therefore, designers in one organisation may benefit from insightful ways of framing the *object of design* of designers from the partner organisation. A concept developer who worked on an inter-organisational design project provides an illustration:

"*Collaborating with people who work in adjacent fields…that sort of collaboration can give you so much inspiration. Because you look from a very different perspective at the same topic, you learn at lot…that can really give you a new angle for product development.*"

Discussion

This paper presented the argument that the activity of design in an inter-organisational setting can be studied from the perspective of the *shared object formation* of the various practitioners. We argued that people have to overcome the inconsistencies between their diverse work practices and the problems attached to the dispersed, fragmented view of the object of design. Furthermore, tracing the process of how disruptions emerged can help to understand when these occur during inter-organisational collaboration and how practitioners may overcome these.

Inter-organisational designing warrants further research to increase our understanding on how practitioners collaborate across organisations. To investigate how actors achieve work practice integration, a process theory explanation is needed that addresses the sequence of events that eventually lead to integration. It requires the researcher to 'open the black box' between input and output, focusing on the processes in between. Further research could follow our suggestion on studying the collaboration from the perspective of the evolving object in the form of the multiple artefacts that are created over time and to analyze these for form and content and use them as a prompt during interviews to elicit information about authorship and use.

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FINDING FREE FORM DESIGN
Research by drawing

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Word cloud of this chapter, created with http://www.wordle.net

Abstract

The use of computers in architectural design has changed over years. Currently the application of computers differs amongst architects, especially in the design of Free Form Design buildings. This paper concentrates on the influence of computers on the Free Form Design process and on the design as a resulting product. In particularly the evolution of the impact that computers have to develop from highly qualified draughtsmen to design decision makers. This study offers a theory of methods which, why, when, where and how computers (programs) are involved in Free Form architectural designing and the specific consequences of different kinds of application. By use of both literature studies and active reproduction of design steps by computer programs it was concluded that there are four types of computer application levels to be distinguished: Tradi-digital, Semi-digital, Formal-digital and True digital.

Introduction

Pre-historic or early Free Form Designs (FFD) were designed and built in the first six decades of the 20th century without the help of computers (Gaudi, Saarinen, Steiner, Otto, etc) for the simple reason that computers were either not invented or equipped for that task yet.

In the early 1970s, a need for rationality in the design process was beginning to gain ground, primarily due to the introduction and the rise of the computer as a logical device. Rather than competing with or replacing designers and architects the approach in the 1980s was predicated on the belief that the computer should assist in the design process. It was introduced as an aid for the goals and aspirations of the designer. In the 1990s the computers were able to carry out simulated environments and complex drawings. The original goal of the introduction and development of the computer in the building process was to free the architect from repetitive or time consuming work. This process is known as 'Computerization.' Now the possibility has arisen to empower the architect with new means to explore beyond the traditional framework of traditional design: 'Computation.'

Most sciences have their own specific scientific methods, which are supported by methodology (i.e., rationale that support the method's validity). Generally architecture is not based on a specific scientific methodology. The kinds of problems that architects tackle are regarded as ill-defined or ill-structured, in contrast to well structured or well defined problems with clear goals, rules or proceedings as methodology (Cross, 2008). Architectural problems usually are intertwining of many different aspects. So at the start of a design process, the architect is usually faced with a very poorly defined problem. As Jones (1992) has suggested: "*it is therefore appropriate to think of an architect as an explorer, searching for the undiscovered 'treasure' of a satisfactory solution. The ability to design depends partly on being able to visualize something internally, in the 'mind's eye,' but perhaps it depends even more on being able to make external visualization; drawings are a key feature of the design process*." In practise this means that during the design process the architect experiences that the clearer the direction of a solution becomes, the clearer the problem becomes or the sharper the definition the borders of the original problem.

In the traditional architectural design process three levels of design-drawings are distincted as functional:

- preliminary design drawings,
- definitive or final design drawings,
- building preparation or working and shop drawings.

This classification runs parallel with the phases in the building preparation process. It's obvious that the earlier a computer program is chosen and imbedded in the design process the more influence it might have. Besides the specific program chosen, four aspects of implementation will have influence on the design and engineering process, each in their specific way. The influences of these aspects are related to the reason why, the time when, the place where and the way how the computer program is imbedded in the design process. For example the use of scripting at the beginning of a design process has a totally different influence on the design process compared to incorporating computation at the end of the design process. In the latter situation the computer is merely used as a tool for solving form questions. This is in contrast with the cases where the computer creates the actual design of the building.

This study presents a theory of methods which, why, when, where and how computers (programs) are involved in the development of Free Form Designs and the specific consequences of the different kinds of involving. The fact that Free Form Design architecture is highly related to both computerization and computation, in contrast with the current architectural practice, makes research on Free Form Design Architecture most suited to be analyzed and cover the whole range of used methods. It gives an interpretation of the current state-of-the-art and expectations for the future. The benefit of this knowledge is that FFD can be better understood, judged and, even more important, better conceptualized.

Methods/methodology

The research was conducted in three steps. Firstly a literature study was performed about design and research methodologies that might lead to insight in a general methodology for the application of computer tools in the design process of FFD. Furthermore a study was performed into general computer use in architectural design.

Because the first research step showed that the best way to study the actual design process is by redoing certain actions (reconstructing the computer application) the second part of the research aimed at gathering as much information about the design processes of FFD buildings. In total more than fourty FFD buildings were studied. With this information it became possible to reconstruct the building designs in computer models. This action was performed for over fourty FFD buildings.

The third step provided insight in the modelling actions and computer functions that were used to reach the actual form. It showed the complexity of the design in relation to the computer facilities and the role of the computer in creating the design. With this information it became possible to distinct between projects based on the necessity of computer use and the actual use of the computer, but also on the level of complexity in this computer use.

This last step required thorough knowledge on the main computer programs available, therefore the selection of the buildings studied was limited by the fact that it ought to be possible to draw them in Catia, Bentley systems, Rhino, Maya or 3D Studio max. As these are the main computer programs used in architectural offices and they provide for unlimited form freedom in drawing this was not a problem.

A lot of information was also drawn from the complexity of the form of the design. It became possible to bring order in the list of buildings based on their form complexity. It was established that the complexity of the form was an indication for the way the computer was used and whether this could be classified as computation or computerization. All three steps together made it possible to come to a classification of design processes in FFD architecture based on the role of the computer.

Results

Based on the information gathered it was possible to come to a four way division in computer approaches for designing FFDs:

- Tradi-digital.
- Semi-digital.
- Formal-digital.
- True-digital.

Tradi-digital FFD

In the Tradi-digital FFD way the complete conceptual formalisation and realisation of a design find place outside and without the computer. The only function the computer has is that of a draughtsman, taking over a hand sketched conceptual design; similar to the traditional way of working in an architect's offices since decades, although by a highly qualified draughtsman this time.

Traditionally, the dominant mode for discussing creativity and originality in architecture and in Free Form Design has always been that of intangible notions of intuition and talent, where stylistic ideas are pervaded by an individual designer, a "star designer," or a group of talented partners (Terzidis, 2003) That is why the computer, although already suitable equipped to function in another way than a sophisticated drawing machine, is still used in the Tradi-digital group cases as a drawing tool instead of a designing tool. The most prominent example of this practice is the case of architect Frank Gehry. In his office, design solutions are not sought through methodical computer-aided design methods but rather by the use of metaphors, allegories, or analogies. The design team spends countless hours of thought, modelling, iterative adjustment, and redesign based on the metaphor of a crinkled piece of paper. In this case it was the grand master Gehry who prohibited the computer application during the conceptual design. Calatrava is another example of an internationally recognized master who does not allow 3D drawings in his office. Frei Otto prohibited the computer to enter his institute in the 70s when modelling the roofs for the 1972 Olympic games of Munich. Eventually he was overtaken by the computer generation of German engineers. New technology outside of the scope of the master: a generation gap that is expected to disappear with the older generation.

The computer is then seen as a means for the draughtsman of complex structures primarily concerned with the technicalities of converting design ideas and models into digital geometries. Very little effort, if any in the Tradi-digital group, is concerned with the idea of using more sophisticated computer features for actually designing. A paradigm shift is not yet noticeable in this group of designers.

Semi-digital FFD

In the Semi-digital FFD way the conceptual formalisation of the FFD design find place outside the computer but the realisation of FFD find place with and within the computer. This second group of Free Form designers, here called Semi–digital, are more or less aware of the possibilities which are given by the new CAD programs. Although they still think traditional about the design process they get inspired by the idea that the computer can manipulate their design (concept) very easily. They still live with two feet in the traditional designing world and seem not yet really aware of the potentiality of the new CAD tools. Their use of the computer is reduced to deform, disturb and alter the overall order and organization of the buildings. Terzides (2003) distinguishes caricaturing, hybriding, morphing, kinetic, folding (unfolding), bending and wrapping of forms.

The simple examples are the twisters and sometimes tapered/bending towers. Some examples: the HSB Turning Torso in Malmo of Calatrava (normal twist), the Fiera building in Milan of Liebeskind (diagonal twist), the Cobra Tower in Kuwait (two cylinders 450 degree twist around centre), the Gazprom tower (five twisted parts in twist and tapered + emerged) of RMJM, etc.

Formal-digital FFD

In the Formal-digital FFD way the conceptual formalisation of the design starts with and within the computer, and this integrated use of the computer goes on to the preparation drawings for actual realisation, too. In the Formal-digital FFD way the designer is still fully in charge of the designing process and of the subsequent steps of the process up to the end results. For the Formal-digital CAD design users group this implies that a certain level of dependency on design possibilities of the used programs is dictated by the CAD language tools. So this group is almost unknowingly converted to the constraints of a particularly computer application style, i.e. computerization or even computation. This is a category where form follows (Cad) program. A typical example of this group is Zaha Hadid. When ever a new/interesting feature in a CAD program emerges – for example the T-splines plug-in for Rhino – the form language of Zaha Hadid adapt this immediately.

True-digital FFD

In the True-digital FFD way the conceptual formalisation of the design starts like the Formal-digital mode with and within the computer up to the preparation of the realisation too, but now the designer is only partly in charge of the designing process and hardly in the end-results of that process, because the designer creates only the borders in which the design process generate “its” own results. This can be recognized as Computation. The way the borders are created divide the possible results in the imaginable more or less expected results and the non-imaginable or even unexpected ones. The connotation ‘serendipity’ enters the scene here. This implies thinking and reflections about the paradigm shift of ‘who is in charge in designing?’ Real built examples of this category are – at this very moment – not yet realized they are still virtual. Partly – in building components - this “way of designing” is already frequently used by scripting and special plug-ins (for example Grasshopper).

Traditionally, the dominant paradigm for discussing and producing architecture and the same is valid for FFD evaluation, has been that of human intuition, emotion, originality and ingenuity. For the first time perhaps, a paradigm shift is being formulated that outweighs previous ones. The design of True-digital FFD employs methods and devices that have no precedent. True-digital FFD takes the position that designing is not exclusively a human activity and that ideas exist independently of human beings, then it would be possible to design a computational mechanism which would associate those ideas. In either case, Computation can be seen as a purely physical phenomenon occurring inside a closed physical system called a computer.

Conclusions

Originally the role of computers in Free Form Design was to replicate human endeavors (Tradi-digital) and to take the place of human influence in the design process. Later the role shifted to create systems that would be intelligent assistants to designers, relieving them from the need to perform to more trivial task and augmented their decision making capabilities (Semi-digital). Today, the roles of computers vary from drafting and modelling to form based processing of architectural information, (Formal-digital) while the future use of computers (True-digital) appears to include a variety of possible roles. It is obvious that a combination of above approaches is more and more practical at this moment. Furthermore research into human factors in combination with computation should be studied.

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A FRAMEWORK FOR DESIGN EDUCATION

A first step in design education research

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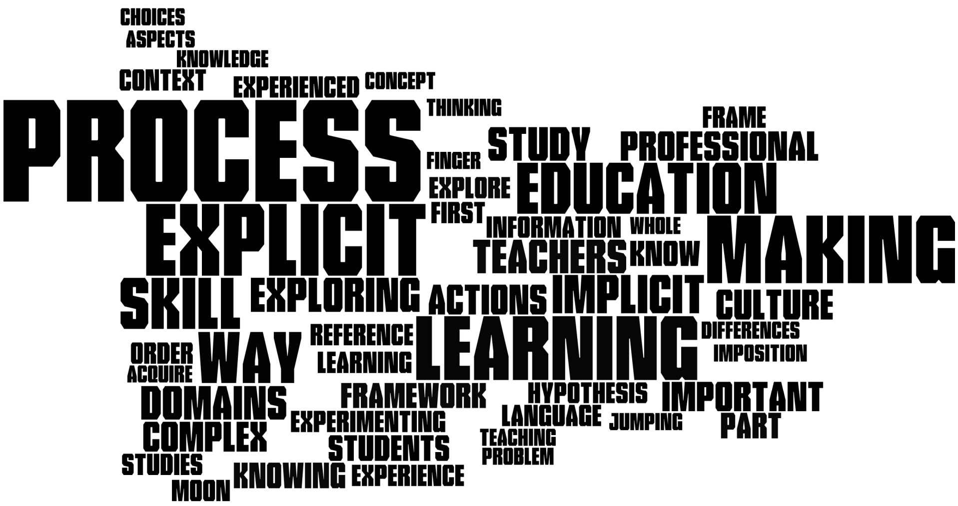

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Abstract

Designing is a complex and open activity. Traditionally it is learned in a studio, in a master apprentice context in which the teachers don't necessarily have a professional didactic background. For the most part, performing a skill is an implicit activity. Learning and teaching, however, are largely explicit actions. Therefore, it is important to know about didactics and designing in an explicit way. The only way to have any guarantee off success as a teacher is by making explicit the process of learning and designing, in this way the student understands what we are explaining and showing them. So, what do teachers have to know about designing? Where should they put their emphasis in their teaching? For developing design education, for doing more research on design education, and for making the design education more explicit, it is essential to start with a (broader) framework.

Design and education

Designing is a complex and open activity. Students have to make the culture of designing their own. They have to learn the process, which any experienced designer follows by custom, to come up with a design, and they have to acquire the knowledge necessary for this process. Nigel Cross (2007) calls it a 'designerly way of knowing.' Besides the culture of the natural sciences and the culture of the humanities, he defines designing as the third way of thinking: "*the collected experience of the material culture, and the collected body of experience, skill and understanding embodied in the arts of planning, inventing, making and doing.*" Important in the design education are the differences, upended by research, between experts' designers and beginners. Experts use strong concepts and are more flexible and profound in exploring these concepts in all means and domains.

Schön (1985, 1987) names designing as "*a collection implicit actions of the professional.*" Mostly, it is characteristic for performing a skill, one in which the performer doesn't know or partly knows what (s)he is doing. However, Cross (1996) already concludes: "*Whilst I'm quite happy to accept that designers themselves may find it difficult to articulate their skills, I believe that design educators must attempt to be more articulated if they are to develop the pedagogy of design.*"

Traditionally, designers (architects, urban and technical building designers) teach by their own experience in designing. They don't have a professional didactic background. In fact, designers have an implicit picture of how to teach, build up during their own study; they repeat what they think their teachers did. Often teachers 'solve' this paradox of 'implicit knowing making explicit' by trial and error. With practice, they learn what to do as a teacher.

Research

Research has been done on the subjects of creativity, designing, learning processes in general, solving complex problems, and the differences between novices and experienced designers. However, about the combination - on the interface - of these research fields not much is written. In all probability, the research of Donald Schön

(1985, 1987), is still the most important and profound study on architectural design didactics.

The main focus of my research is to acquire more information and insight in the education of designing, or more specific: in making explicit the design process. Naturally, all this is part of a broader goal: finding an inspiring and constructive way for educating students in designing and improve the design education where possible. For doing research on making explicit the design process, it is important to start with a (broader) framework. Therefore, in the first research study a framework for design education will be formulated. The framework is context for the other research studies and will develop over time, through those studies. This article will give some information about the research studies and will outline the first study, a framework for design education.

Learning a complex skill

You can describe the learning of a complex skill as internalizing a culture; it's acquiring uses and patterns, (implicitly) used by an expert. The learning process *arises from* implicit knowing and acting, *includes* making explicit and becoming aware, *results* again in implicit knowing and acting and *takes place* in a respectful environment. Three factors are essential: doing, making explicit and respect.

Doing

The design process is a mental process, in which different kinds of information and knowledge come together in a coherent and consistent whole. Furthermore, thinking is a skill. Lawson (2006) concludes: "*design is a highly complex and sophisticated skill, not a mystical ability*" and "*design is a skill which must be learned and practised rather like the playing of a sport or a musical instrument.*" Experts perform a highly developed skill unconsciously. Basically, by doing you learn a skill.

Making explicit

Experts perform a skill unconsciously, however, beginners "*must first analyse and practice all the elements of their skill and we should remember that even the most talented or professional golfers or musicians still benefit from lessons all the way through their careers*" (Lawson, 2006). Therefore, making explicit is also an important part of the educational process. There is a boeddhist saying: "*The finger that points to the moon, is not the moon*" (Tswang Tse). So, in pointing to the moon with your finger, don't mix up the finger with the moon. However, you can indicate. Referring with a finger to the moon helps a lot.

Respect

Learning in general is a journey in the unknown, the teacher seems to know things that the students don't know. Learning to design is even more a journey in the unknown: the design process is complex and open. Learning in general and, more specific, learning to design will be easier, when embedded in an environment of respect and confidence.

Making the design process explicit

In learning and teaching the implicit has to become explicit. What actions and habits do students need to learn? Which implicit things do the teachers need to explicate? Based on literature and personal experience, and developed from the point of view of learning to design, the following is characteristic for designing. Central focus is 'the imposition of an order,' also named a hypothesis, quality, concept, or statement. A designer sets up an experiment, or possibly even a better series of experiments, with 'an order.' The experimentation includes exploring and making choices. And the design process is inseparably embedded in a context: a frame of reference and language.

Hypothesis or imposition of an order

After a period of thinking about the design process as analysing facts and coming to a synthesis following logical steps, researchers like Schön, Cross, and Lawson have tried to describe the design process in a way corresponding more to reality. Schön (1985, 1987) uses the notions 'naming and framing' and 'imposition of an order.' Design is "*a situation of complexity and uncertainty which demands the imposition of an order.*" Cross en Dorst (Eastman, C., Newstetter, McCracken, M., 2001) describe the design process as a co-evolution of solution and problem spaces: "*Since 'the problem' cannot be fully understood in isolation from consideration 'the solution,' it is natural that solution conjectures should be used as a means of helping to explore and understand the problem formulation.*" Designing is a solution focused process: the analysis of data is happening by testing a hypothesis or concept. The aim is a consistent and coherent, characteristic whole.

Experimenting: exploring and making choices

Designing, in the words of Schön (1985, 1987) is a way of experimenting with a hypothesis. The experimenting includes actions like exploring aspects in different domains, looking for their implications and consequences while evaluating, making choices and provisional decisions. It's about intuition and creativity, intense working and taking distance, diverging and converging, and so on.

This experimenting with a hypothesis or concept is of special interest in design education. What are the actions followed by experienced designers? Research (Eastman, C., Newstetter, McCracken, M., 2001) has shown differences between students or novices and expert designers. Expert designers use strong guiding themes. They explore the guiding themes or concepts more rigorous and profoundly then starting designers. Because they have more experience they more easily choose a relevant analogy and they have a better feeling for distinguishing relevant and irrelevant information. In the process of exploring they jump more from one domain to another, they explore implications and consequences, they compare alternatives and means in the different domains. They have more self-confident in changing, defining and redefining the problem and the solutions they come up with. They make more transitions, they go more back and forth. They include more information, criteria and domains into a parallel working process.

Context: frame of reference and language

The process of experimenting is embedded in a frame of reference or professional culture, recorded in the build environment and uses a professional language, a language of sketching and modelling. For learning to design, you have to study the professional culture, you have to develop a library of build examples in a profound way. All aspects, all domains, all theories and rules of thumb are in this 'living' frame of reference.

Further research studies

The framework is context for the other research studies, focusing on the element of explicating. A second study, parallel to the work of Donald Schön consists of observing what teachers do, in making explicit. Guided by several questions, the process of observation will hopefully lead to more insight into what teachers normally do or don't do in making explicit.

A third study consists of an intervention. Concerning the differences between novices and experienced designers, research has shown: instead of a linear process experienced designers follow an 'integral path,' they explore more freely all design domains and aspects: jumping from whole to part and vice verse, jumping between domains, and exploring implications following a decision in one domain for another. In the intervention, we train the students more explicit in these jumping and exploring actions, in this way of thinking. Does this help students? The very first preliminary results show some positive signs.

Depending on the outcomes, probably a fourth study will be done.

Conclusion

Students have to learn how to design, they have to acquire the design process, and they have to acquire knowledge, in the form of facts, rules of thumb, theories, examples, and so on. In short, it's about the knowing what and knowing how.

Probably the most important factor in design education is doing. But making explicit and becoming aware of what you have to do as a student are important factors. It also helps a lot when the environment, in which the learning process takes place, is respectful.

Explicating the implicit is an important part of teaching. Research about designing gives a good base to explore more about actions and habits that student have to learn to be a designer.

In the main line the design process is about experimenting with a hypothesis or concept, it's about exploring: jumping between domains and aspects, between the whole and a part and discovering implications. It is also about making choices, evaluating, taking distance and deciding. And lastly it's about a context of knowledge, a frame of reference, and a language of modelling and sketching.

There are still a lot of questions to be answered. Summarized: what do we (have to) know and where do we (have to) improve as teachers for explicating in a more detailed way? The proposed research will focus on the answers.

DESIGN RESEARCH IN EDUCATION

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Word cloud of this chapter, created with http://www.wordle.net

Introduction

This contribution introduces the design research approach in the educational setting of SLO, the Netherlands Institute for Curriculum Development. SLO is a national expertise centre that focuses on the design and evaluation of:

- national curricular frameworks (core objectives, attainment levels, examination programmes, curricular strands);
- exemplary curriculum specifications at school and classroom level (such as learning and teaching materials).

Design research is defined as the systematic approach of analyzing, designing and evaluating interventions in order to solve complex curriculum problems for which no ready-made solutions are available, aimed at: high quality interventions (e.g. curricular frameworks, educative materials), design principles (as contribution to the knowledge base), and professional development (of those involved in the study).

Implementing a successful change in an educational setting will benefit from a combined approach: Building up from the bottom (such as teacher and school involvement), steering from the top (such as national educational policies and directions) and support and pressure from aside (cg. support agencies, textbook publishers, teacher training colleges) (Hargreaves and Shirley, 2009).

To support educational change processes, educative materials (learning resources and teacher guides) play important roles (Van den Akker, 1988; Ball and Cohen, 1997; Davis and Krajcik, 2005). Especially during the initial implementation stages, these materials (for use at classroom level) can provide teachers with theoretical background information on the meaning of the change; they can demonstrate the practical meaning of the change at stake; teachers and learners can experiment with the materials to get insight into the consequences of the change for their daily practice; and materials can stimulate discussions about the educational change among teachers and other stakeholders.

TABLE 9: Quality criteria

Relevance	There is a convincing need for the intervention and its design is based on state-of-the-art (scientific) knowledge.
Consistency	The structure of the curriculum is logical and cohesive.
Practicality	
Expected	*Expected practicality*: the intervention is expected to be usable in settings for which it has been designed.
Actual	*Actual practicality*: the intervention is usable in settings for which it has been designed.
Effectiveness	
Expected	*Expected effectiveness*: using the intervention is expected to result in desired outcomes.
Effectiveness	*Actual effectiveness*: the implementation of the intervention leads to the desired outcomes.

To fulfil these functions, educative materials must be of high quality. This means that the materials should meet so-called quality criteria (see Table 9). They should not only correspond to the innovative ideas formulated at different educational levels and contain state of the art knowledge, they should also have empirically proven practicality and effectiveness (cf. Nieveen, 1999; Thijs and van den Akker, 2009). Ensuring the quality of curriculum materials is, to a large extent, the responsibility of developers of lesson materials. During the development process they should give great attention to evaluating and improving the quality of their products.

Although developers agree on the importance of evaluation and improving the quality of their products, systematically embedded evaluation activities are often neglected (cf. van den Akker and Verloop, 1994; Wedman and Tessmer, 1993; Gerhardt and Brown, 2002). This lack of formative evaluation is also applicable to design projects within the Netherlands Institute for Curriculum Development (SLO). This institute carries out a large number of design projects for elementary, secondary, and vocational education. Developers design plans and materials at national, school, and classroom level. Already in 1990 a case-study research (Van den Akker, Boersma and Nies, 1990) confirmed that curricular decisions were predominantly inspired by ideas of curriculum developers themselves, and insufficiently based on evaluative information about their quality in practice. Later studies (Nieveen and van den Akker, 1999 and Gervedink Nijhuis, Nieveen, and Visscher-Voerman, 2006) show that this shortage of formative evaluation and a lack of repertoire of suitable evaluation methods turned out to be persistent. The persisting problem of neglecting the potentials of formative evaluation was for SLO in 2005, when a new board was installed, reason to investigate structurally in changing this situation.

In this paper we will describe the approach the institute set out for (called a curriculum design research approach) and efforts taken to implement this approach into SLO projects. Finally we will embed these efforts in a broader call for evidence-based approaches in education.

Curriculum design research approach

Educative materials that support teachers in a context of innovation require a careful design research approach (van den Akker, Gravemeijer, McKenney and Nieveen, 2006; van den Akker, 2009). Generally, it is characterized by iterative cycles of analysis, design, development, and evaluation (see also Figure 28). During the whole design process, teachers, subject experts and material designers are closely connected. Such an approach will result in a combined outcome: examples of educative materials with a proven quality in terms of relevance, consistency, practicality and effectiveness that are suitable for further scaling-up, will contribute to the professional development of teachers, and to the knowledge concerning the design of such materials.

A design research perspective presents rich possibilities to strengthen the quality of curriculum development and curricular products. This becomes apparent in different ways:

- Analysis activities early in the process, to provide a solid ground for subsequent design decisions.

- Frequent formative evaluation of (intermediate) curricular products (prototypes) during the process, aimed at determining the quality of prototypes and the generation of improvement proposals.
- Summative evaluation, at the conclusion of a process, aimed at the determination of the effectiveness of the end product.

The remainder of this section will elaborate the way evaluation is interwoven in the full development process of educative materials.

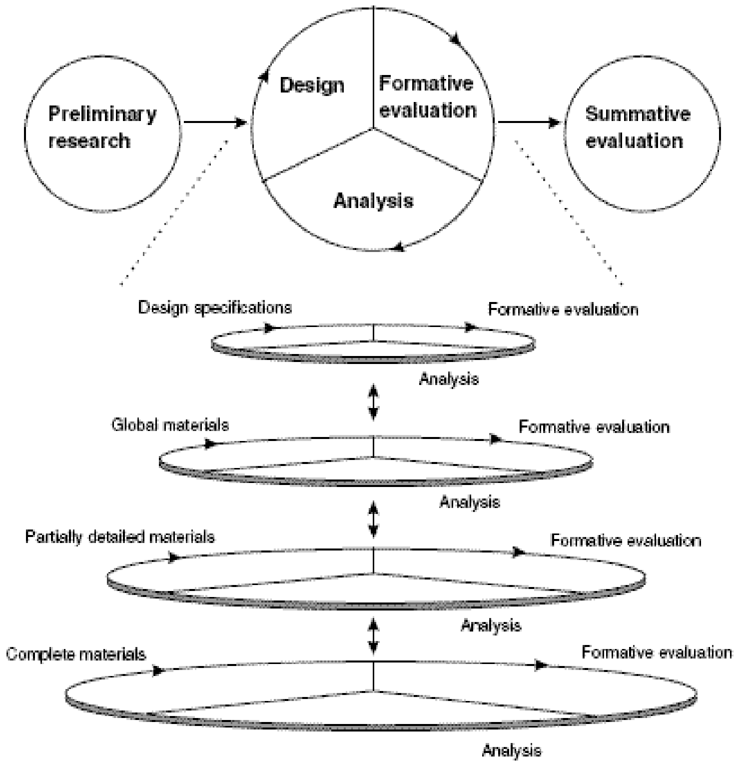

Figure 28: Cyclical design research approach.

Curriculum evaluation

Formative evaluation

Formative evaluation is a crucial feature of every education design research process and thus in each design research project. It provides insight in the potentials of the intervention and its key characteristics. Based on comparing and synthesizing definitions of various scholars in the field of formative curriculum evaluation (Brinkerhoff, Brethouwer, Hluchyj and Nowakowski, 1983; Flagg, 1990; Scriven, 1967, Tessmer, 1993) we follow the definition of Nieveen (1999):

"*Formative curriculum evaluation is a systematically performed activity (including preparation, data collection, data processing, and reporting), integrated in the development process of an instructional intervention, aiming at quality improvement of a (partially) developed prototype of an intervention by locating shortcomings and generating revision decisions*."

Ideally, each of the four quality-criteria (relevance, consistency, practicality and effectiveness) will be the focus of curriculum evaluation, at a certain moment during the development process. At the start of the design process the focus will be more on questions concerning the relevance and consistency of an intervention, later on the focus will shift towards the practicality and effectiveness of the intervention. Depending on the focus (quality aspect) of the evaluation and the development stage of the intervention (design specifications through a complete intervention) various evaluation methods are suitable (Nieveen, 1997, 1999, 2009; Thijs & van den Akker, 2009) (see Table 10):

- Screening: members of the design research team check the design with some checklists on important characteristics of components of the intervention.
- Focus group: a group of experts (for instance, subject matter experts, instructional design experts, and teachers) reacts on a prototype of the intervention.
- Walkthrough: a member of the design research team and one or a few representatives of the target group together go through the prototype of the intervention.
- Micro-evaluation: a limited number of representatives of the target group use parts of the prototype outside their day to day user setting.
- Try-out: the target group used the intervention in their day to day user setting.

For each method, one or more activities can be chosen, including the corresponding instruments (such as checklists, interview guidelines, observation guidelines, questionnaire, log books) to gather the data needed.

TABLE 10: Table for selecting formative evaluation activities (in grey the recommended combinations are given)

Design stage criterion	Design specifications	Global design	Partly detailed intervention	Complete intervention
Relevance	Screening, focus group	Screening, focus group	Screening, focus group	Screening, focus group
Consistency	Screening, focus group	Screening, focus group	Screening, focus group	Screening, focus group
Practicality				
Expected	Screening, focus group	Screening, focus group	Focus group, walkthrough	Focus group, walkthrough
Actual			Micro-evaluation	Micro-evaluation, try-out
Effectiveness				
Expected	Screening, focus group	Screening, focus group	Focus group	Focus group
Actual			Micro-evaluation	Micro-evaluation, try-out

When planning an evaluation, it is important to consider the role fulfilled by developers themselves during the evaluation. During later development stages, it will be desirable to involve external evaluators, rather than the developers themselves, to determine the actual effectiveness of the curriculum (see also paragraph about summative evaluation). During the early stages, however, it seems legitimate and even desirable to have the evaluation activities carried out by the developers themselves. There are two reasons for this. First of all, it is more likely that the results of the evaluation activities will actually lead to modifications in the curriculum. The development team can carry out the evaluation at any desired moment and the results are quickly implemented in revisions of the product. Secondly, the developers learn a lot from their evaluation activities. For example, they can see with their own eyes what can go wrong when the product is used in practice. However, the developers should be well aware of their natural inclination to become so attached to their own design that they might not be able to make objective assessments of any problems occurring with the design. At that point, the involvement of external evaluators becomes desirable.

Summative evaluation

Whereas formative evaluation focuses on locating shortcomings in (intermediate) products, and generating revision decisions, summative evaluation is aimed at determining the impact and effectiveness of the product. The focus is on the extent to which implementation of the product leads to the desired outcomes. The desired results are related to the intended objectives of intervention. For example, the objective might be to give publishers a curricular framework to guide them during their development of methods in order to meet with core objectives. Another objective may be to improve teacher's pedagogical content knowledge in view of implementation of a new curriculum. In schools summative evaluation primarily focuses on pupils' learning results. Therefore, in this paragraph, we will concentrate on studies into the effects of instructional material at pupil level. Such an evaluation does not only concern the question whether the desired learning results occur, but also whether the effects established can be ascribed to the teaching material developed.

The most powerful study design to reveal effects – more particularly: cause-effect relationships – is the classical experiment (Rossi, Lipsey and Freeman, 2004; Swanborn, 2007). Such a study design concerns two study groups (an experimental group and a control group), two measurements (pre-test and post-test), and the random appointment of respondents to one of the two conditions. In the educational practice, however, the random appointment of respondents is not an easy matter; often, it is an almost impossible task to withhold a certain form of education to a group of pupils, or to change grouping arrangements in schools. An alternative study set-up to determine causal relationships is a quasi experimental study design. Like the classical experiment, a quasi experiment comprises an experimental group and a control group, and a measurement prior and after the programme. The difference is the random appointment of respondents to groups. In the classical experiment, individual *respondents* (e.g. pupils) are appointed at random to the groups. In the quasi experiment, *existing groups* (e.g. classes with pupils) are randomly appointed to an experimental group and a control group. When planning and performing a summative curriculum evaluation by means of a quasi experiment, it is important to take the following issues into consideration (Gravemeijer and Kirschner, 2008; Swanborn, 2007; Wayne, Yoon, Zhu, Cronen and Garet, 2008).

- *Discrepancy between the intended and implemented curriculum*: when implementing a curriculum in educational practice, the various parties involved, such as teachers and pupils, will usually carry out the curriculum according to their own needs and wishes. This may cause a discrepancy between the intended and the implemented curriculum, which may, in turn, affect the learning results. This means that insight into the implemented curriculum, obtained, for example, by means of observations and interviews concerning the teaching practice, is important for the interpretation and explanation of the effect results.
- *Comparability of groups*: if it is not possible to randomly appoint respondents to groups, it is essential to ensure that groups are made comparable by means of matching or statistic control. The groups must be comparable in characteristics that influence the effectiveness of the curriculum. If a relevant feature is not included, this may influence the results of the study. Suppose the effectiveness of new teaching material for mathematics is investigated. If this material would be more suitable for girls, and the experimental group would contain a relatively large number of boys, the results might wrongfully show a lack of effect. Furthermore, it is important to look for an adequate representation of the population of schools, allowing generalization of the results.
- *Curriculum-assessment overlap*: an important point of attention is the extent to which tests of learning results are geared towards the curricular intentions. If this is not the case, possible effects may not be revealed. Also, the moment of the assessment should be well-chosen.
- *Sufficient time, money and number of respondents*: usually, the set-up of an experiment or quasi experiment is costly and time-consuming. Many respondents are needed and, in addition, it takes a long time before learning effects can be measured. This makes it difficult to find a sufficient number of schools and teachers willing to participate. Especially the willingness to participate in a control group is often very low.

It will have become clear that a summative curriculum evaluation is a complex, costly and time-consuming matter. Therefore, it is important not to carry out such a study until the curriculum is developed to such an extent that it has sufficient potential effectiveness. Furthermore, it is essential that implementation studies take place parallel to the experimental or quasi experimental study. This way, potential implementation problems during the effect study can be anticipated. Furthermore, a (rich) description of the implementation context will also benefit (future) users who want to use the curriculum in their own setting.

In the next paragraph we will focus on the way SLO tries to implement the curriculum design research approach within their institute.

Implementing a curriculum design research approach

In order to implement the curriculum design research approach into the development projects of SLO, the institute had to create an effective working and learning environment. Such environments are stimulating (Boekaerts and Simons, 1995) and rich with regard to learning opportunities (Onstenk and Blokhuis, 2003). Professional designers will feel stimulated when there is enough room for professional development and the organization supports the actual planning and performance of evaluation activities. In order to reach such an effective working and learning environment a comprehensive set of interventions has been developed (see Figure 29).

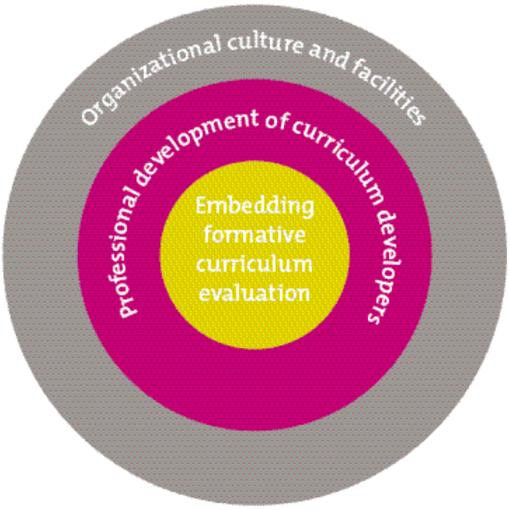

Figure 29: Comprehensive set of interventions to embed formative curriculum evaluations.

This set of interventions is implemented in order to get to a situation in which developers have a clear and realistic view of what evaluation is and how it can be embedded in the curriculum development process. To reach this aim, two sets of interventions are distinguished: (1) concerning organizational culture and facilities, and (2) concerning professional development.

Concerning organizational culture and facilities

- Continuous communication about the importance of evaluation for curriculum development, using various channels and media (internal memos, articles, news items on the Intranet, and meetings with the department managers).
- Inviting board and heads of departments to facilitate, motivate and appreciate good practices.
- Extra budget for performing evaluations.
- Sufficient qualified personnel: within each sub department of SLO an Evaluation-coach is available. This coach can also support individual curriculum developers. These coaches are curriculum developers who are trained by the Evaluation-team.

Concerning professional development

- Workshops to increase insight in evaluation theory and practice.
- Development of various guidelines for planning and performing an evaluation.
- Installation of an Evaluation-team consisting of two senior researchers with a lot of experience in the field of evaluation to support developers in planning and performing formative evaluations.
- Development of an Electronic Performance Support System (EPSS) for curriculum evaluation (in Dutch only: http://leerplanevaluatie.slo.nl).

Mid 2007, the Evaluation team was installed to change the situation within SLO in such a way that curriculum developers embed evaluation activities in their curriculum development processes. During the first year, 70 project managers asked the Evaluation team for support (about half of all development projects carried out within the institute). They mainly asked for support on planning an evaluation (formulating evaluation questions and choosing appropriate evaluation methods). The Evaluation team also received many questions concerning data-gathering instruments. Moreover, the budget made available for evaluation purposes was used intensively. In July 2008, a questionnaire was sent to all (140) curriculum developers. Most important outcomes were that:

- Formative evaluation receives a greater amount of attention: 60% of the developers performs formative evaluations within more than half of their projects; 95% of the developers thinks evaluation is valuable and necessary. It is considered to be the moment to reflect on the developed product.
- The image of formative evaluation still needs improvement: 90% of the developers considers it to be time-consuming; 60% of the developers experience a lack of time and 25% report that they are unfamiliar with a range of evaluation methods.
- Nevertheless, the Evaluation team seems to be on the right track: 95% of the developers is positive about the schooling and workshops offered by the Evaluation-team, and all developers indicate the individual coaching by the Evaluation-team to be valuable.

To conclude, SLO is moving towards a situation in which curriculum developers integrate formative evaluation activities into their development processes, but remains a balancing act between trusting the professionals on the one hand and pressuring to change working habits on the other hand.

Conclusions and discussion

The plead for evidence-based approaches in education (paying more attention to the effectiveness of teaching methods and the utilization of such knowledge in educational practice) has spread in many countries around the world. When do we have sufficient evidence to conclude that an educational innovation is effective? Different answers can be formulated. We will briefly elaborate two perspectives, and will then present the view of the Netherlands Institute for Curriculum Development (SLO) with its design research approach.

Unites States of America

The first perspective is the "What Works Clearinghouse (WWC)" in the United States of America. Since the beginning of this century, the USA uses an evidence-based educational policy, whereby evidence is only valid if the underlying studies meet with strict 'evidence standards' (see Figure 30). A firm requirement is that the studies must be experimental or quasi- experimental, whereby respondents are randomly assigned to experimental and control groups (What Works Clearinghouse, 2009). With this strict focus on evidence, the WWC only accepts so-called hard evidence.

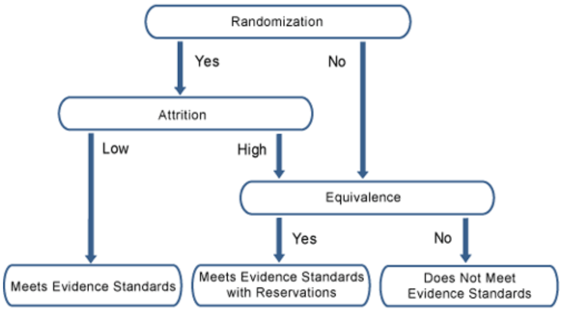

Figure 30: Evidence standards of the “What Works Clearinghouse” (What Works Clearinghouse, 2009).

The Netherlands

The second perspective originates from the Dutch Advisory Council for Education (Onderwijsraad, 2006) in its advice about evidence-based approaches in education. The Council stresses that not enough effort is made to gather evidence concerning the effectiveness of educational methods and to cash in on this knowledge. The Advisory Council proposes a phased approach in order to arrive at more evidence-based education. Depending on the state of the knowledge development in a certain area, various degrees of evidence may be provided. In order to obtain a provisional idea of what is working, why, and how, within a certain – new – domain, many years of exploratory studies, development and practical experiences are needed first. Only then experiments with control groups will be justified. The proposed approach by the Advisory Council proposes is characterized by stacking various forms of evidence (see Figure 31).

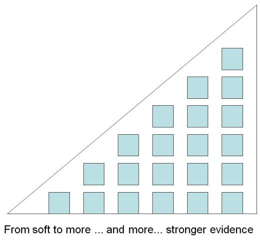

Figure 31: Stacking evidence (Onderwijsraad, 2006).

On one key point this approach deviates from the way in which WWC deals with evidence; that is that 'softer' forms of research (resulting in preliminary evidence) do play an important role in the approach advanced by the Dutch Advisory Council for Education, and none at all for the WWC.

Different from the view of the Dutch Advisory Council for Education, SLO is not only interested in presenting evidence for learning effects of pupils. It gives a wider interpretation to the term ‘quality’ by distinguishing four interrelated quality criteria: relevance, consistency, practicality, and effectiveness. Evidence for these four criteria is obtained by means of the cyclical design research approach from the start of each development process.

ANALYSIS OF DESIGN CONSULTATIONS

Conceptualising interactions between novices and expert design engineers

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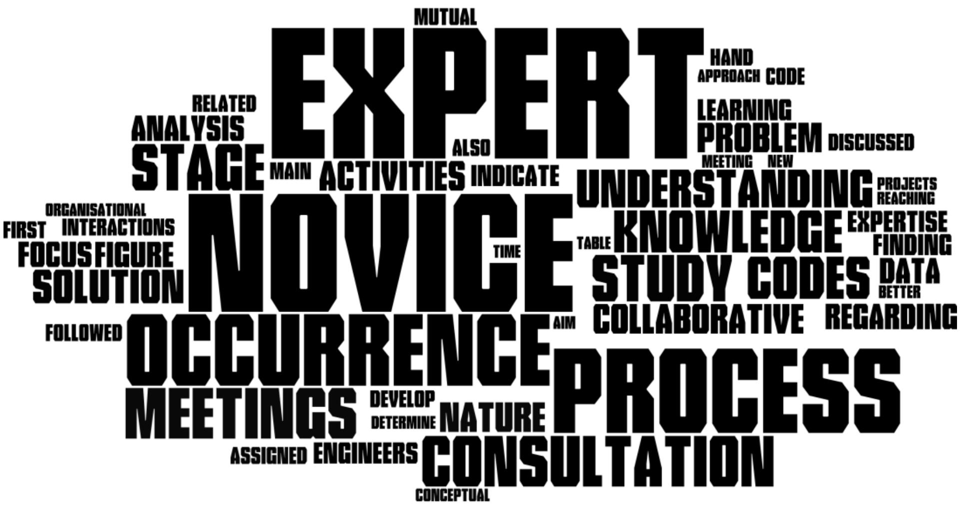

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Introduction

From research on expertise it is known that it takes about ten years to become an expert in a specific field and that the development of expertise goes along with extensive practice. For industrial companies it is beneficial to accelerate this process to enable the faster building of expertise of company newcomers. The most obvious difference between an expert and novice is that an expert simply has more detailed knowledge (Sonnentag, 2000) and the way experts structure their knowledge also differs: experts store their knowledge in larger chunks (Cross, 2004; Petre, 2004) and create integrated knowledge structures (Sonnentag, 2000). Due to these integrated structures, experts can, for instance, more effectively focus their solution search effort to the more fruitful areas of the solution space. Furthermore, experts develop guiding principles that help them prioritise and find direction in the design engineering process (Lawson, 2004). Finally, and potentially most importantly, what distinguishes experts from novices is the difference in experiential knowledge (Lawson, 2004). As Lawson points out, no declarative knowledge structures enables design engineers to proceed from a problem to a solution in a single step. Expert designers make analogies between past experiences and the current problem by retrieving past design episodes and generating new solutions based on that knowledge (Hargadon and Sutton, 1997).

This study focuses on the development of expertise of novice designers while working on industrial projects in collaboration with experts. We built upon previous research regarding information-seeking behaviour of novice design engineers (Deken, Aurisicchio, Kleinsmann, Lauche and Bracewell, 2009; Deken, Kleinsmann, Aurisicchio, Lauche and Bracewell, 2009). One of the main conclusions was that novices in the previous studies relied heavily on expert input to progress in their projects. It was found that information-transfer, in our particular study, was not the most important process occurring during these meetings, as was for instance found earlier by (Ahmed and Wallace, 2004). Rather, we found that much knowledge creation occurred in the form of collaborative design. Building upon this finding, this study further investigates the nature of the co-design between novices and experts in consultation meetings. We will argue that more research is needed to better characterize how novice design engineers acquire design expertise during organisational entry.

Research approach

This study draws upon the data collected by Deken and colleagues (Deken, Aurisicchio, et al., 2009; Deken, Kleinsmann, et al., 2009). In their field study, novice design engineers in Rolls-Royce Aerospace Engineering were followed during their organisational entry. Here, we draw on the naturally occurring novice–expert interactions that were part of the novices' design projects (N=28). For this study, seven meetings were analysed in-depth. Meetings were selected for analytic purposes (Gerring, 2007), aiming for a balanced set of meetings distributed over the design process stages and trainee teams. A detailed overview of the selected meetings is provided in Table 11. The gathered audio records were transcribed verbatim in order to prepare the data for data analysis. We adopted a grounded theory approach (Strauss and Corbin, 1998) for our data analysis. By making use of open coding, the (inductive) identification of concepts, their properties, dimensions, and insights into the nature of novice and expert interactions were gained. The assigned codes were linked to key words or phrases that were coherent to a particular type of novice–expert interaction that occurred. An example is given in the following quote from the first meeting by team B; that was assigned the code ‘problem definition’. The example shows that novice *D* is trying to identify the situation at hand, and determine the core of the task they have been assigned with:

“*But what are we actually looking for? I mean, with the CFD model we've got – we know the speed of the flow, are we actually looking at reducing stagnation or point of reduced flow in the pipe? Is that the – because one thing – we don’t really understand I think the actual mechanics I think of what causes this stuff to build up. And without that background knowledge, -*”

TABLE 11: Sample of meetings

Meeting	Team	Design stage	Number of words	Duration
1	B	Task clarification	11709	01:07:24
2	A	Task clarification	7698	00:39:30
3	A	Conceptual design	9932	00:54:06
4	B	Conceptual design	8000	00:43:08
5	B	Conceptual design	8539	00:50:06
6	C	Detailed design	3520	00:27:41
7	C	Detailed design	9771	01:01:01

The assigned codes where then clustered to determine their similarities, differences, and the factors of distinction. The grouping of codes similar in nature, topic, or direction resulted in four main clusters of codes, as is depicted in Figure 32. ‘Process & Organisation’ refers to codes that involved a phrase or discussion pertaining to the design process, or management issues that relate to or facilitate the design process. ‘Objective determination’ was about instances aimed at increasing understanding regarding the situation and problem at hand. During ‘Solution search’ new design solutions were proposed, discussed, and evaluated. Finally, during ‘Reaching consensus’ the novice and expert discussed their background, capabilities, jargon, expectations, and uncertainties regarding the novice’s project.

Figure 32: Clusters of codes.

Results

Table 12 shows an overview of the frequency of occurrence of codes as a percentage of all the codes listed during a meeting. Taking all meetings into account, it can be seen that the code that occurred most is ‘suggestion from expert’ (17%), followed by ‘reference to other parties’ (15%), ‘identification of a complication’ (11%), and ‘confirmation of thoughts and ideas’ (9.5%). The frequent occurrence of ‘reference to other parties,’ was unexpected, and is not usually associated to novice–expert consultations. When looking at the first three meetings, the most frequently occurring code is ‘reference to other parties’, after which the focus of the last four meetings shifts to the occurrence of the code ‘suggestion from expert’. These occurrences imply the type of discussion that is being held, as well as indicate the stage in the design process.

Table 12: Code frequencies.

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Overall
acknowledgement of progress	0.0%	1.2%	1.3%	1.8%	1.5%	0.0%	3.7%	1.5%
clarification of competences	1.6%	13.6%	1.9%	0.0%	0.0%	3.4%	1.2%	3.2%
clarification of misunderstanding	11.1%	6.2%	1.3%	3.5%	1.5%	3.4%	0.0%	3.4%
co-ordination and management	6.3%	3.7%	5.7%	0.0%	4.6%	10.3%	2.5%	4.5%
confirmation of thoughts and ideas	14.3%	1.2%	8.8%	0.0%	10.8%	13.8%	19.8%	9.5%
consideration of several possibilities	4.8%	3.7%	5.7%	3.5%	10.8%	6.9%	1.2%	5.0%
defining a specific problem	1.6%	4.9%	1.3%	5.3%	6.2%	3.4%	1.2%	3.0%
determination of a solution	0.0%	3.7%	0.0%	1.8%	0.0%	0.0%	0.0%	0.7%
discarding an expert suggestion	0.0%	2.5%	0.6%	1.8%	3.1%	0.0%	1.2%	1.3%
expectations being conveyed	3.2%	2.5%	0.0%	0.0%	0.0%	3.4%	0.0%	0.9%
explanation of possible solution	3.2%	0.0%	6.9%	0.0%	4.6%	17.2%	13.6%	6.0%
explanation of technical terminology	0.0%	1.2%	0.6%	0.0%	0.0%	0.0%	0.0%	0.4%
funny remark	4.8%	1.2%	0.0%	1.8%	0.0%	0.0%	0.0%	0.9%
generation of requirements	4.8%	3.7%	7.5%	0.0%	6.2%	3.4%	1.2%	4.5%
identification of a complication	3.2%	12.3%	12.6%	14.0%	12.3%	3.4%	12.3%	11.0%
participation increase	0.0%	0.0%	1.9%	1.8%	0.0%	0.0%	1.2%	0.9%
problem definition	12.7%	6.2%	1.9%	0.0%	4.6%	3.4%	2.5%	4.1%
process based recommendations	0.0%	1.2%	0.0%	1.8%	0.0%	3.4%	0.0%	0.6%
progression into a solution set	0.0%	3.7%	3.8%	17.5%	3.1%	3.4%	2.5%	4.5%
reference to other parties	15.9%	18.5%	24.5%	14.0%	3.1%	0.0%	12.3%	15.7%
reference to previously discussed issue	0.0%	2.5%	0.6%	0.0%	0.0%	0.0%	0.0%	0.6%
suggestion from expert	11.1%	6.2%	12.6%	31.6%	24.6%	20.7%	23.5%	17.0%
uncertainty in reference to related topic	1.6%	0.0%	0.6%	0.0%	3.1%	0.0%	0.0%	0.7%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

The amount of codes per activity gives a superficial indication to the nature of the meetings conducted, and does not provide a distinct overview of what matters are discussed the most. By taking the sum of percentage frequencies within a category, it can be concluded that ‘Solution Search’ was the most frequently occurring (34%), followed by ‘Reaching Consensus’ (24%) and ‘Objective Determination’ (23%) and ‘Process & Organisation’ (19%). These numbers indicate that on the whole, the seven novice–expert consultations were primarily related to finding a solution to a given problem, followed by gaining mutual understanding, as well as understanding the problem at hand. They also indicate that topics related to the design process and the facilitation were relatively less occurring.

The main purpose of this analysis was to determine the nature of novice–expert consultations, and to identify what types of activities are undergone in order to facilitate the design process. The results clearly indicate that, there is an unequal distribution of time and focus during novice–expert consultations. This is not only a typical occurrence due to the fact that each meeting was held during a different stage in the design process, but is also related to the purpose of novice–expert consultations in general.

Building upon the results gathered, Figure 33 was constructed in order to depict which types of activities were of importance during the three main phases of the design process and indicates the relevance of each category in relation to one another during each stage. The focus of the novice–expert consultation, lay in ‘Reaching Consensus’

(31%) during the first stage of the design process. More time was allocated *to understanding each other*, and *what was expected* from each party. These figures also indicate how essential it is for novices and experts to find *common ground* at the start of a design task for the consultation to proceed successfully. During the conceptual stage, the focus shifts from forming mutual understanding to the collaborative solution findings as is depicted in Figure 33. This is a natural occurrence as the time spent initially to understand the design context, allows for the transition into a more solution-focused interaction. A similar trend is witnessed in the latter stage of the design process (detailed design), as the frequency of ‘Solution Search’ codes remained high. The importance of understanding the solutions discussed, as well as each other during this critical phase of the design process is represented by an increase in activities related to mutual understanding. Throughout the stages, process-oriented activities and activities regarding the formulation and comprehension of the design problem remained relatively frequent. However, a gradual decrease can be derived from the information depicted in Figure 33 above, which is a result of the shift of focus to finding a design solution.

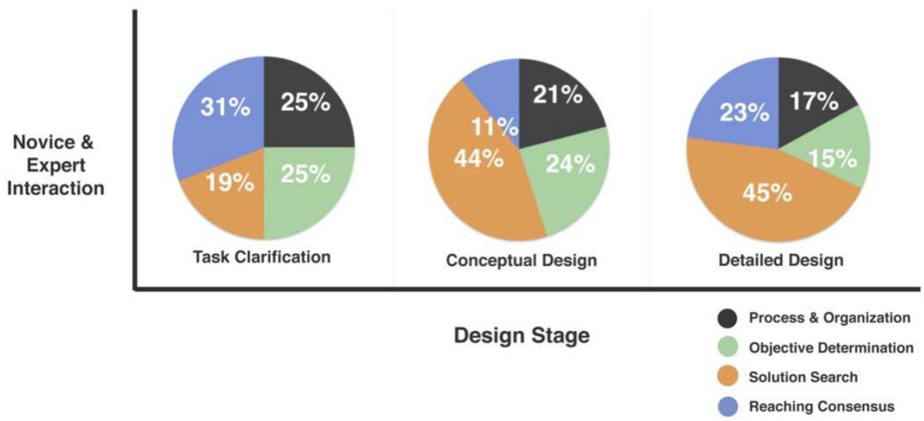

Figure 33: Novice–expert activities in relation to the design stage.

Discussion

In conclusion to the results obtained, and the occurrences that took place, it is evident that the nature of novice–expert consultations are based primarily on collaborative *solution finding*, as these were the most frequently coded activities detected during the seven meetings analyzed. The occurrences during the progression of the design process indicated a vast shift from *mutual understanding* and *objective determination* in the initial steps, to *solution finding* in the middle and final stages thereof:

The current study reanalyzed an existing dataset to better understand how collaborative design occurred in novice–expert consultations. We reanalyzed the data since the prior analysis aimed at studying knowledge and information processes—resulting from the assumed novice’s information-seeking behaviour, which we expected to be the factor most determining the discourse. Therefore, in the present study we had to develop a ‘new lens’ to study the collaborative design processes, hence our inductive data analysis approach. A further step in this research project will be to employ a more fine-grained analysis regarding *patterns of the characteristic discourse elements* in novice–expert consultations.

Compared to teacher–student interactions, the novice–expert consultation meetings were of collaborative nature—they *together* took on the challenge of better understanding the problems at hand and proceeded into collaborative solution-finding efforts. The first author plans to undertake an empirical study at Volvo Aerospace Engineering to complement the ‘apprenticeship-like’ interactions between experts and novices, as were collected in Rolls-Royce, with discourses from formal learning instances during which trainees are coached by (professional) trainers to develop their design skills.

We aim to complement the two field studies for gaining insights on how novices upon organisational entry ‘learn the ropes’ of design engineering practice—both through formal and informal learning processes. Rather than comparing novices with expert designers on the level and quality of their design skills, we aim to study specific instance of design learning to shed light on *learning processes* rather than solely focussing on the outcomes of years of practice. Through theorising about the observed learning processes, we aim to develop guideless for training design engineers in organizations, thereby complementing research regarding studio practices and design engineering education in general.

INNOVATION THROUGH RESEARCH BY COMPLEX DESIGN AND ENGINEERING

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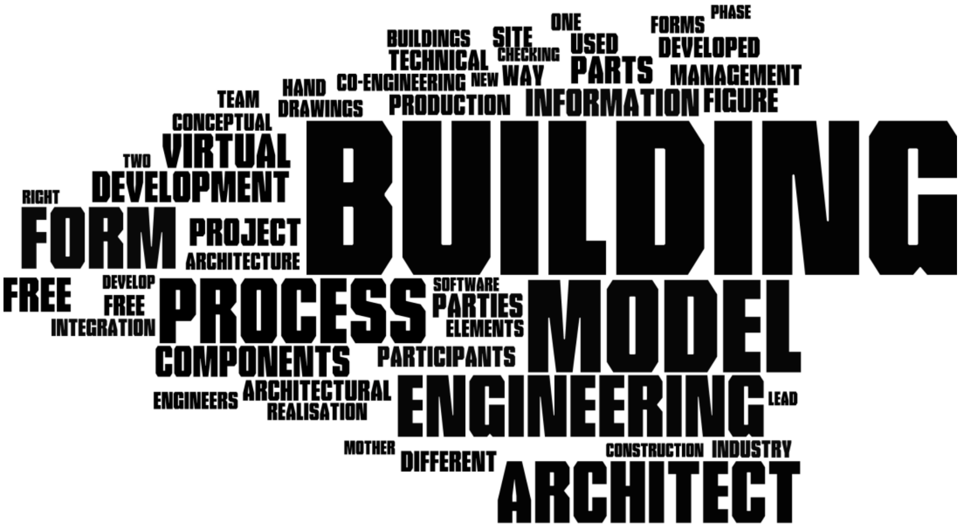

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Introduction

Over the last two decades the building industry has been confronted with spatial architectural designs that have greatly benefited from computer-operated design and modelling programmes such as Maya, Rhino and 3D-Studio Max. These architectural designs are referred to somewhat interchangeably as ‘free form design,’ ‘fluid design,’ ‘liquid design’, and ‘blob design’ and consist of sculptural organic building forms that can only be generated or developed using sophisticated software packages. For the sake of the realisation of free form designs traditionally separated design, engineering and production processes have within one project transformed into integrated ‘co-design, co-engineering & co-production’ processes. This shift has implications both for architecture and for the management of architectural design, engineering and construction processes. In other words it may be said that the realisation of Free Form buildings demands close working relationships between the project partners and the ability to trust the abilities of co-partners in this highly creative, demanding and pioneering field of architectural design. Free form architectural designs would appear to fit the modern thoughts of design management, which places equal emphasis on people, process(es) and product. This PhD research aims to provide an insight into the design and realisation processes for free form architecture based on case study experience of working with innovative approaches via Octatube, an integrated design & build construction company located in Delft, The Netherlands (Figure 34, 35, 36, and 37).




Figure 34 (top left): wing roofs of the Rabin Centre in Tel Aviv. *Figure 35 (top right)*: green house at Malmö. *Figure 36 (below left)*: Floriade pavilion at Haarlemmermeer. *Figure 37 (below right)*: Town hall at Alphen a/d Rijn.

Free form designs: exploration meets exploitation

In the conceptual design stage, free form designing architects usually do not employ geometrical repetitive forms and systematized structural schemes or material behaviour. They design buildings like sculpting artists in a creative way and exploring way. Participating structural and technical engineers were initially paralysed when they had to develop their technical solutions within the contours of these organic forms in order to materialise the concept of the building, as they set to the challenge looking for technical and economical feasibility. Often their knowledge was not automatically updated or geared to the new design challenge, which hindered effective interaction with the architectural designers. Over the past two decades engineers on the one hand were forced to develop their flexibility in technological knowledge used in action and on the other hand their 'soft' people skills needed to be professionally developed. The question was how to consolidate the exploration oriented 'computer supported sculpturalism' of the architect with the exploitation oriented mindset of the structural and technical engineers. Mutual trust between collaborating parties plays an important role in this consolidation process, which is the opposite of the intrinsic suspicion inherent to the ad hoc selection of the open market tendering system being used in the industry.

Integration of processes

Any change to the established way of designing buildings requires the support of the technology. In the scheme (Figure 38, Eekhout) impulse for new architecture initiated on the right hand side of free artistic design can only be realized by developing new technologies. Depending on the characteristics of the technical innovation demand sometimes new fundamental research is required. In the free form scheme, architects acting as sculptors move more to the right side of the scheme.

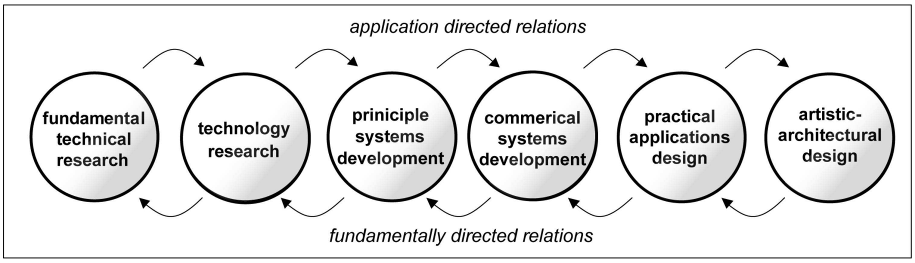

Figure 38: Relation between fundamental research to artistic design by M. Eekhout.

Fluid designs are first of all material compositions with an unconventional form, whereby architects hope that the spatial composition will be the first and only derivation in the building cycle. A complicated form, however, requires complicated geometrical surveying in the design and engineering phase, in the production of individual building parts, and in the composition and integration of these parts on the building site. These mainly logistical processes are of concern for the project architect as well as for the main contractor and the co-makers and subcontractors. The process needs a uniting approach in order to realise the design.

Towards a higher degree of co-operation and collaboration

A free-form geometry involving all building parts of the building design leads automatically to a very close co-operation and collaboration between the partners in the building project. This requires a change in attitude compared to more traditional processes in which most architects are usually more familiar with maintaining some distance from construction activities. The building team is configured as the sum of all participating architects, designers, advisors, main contractor, building managers, component designers, sub-contractors and producers involved in the four stages:

- Design of the building and its components.
- Engineering of the building parts (elements, components and site parts).
- Productions of elements and assembly to components.
- Building on site and installation of prefab components.

Each phase has its own characteristics of design considerations and assuring quality of the building as the end product being a composition of the different building parts, installed on the building site by various partners. The first phase of design of the building and its components will be the domain of the architect and the structural engineer. The tendency here is for standard products to become systematized and for building systems to become special project systems. The need for special tailor-made components will however increase because of the special form of the building, which on its turn has an influence on the final form and position of each composing element/component. The tendency towards individualisation can be described as industrialisation in lots of one.

While the complicated form can only be developed fully with the use of mathematical design programs, the design phase has to result in a 3D virtual mother model of the building, which is logically preferably drawn and maintained under the control of the architect. In this digital model the principal elements and component sizes and their principal connections need to be coordinated. From this model each partner will start their own co-engineering work. The development of the 3D model in the next stages must incorporate all relevant engineering data of all the components of the different building parts, each building part to be worked out by the different co-engineering members of the building team. The information contained in this virtual model contains the potential to be developed into a Building Information Model (BIM). The BIM may then be used for tendering purposes, although it is still common for information to be conveyed on paper drawings. However, a 3D virtual model is inevitably part of the future as digital building information tools are introduced and become more commonly used.

Consequences for co-engineering, production, and installation

All engineering activities have to be based on a central 3D virtual mother model, possibly accessed via the internet, which forms the digital base for the engineering of the total building. The keeper of the model is indispensable for maintaining the model and checking for consistency of use during the life of the project.

The free form projects described in the research case studies are exemplary for the bottom-up driven development of 3D virtual building information models by architects and design & build contractors, which has been going on for the past twenty years. Free form projects are for the building industry the frontrunners for the introduction of building information models (BIMs) because the realisation of free form architecture can only be mastered through a digital, multi-party, collaboration process. At some point in the near future this development will inevitably meet the top-down introduction of BIM and development of IFC standards and IFD libraries, which are born out of the aim for greater efficiency and are also an answer to globalisation of the building industry as they share mutual interests. The development of software certainly plays a major role in this process where the geometry driven free form architecture and the object driven development of building information models are to collaborate, although this still has some way to go before compatibility is achieved.

For the co-ordination and integration of the different co-engineering parties in the building team three clearly distinct modus operandi could be followed: separate model, engaged model, and collaborative model.

Separate model

Every participant takes the basic form data from the conceptual design model and works on it in separate software programs. Problems relate to checking the quality of the information, coordination, changes and modifications of ‘separate’ information packages. Where two or more building parts join, each side has to be engineered by the separate building parties and the joint has to be agreed on commonly. Software packages have become compatible by the market entrance of IGES and STEP protocols in recent years. However, checking the different results is still extremely time consuming and mistakes only emerge on the building site.

Engaged model

When the architect would be engaged to keep a close watch on the 3D Model (BiM) a better involvement of all parties is expected. The question of the responsibility remains, however.

Collaborative model

All participants work with the same 3D virtual engineered design model in a logistically controlled way. At the entrance the model is unfrozen and detailing and modifications of elements and components by each party can be fed in successively. Than the whole engineered design model is to be updated and checked for conflicts. The end situation will be frozen and communicated to all building parties, and is to be used as input for production activity. Simultaneous work on the 3D model by more than one engineering sub-contractor is not allowed, as it will lead to confusion and possible legal problems. In this model participants all work with the same software programs. Driven by the aim of cost effectiveness, this model has the tendency to lead to the development and use by all participants of an universal 3D virtual design system, capable of handling the conceptual design, the overall building design, the statics analysis, the engineering, the shop drawings up to the quantity lists and the manufacturing and assembly.

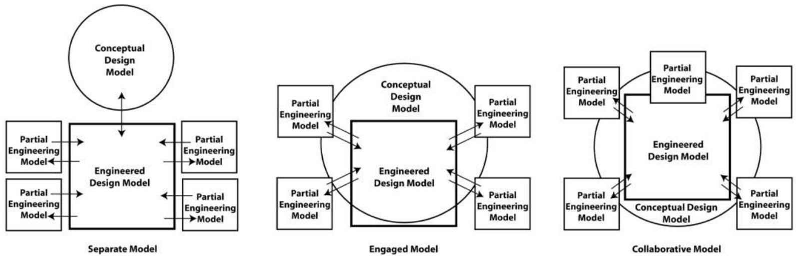

Figure 39: The position of the architect in relation to the mastership over the 3D model.

In the process the building participants have to bear in mind that after each of the building-directed engineering contributions, regular geometrical checking on conflicts has to be done. Neglecting this effort will lead to large problems in the integration and co-ordination of the engineering, in production and installation further down the line. Four building parties are able to execute this effort: the architect, the building technical engineer, the building contractor and the geodetic surveyor. Each option has its advantages and disadvantages. Each proposed party has to realise a sort of forward or backward integration. Software is developed towards this goal of detecting conflicts in the mother model. Here lays an opportunity for architects to re-establish their central role in the building process.

Recommendations and closing comments

There are several lessons learned from the case studies concerning the design management of complex liquid design & engineering. These are presented under the headings of process, products and people.

Process

1. Realizing a free form design must be approached as a collaborative process of design, engineering, production and construction. The experimental character of this process has to be recognized and dealt with as a management challenge, in the sense that the collaborative process itself needs to be designed.
2. The architect has a choice between two forms of collaboration:
- *Hierarchic*: develop the design with the advisors, tender and have the design further developed by the engineers of the contractors, or
- *Building team*: by composing a team of advisors and engineering co-makers that develops the design and complete engineering of the building, after which the final tendering and realization takes place.
3. Risk management should be explicitly be made part of the process. Failure to appreciate the complexity of blob designs will have consequences for the project and/or its participants. On the one hand the results of poor risk management will lead to buildings that are more expensive for the client than anticipated or to buildings that are qualitative inadequate. On the other hand contractors and sub-contractors have a lot to lose: they risk to pay underestimations out of their own pockets.

Product

4. The architect has three choices for the supply of design output:

- Only to produce the design concept and the presentation drawings.
- *Produce* the conceptual design, presentation drawings and the initial 3D model that will be used at the entrance of the engineering stage.
- *Produce* the conceptual design, the presentation drawings, the 3D engineered design model and coordinate the integration of all engineering contributions from the co-makers.

5. The coordination, the set-up and the development of the 3D virtual mother model has to be accounted for economically, either directly through an additional client's fee or indirectly via coordination costs applied by each partner. The costs should be emphasized in the building realisation budget.
6. The design and detailing of elements and components will have to allow for accurate 3D measuring with "click" points to be positioned accurately as reference points both in the engineering as well as in the site surveys.

People

7. Trust between the different parties is essential. If trust is not made possible between the project participants, it will be difficult to realise collaborative engineering but instead will back-fire in contra-engineering.
8. Co-engineering participant companies need to incorporate excellent engineers who are knowledge wise geared to the challenge and who know how to effectively communicate their experiences.

Free Form Design descended from the virtual world of computer graphics, landed in the laptops of architects and the building industry was frightened. The gap between designing and building had to be bridged through architects and designers who had to develop their virtual designs into feasible designs. Hence they had to go all the long way of research by design or research by design and development. In Free Form Design projects these three aspects are blurring, not as they are not distinctable, but as they are super integrated.

EXPERIMENTING WITH PROTOTYPING

(Research by design)

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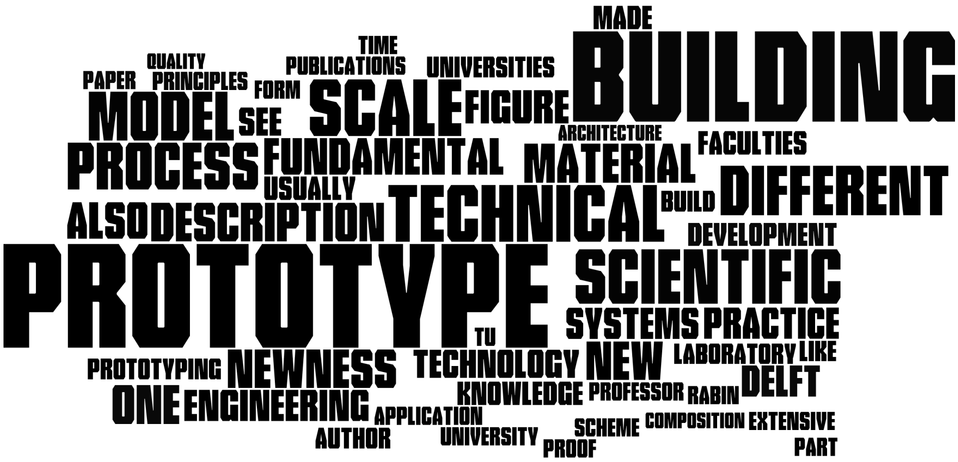

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Abstract

This contribution defends the position of the practical designing professor who regards his design & build office as his research laboratory, on the results and processes of which he contemplates in his research publications. He even goes to the extreme of theoretical publications, but always this knowledge and insights are gained from practice. Being a practicing designing architectural engineer as well as a university professor enables the practice professor to combine his positions in industry and academia. Experimenting and prototyping play an important role in order to increase knowledge and insight by continuous engaging inventions into innovations.

Theoretical research and practical design

Scientific Design in Architecture knows many methods, see '*Ways to Study and Research*' edited by Taeke de Jong and Theo van der Voordt (2002). My personal contribution has been in the design methodology as described in the yellow book '*Methodology for Product Development in Architecture*' (Eekhout 2008a). This is a theoretical philosophy from the practical background of designing, experimenting, prototyping and building of the design proposals. Theory distilled from practice. Traditionally the Building faculties at the former Dutch Polytechnics in Delft, Eindhoven and Twente were very material-based, before they became Technical Universities in the 1980s. Since then also the phenomenon of academic research, quite independent from practice came up, in imitation of the science-based faculties of the technical universities and of the general universities. At the Dutch faculties of Architecture in Delft and Eindhoven a small part of research is truly academic and scientific, done usually by full-time professors and researchers, devoting their time in long term, fundamental and academic research. They usually have only light connections with the building sector. But their advantage is to go into a full depth of fundamental research. While the other (and major) part of part-time professors are only part-time engaged to the universities and more design & engineering directed. They devote the majority of their time in their own design and engineering practices. Usually they are engaged to the university for 0.2 to 0.4 fte only: one or two days a week. Usually they devote their time to education, more than to research. These practice professors (in Dutch 'praktijkhoogleraren') regard their work done in their offices as their laboratory research, on which they contemplate and philosophize at the university and also publish. This attitude has been illustrated by famous architects-professors from the 1960s and 1970s post-war reconstruction (in Dutch: 'Wederopbouw') generation of architects like Hans van den Broek, Jaap Bakema, Aldo van Eyck and Herman Herzberger. This generation was not known for their research publications, in contrast to the contemporary expectations of practice professors. They became famous because of their lectures which were attended by many students. At which occasions they contemplated verbally on their work and the broader scope of the context in which their designs had to be positioned. In the last generation of 30 years the attitude at the technical universities has changed and drifted more towards theorizing. The professors are expected to be leading both in education and in research in their fields of expertise. The author regards himself as a practice professor, with his main domain in his design & build company Octatube in Delft, contemplating at the Technical University of Delft on the findings and processes of his projects and publishing on this in academia. This contribution, too, defenses that position in this symposium on ‘Design Research in the Netherlands’. Each professor is by law responsible for Education and Research in his field of expertise or the domain of his chair. He/she has to publish scientifically and for the profession and society in order also to fulfill his 3rd task: ’Valorization’ and to attract collaborations with external parties and consortiums.

Kinship between fundamental research and free design

In each of the three Dutch TU’s the faculties can be divided in three main types:

- Sciences (at TU Delft: Applied Sciences; Electrical Engineering, Mathematics and Computer Sciences).
- Engineering (at TU Delft: Civil Engineering; Aerospace Engineering; Mechanical, Maritime & Materials Engineering).
- Designing (at TU Delft: Architecture; Industrial Design Engineering; Technology, Policy & Management).

The habits of the three main types of faculties are different. The markets are different, the players are different and people in these different faculties usually do not understand each other quite well as they are not accustomed to each other’s language, methods and strategies. They have different goals. Yet when one overlooks the total playing field of the technical university in each research project there are fundamental aspects, technology aspects and design aspects. So in case of a Babel-like confusion there will be a loss of integration and as a result a possible level of quality. Knowing each other’s specialization, appreciating each other, asking each other’s assistance and collaborating with each other’s influence could make better research results. Inspired by a scheme of emeritus prof. Guus Berkhout which he made in his function as the former vice president research of the TU Delft the author has derived a scheme to show the mutual relationship or rather ‘kinship’ between six major different types of researchers at the technical universities, see Figure 40. The scheme shows that each ring-shaped domain has a core of activities that is principally different from its neighbor. Usually the players are different, the language is different, the playing rules are different: these are very different arenas. Yet they have something in common which relates them. Each domain looks to the left hand domain as its more fundamental relative; while looking to the right one sees the more application-directed relative. Fundamental technical research is the most fundamental science available on the technical university. They have a more (‘purely’) fundamental relative at the general universities, who see them in return as applied fundamentalists. They regard the fundamental technical research on their right hand side as applied playing field that is filled with the principles they have invented and researched and forms them into a wider, broader technology. On their turn these fundamental technical researchers will see their right hand neighbor as developments of principle engineering systems. On their turn these principle systems look to the right and see commercial systems, made on the basis of their principle systems, but ready to be applied in practice. These commercial and or societal systems looking for applications will find that they need their neighbors, the application designers to bring their results to the markets. The most creative of these designers do not mind restrictions or any systems: they are free thinkers.

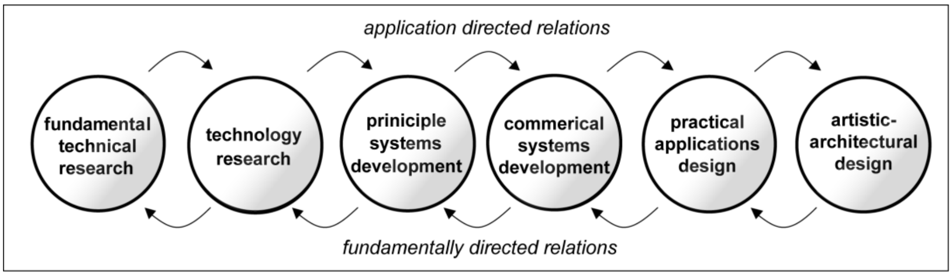

Figure 40: Relationship between the extremes of fundamental technical research and free artistic design.

Within one project a scientist can also experience that, although his home base is technology development of application design, he would need to go to the fundamental side first to develop new principles or have new principles developed, before he sees how these new principles could lead to an adaptation of the technology, to new system principles and to new commercial systems, that can potentially be realized: applicable systems. Before he can look for an application environment and apply the new system over there. May be, with enough freedom in his head also the composition in itself has a degree of surprising and unexpected newness. So for example a temporary structure out of cardboard would need an in-depth study of the paper or wood from which the layers are made and the glue that bonds the paper, layers study of the structural characteristics of paper tubes in the sense of strength, stiffness and stability, and of the outer layer protecting the paper tube against his proto-enemy ‘humidity’.

Having found a new formula for the basic material and the bonding plus an improvement of processing these material industrially, he can go back to structural design technology. Think of the best ways in which improved cardboard tubes can be used to build a structure with certain characteristics. Finally he could look for a challenging application and an application, like a paper dome for a temporary building in IJburg/Leidscherijn after global design of the Japanese architect Shigeru Ban from Paris. Or he could go to a crazy designer like the artist Theo Janssen with his beach animals (he calls them ‘animari’) that almost walk on the beach against the wind, thanks to the energy impulses from the wind, see Figure 41 (Janssen 2004).

Being able to jump around on the six ring scheme means that one is able to go deep in research at one moment, be responsible in the width of technology and at another time be creative and original enough to compose with new principles and a new technology a surprising new design that astonishes the world. It is only the very few that is able to do the fundamental research themselves, be responsible technology engineers and do an extremely surprising design composition as well. One tone down we could also be satisfied with realizing these different domains, different playing fields. And to connect oneself to the best brains on the extreme domains when one is not able to perform it himself. This does not change the validity of the scheme: going through it or flying over it is both possible as long as the different domains are recognized and respected. And the scheme is a principle scheme, not to be taken too literally.

Figure 42: Theo Jansen's 'beach animals' of PVC tubes 'Animaris Currens Ventosa.'

Prof.dr. Rutger van Santen, previous rector of TU Eindhoven mentions five criteria for scientific design in his lecture on 04.11.2009 for the Research School Bouw:

- Publications.
- Societal impact.
- Development of new knowledge.
- External stakeholders.
- Reputation.

How do prototypes fit in this list? They are carriers of new knowledge and insight in a material form. Without publications or an extensive description on the prototype this proto does not spread the knowledge. In the Octatube laboratory in Delft a number of prototypes are built as segments of a building structure that, after an extensive process of design, development, research and engineering were built to be a proof of the developed quality. One prototype is the façade segment for the Finnsbury Pavement project in London. Another row of examples are the different prototypes of wing segments we made for the Rabin Centre, which showed different modes of construction for the Rabin wings, so that we could convene with the architect which way to proceed. These prototypes convinced the designers and engineers of the different possibilities and finally in the discussion with the client, architect Moshe Safdie from Boston, the most attractive mode was chosen on ground of elaborate arguments. See Figure 42.

Figure 42: Three different modes of segment prototype for the Rabin roofs.

Figure 43: Finnsbury pavement façade segment in the Octatube laboratory.

Quantitative and qualitative publications

The author has published ten books and more books are in preparation. He publishes regularly contributions for conferences and symposiums and scientific and professional journals. In Delft the reward system for all TU faculties, called the 'BTA Compensation System', compensates research efforts by a 1st money income stream for publications, according to a ranking list, from fourteen points for an international scientific book to one point only for a professional magazine publication. Each point has a certain money value. The balance between gross salary of a full time researcher and his obligatory BTA points having a value of around 2.750,= Euro is 25 points, which not many researchers achieve. However, this balance is ever more important as the government is withdrawing its funding for Education and Research to the universities. This also counts for the technical universities, which are forced to concentrate their 1st money income first on education. The left-over part is for research. But researchers who produce qualitatively interesting and quantitatively sufficient output are free from the next efficiency operations which rush and haunt the technical faculties in the recent years and the years to come. The author has an appointment of 0,4 fte as a professor with an average yearly output over the last seven years (assessment 2002-2009) of 17.87 BTA points.

Scale of prototype designs in architecture

Buildings and architecture are so big in scale and size that they cannot be made as prototypes and having them tested as this is too costly an affair. But parts of buildings: i.e. building technology knows building products, building systems and special components. They are often smaller in scale and can be isolated as prototype components of restricted scale where real material prototyping and testing can be performed and has to be performed as systems often have large repetition in production. A solitary building even repetitive houses of or apartments are too large to be built, tested and evaluated. So due to scale in town planning and architecture material and real scale prototyping is not affordable, usually not done and hence the final building or the urban design is the prototype (in direct realization), the prototype artifact. In building technology, where the artifact is the technical composition of a building made of elements and components, experimentation with prototypes often improves knowledge and insight and produces feed backs by technical testing and human acceptance and usage. This contribution emphasizes the use of experimentation by the making of prototypes of parts of the building technical products or systems, of prototyping in the form of the total composition of the building technical product or system. If necessary or otherwise unavoidable to see the building technical artifact of the building as a prototype. And in order to gain knowledge and insight how to progress from there.

Prototypes

The focus of this contribution is on the function and possibilities of experimental material prototypes of different sorts in the process of design and the improvement of knowledge and insight in the process of design research gained by prototyping. Finally the essay advocates that prototypes be recognized as feats of scientific quality in the scientific evaluation of design research, but with proper descriptions of the process and its results as prototypes in publications.

Since 1905 according to the Dutch Law of Higher Education it is possible to obtain a PhD degree in Science on the basis of a design. The lettering of the description refers to a machine, according to the logical world of the 19th century industrial revolution. But the contemporary interpretation of this working object is also a ‘designed object.’ In the faculties of Architecture there are three sorts of material design:

- Urban design.
- Architectural design.
- Building technical design.

It implies for Urban Design that there will always be a scale model of some sort and some scale involved; for a building or architecture a scale model or scale representation is natural and logical; for building technical design, the scale model could also be a real size model, according to the size of the element, component or assembly involved. In all cases the Law expects that aside of the ‘designed object’ a description of the functional working of the designed object is added. This description is not a conventional dissertation, but could be a shorted variation, depending of the subject. Now we are arriving at the level of the prototype. The prototype is always a designed object. The prototype would need a description of its functional working and a scientific description and motivation of the design and development process would suffice for such purposes.

The prototype as the designed object has a scientific value when it has ample newness, that is the scale of newness should be beyond the environment of the author, of the university, of the country, for the world. As a symbol of that newness there should be an approval on newness according to the accompanying PhD commission which is per definition collected from the best brains available on the specific field. Newness could lead to inventions, but these are usually seen as material inventions, while progress in science can also be made in immaterial newness. Depending of the position of the PhD candidate in the six rings from fundamental researcher to free designer, the subject of the prototype could be fundamental, technical or designed. The extremes can range from the discovery or development of new principles to the composition of a work of art, provided there is enough reasoning, process description and newness in this writing to be found. Preferably a scientific process description should be added.

Likewise, when a designed object is good enough for a PhD dissertation, a designed object in the form of a realized designed artifact, should also have scientific value, provided it is accompanied with extensive functional working description of a process description of adequate quality.

This means that practice professors who claim to have their laboratory in their engineering offices can contribute to the building science when a high quality or an adequate description is added to the prototype. It also includes that exhibition models and representations, if provided with an in-depth description, have scientific value. When these descriptions on prototypes are presented as results of 'research by design' the personal involvement of the scientist should be obvious. Design has its gravity outside the university and it is in design offices that design usually is performed in practice, in larger than one companies. In these cases the designer has to prove or convince that his personal involvement is large enough to regard it as a personal project.

Newness and patent application

The newness as a proof of invention as one of the prerogatives of scientific design and development knows a paper form for society: the patent, which starts as a patent application, in which the newness in regard to the state-of-the-art is documented. In architecture it is not a custom to apply for a patent on newness in the design, be it a composition, or as an invention, as there is no repetition effect in the prototype mode of design. Also when a design is tendered in the sub-tendering phase main-contractors usually do not like the sub-contractors waving with patent rights. Patents mean a certain degree of monopoly and higher costs. This is not desirable in the building industry with its low thresholds and usual traditional competitive building products. Patents are a token of newness in scientific respect, but are seldom used in the building sector.

Design and build attitude

The author has his experience of more than 25 years of designing, engineering, experimenting, production and realization of building technical products and systems in his design & build company. The results and philosophies of this design & build portfolio has been described in the book 'Innovating and Experimenting with Prototypes in Practice' (Eekhout 2010). The splits between practice and theory, between industry and academia that usually is seen, has also its distinct privileges when both worlds are combined in order to obtain new knowledge and insight and material innovation.

To put it even stronger and more outspoken: in the process of inventions and innovations in building technology, experiments are continuously coloring the development processes. In order to lead these processes to a successful result, the process leader should lead both the design & engineering part as well as the prototyping, productions & realization part of these processes. In the opinion of the author the design & build attitude is the main factor for continuous success in the attained material innovations in his office.

Design & building in practice

Larger design firms have traditionally their own model workshop. Presentation models are used to convince the client or to explain a design for the larger public. It is used for people to overview a presentation in one glance; It is a better 3D-means for people who cannot read drawings. But in this case the subject is 'the scientific prototype' or 'the prototype used for scientific design.' The prototype should show how the designed object works, how it functions. This is obvious in a real machine or an industrially designed object, where the scale could be one to one, but this differs from all scale models that usually are not mechanical. In building technical design, close to machine engineering, parts, segments, elements or components and their connections could be proven in their function by a model. Architect Renzo Piano has an extensive workshop in his office. He sees the connection between the materials and his hands so important that in fact his entire office is called 'the Renzo Piano Workshop.' This is an indication that many people do not care about materials, about the materialized side of design or in a certain degree have a certain 'fear of materials' or 'fear of prototyping,' as one could be blessed with fear of height.

From my own experience, as a son of a building contractor like Renzo Piano, who, as a designer, wants to build or to have built what he has designed, there was always the enjoyment of the material side of design. Many scale model were made in space frames to show in 3D how these complicates structures would work. First for the designers, for the engineers, for the clients, for the production staff and sometimes for the erection crew. I have made a design (with artist Loes van der Horst, for the Hemweg, Amsterdam) for an artwork, a 'tensegrity' structure of masts, tubes, cables and sails that could only be shown in 3D in a model 1 to 20. The year is 1980. We were not able to make accurate and complete drawings at the time, see Figure 44. We even brought the model to the site to show the erection crew which elements were to be put on what position. This is an old-fashioned idea from machine engineering like the building of densely serviced artifacts like a submarine.

Figure 44: Scale model of the competition design for the Hemweg artwork, Amsterdam by Mick Eekhout and Loes van der Horst, 1980.

Digital prototypes

With the aid of 3D modelling programs we are now in the 'tens' and able to draw all these material elements and components into one artifact on the computer screen. But even this computer design is to be regarded as a model, a virtual model. In my experience during the design, development, research and engineering process for the roofs of the Yithzak Rabin centre in Tel Aviv the polyester material of the roof shells was defined in its spatial position by one designer who designed all five roof wings on his computer and his duo-screens and established the geometry finally for all engineers and co-makers after him, see Figure 45.

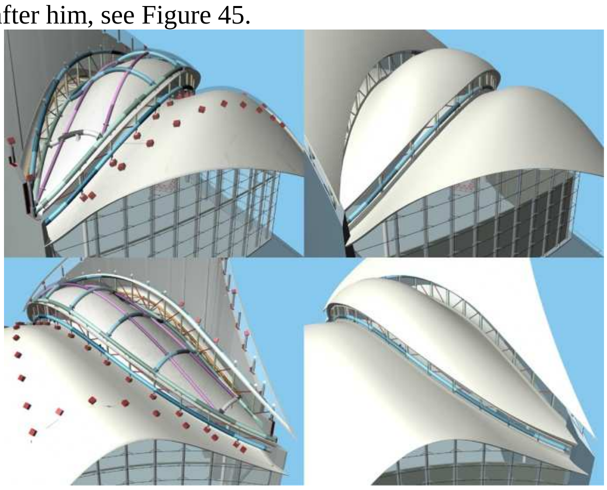

Figure 45: Engineered 3D models of roofs in free form shape for Rabin (Siep Wichers).

The prototype as a stimulant in the design process

The physical contact between designer and the material world often stimulates. Material in the hand brings the designer on other ideas than he would have in his design studio or research laboratory. In the 25 years of Octatube I have always looked for inspiration from materials, from the processing of materials in connections together (i.e. details), small size but real scale connections. I enjoy the laboratory and workshop.

The prototype as a test and evaluation laboratory

In other cases the prototypes serve as a base for evaluation research, like the Concept House that will be built on TU Delft in 2010. The size is only that of an average apartment. The newness is in the servicing around which the axiom is that a complex of sixteen of such units would form a sustainable building which is energy neutral in operation. The evaluation by measuring and analyzing is whether the energy consumptions for the period of one year indeed is as per design and engineering and whether the inhabitants behave in accordance with the behaviour included in the premises, see Figure 46.

Figure 46: Concept House prototype with its servicing as central research subject.

A unique building part, building, or town design as prototype

Material scale models, paper scale models (i.e. drawings) or digital scale models (2D-drawings, 3D-drawings or even a 3D-model of the designed artifact) are all scale representations of a prototype. They are proof of scientific designs when a certain level of newness is contained in them, but they would need an extensive description of the process and the result to be regarded as a outcome of scientific design or research by design. The glass fibre reinforced polyester roofs of the Rabin Centre in Tel Aviv are developed as a prototype of a new generation of roof construction. The process and the end result have been published extensively, for example in the “Delft Science in Design 2” Congress of 2007 (Eekhout and Tomiyama 2008). The roofs are a proof of building technical invention and innovation with this extensive description. The author is writing an extensive and richly illustrated book on the development process of the Rabin Wings, to be published in 2011. The Mercedes Museum in Stuttgart, designed by Ben van Berkel / UN Studio is a complex building where the Möbius geometry represents the endlessness of the engineering and production cycle at Mercedes. The building’s geometry proved to be extremely complex. Yet the building has been realized in the planned time, which makes the building a wondrous combination of architectural concept, co-engineering collaborations, complex management and professional quality level. A thick book was written on the subject (UN Studio and HG Marz 2006). The combination of this all could be presented by Ben van Berkel as a work of scientific design, if he would have been a professor at one of the 3 TU’s in the Netherlands, see Figure 47. And the 3TU could regard UN Studio as their lab.

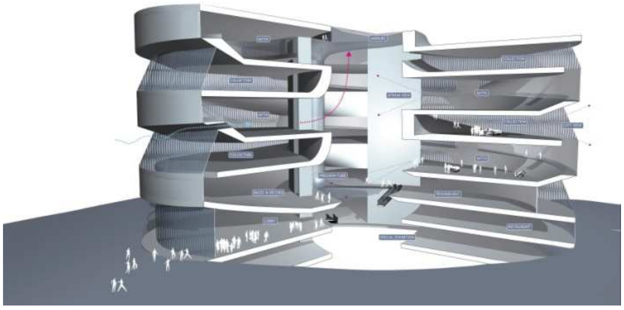

Figure 47: Isometry of the Mercedes Museum, courtesy UN Studio.

Conclusion

In the process of design, development and research in architecture the prototype is often a very legitimate proof of the content of the design and the process it went through and the decisions taken that resulted in the end result of the designed artifact. If three conditions are met:

- Sufficient newness on world scale.
- Description of the design process.
- Description of the designed artefact.

The prototype, be it material or digital, be it on real scale or in smaller scale is a proof of scientific design and as such is regarded as a part of the scientific world. The realized artifacts in the form of building parts, buildings or urban designs can be seen as prototypes as well and are also proof of scientific design when the above mentioned requirements of newness and description are met.

3TU SPEARHEAD BUILDING RESEARCH

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Word cloud of this chapter, created with http://www.wordle.net

Abstract

In 2007 Mick Eekhout received the commission to start a scouting investigation leading to a new valorization directed research programming on the six building faculties in the Dutch 3TU. His activities resulted in his ‘Final Report Formation Scouting, ‘Bridging the Gap’ dated December 31, 2009 (Eekhout 2009). This contribution gives the main outlines of this report. Eighteen societal problems were listed and concentrated into an entire new programming around four themes: Mobility, Environment, Health and Energy. Each theme to consist of two sub-themes: Space & Infrastructure; Town & Renovation; Health & Safety; Energy & Sustainability. The idea being to study these aspects, to propose interesting new ideas and projects form the supply side of research and together with external partners on the subject to tender for project financings. In taking societal challenges and collaborating with specialists, there is external funding possible for three TU research PhD students. So that in the coming five years a complete new programming will be build, completely externally funded based on societal challenges, instead of the current programming mainly built on the specific interests of the professors.

Position of building research in the building sector

The former minister of Education, Maria van der Hoeven, has challenged all universities, so included the three Dutch TU’s to embrace valorization of their knowledge and insight as the third main task next to Education and Research. Valorization is to bridge the gap between the universities and the industry/society. Hence the title of the report: ‘Bridging the Gap.’ The three TU Building Faculties aim to strengthen the economy of the building sector at the end and to increase the efficiency of the built environment for society. By departing from a number of societal problems and by taking them as challenges, academic research is servicing society needs. Collaboration with the Dutch Polytechnics (‘HBO’) and the Dutch Research institutes (‘TNO’ / ‘ ECN’) is inevitable.

Societal problems are often combinations of various kinds of aspects in a complex combination. Scouting the future of the built environment needs a broader and integrated approach of research, much wider than usual in research circles. University research is seen as specialized, deep and long term directed. Now we are challenged to develop a long term ‘umbrella’ vision for the future of the built environment. Inevitable are the collaborations with many parties, all specialists in their fields, to make the total effort of a complex answer on a complex challenge. Many of these parties will be from outside ‘academia’. Within the 3TU the research set up will be designed by umbrella thinkers: researchers who are able to think over many specialized fields of interest and who are able to design a new and over-hovering set-up. Typical is the designing component. It will be both design by research as well as research by design. The 3TU collaboration in the Netherlands as a small country, is new. The former situation is more one of competition, in contrast we will have to divide the 80 chairs into distinct different specialties or themes and to collaborate under these theme headings. It has taken a long time before this cooperation came into the open. At the same time the scope of research has become increasingly international. The Netherlands are only a small country with only three TU's and each of them is located within two hours drive from each other. Dutch research in generally is marginalized. The 3TU building faculties do not make an astonishing impression internationally. Since February 2007 the 3TU's have joined into an official 3TU Federation, which started top down according to the minister's instruction. But for the building faculties the future is really a 3TU collaboration. The 3TU professors know each other. They have to respect each other even more. Only then one could grant each other and co-operate or collaborate. In the digital era it has become increasingly easy. For that purpose a 3TU Building Faculties 'Book of Chairs' was composed, containing descriptions in a standard and comparable format of some 80 professors in the building faculties or strongly related to them (Eekhout 2008a).

The initiative started at the level of the deans of the building related faculties of TU Delft, but after the first discussions with external parties (architects, contractors, engineers, developers, governments) it appeared that a national approach would be more logical than a single TU Delft approach. The building sector is largely nationally connected. The majority of the players is nationally focused. Only a few contractors are working outside the Netherlands. Mainly through participations in foreign daughter companies. In general the presence of the Dutch building sector abroad is not overwhelming. A national co-operation is logical. The choice is to promote export by increased strength rather than getting confused by stronger international partners. The association of Dutch Engineers ONRI/ NL Engineers welcomed the idea of 3TU: "*We had to wait a long time before this 3TU came into being!*"

Financing of new research

Around half of the current research at the 3TU building faculties has a 1st money stream financing. The government is reducing its 1st money stream for research at the universities. The current minister of education and Science, Ronald Plasterk, an eminent fundamental researcher, has allotted 100 million Euro from the middle of the table to the fundamental side. The designing faculties sit at the application side: opposite of the fundamentals. In financial terms of 2010 this means they have to obtain external financing. The current research programming has not been directed on obtaining external funding on a larger scale. Each chair has its research mission and is performs the best research according to his best knowledge and insights in the specific scientific domain. In total the output of research at the building faculties may have a ranking system like the Qanu Assessments as determined by the VSNU, the Dutch universities. The industry, in this case the building industry does not have a similar system, let alone a high esteem. Jack de Leeuw, director of SBR (Stichting Bouw Research) stated to the author in 2007: "The building industry does not think highly of university research" (in Dutch: "*De bouw ziet de universiteiten niet staan*.")

Publishing for the building industry

The original commission to direct and validate building research at the building universities to the building industry, also had to be preceded by an awareness in the building industry that the potential of knowledge and insight in the building faculties might be of value, or rather of high value for the building industry. This awareness can be nurtured and fed by documentation and publications from the side of the university researchers to the building industry, in their own professional magazines, in exhibitions, in lectures and audio-visual confrontations. It is a normal process of public relations and marketing. The value of university research has to be noticed by the building industry. Researchers in academia are usually not rewarded when publishing for a non-scientific public. At TU Delft a fixed 'BTA' system of value of publications is valid, from fourteen points for an international scientific book and ten points for a publication in a highly ranking scientific magazine like 'Science' or 'Nature' to only one point for publishing in a professional magazine. Many researchers do not even take the trouble to publish for the professional practice. Professional publications may not lead to a high appraisal at the universities, it can also be regarded as seed money for validation, in that interest is awakened, consortiums are formed and collaborations in further research can be formed.

Digital portal frame for the industry

A second means to bridge the gap between academia and industry is to publish research findings and potential applications for the building industries in a digital portal, easily accessible for the younger generation of building engineers. These publications are not the scientific publications, but publications where findings, theories, technologies and inventions are treated with an open eye to applications. The scientist has to inform the industry in common language on his findings so that they understand and preferably respond. He then can then communicate and explain in a second round the scientific version. In practice this will require quite some energy before the industry is informed on the quality and potentials for application in university research. It could be organized and stimulated by a professional organization of the 3TU Spearhead Building Research.

Future university project proposals with appeal for the industry

A third step to be taken would be to set up a number of future projects, seen the capacities, knowledge and insight of the university researchers that have appeal or high appeal for the industry. This means that a certain connection or empathy has been developed between academia and industry. Academia has to understand the needs of the industry in order to design and elaborate proper research proposals. These proposals can be added to the digital portal as an open invitation, of can be sent to specific group of building companies and institutions that could be potential interested. Or they could be presented in personal presentations. 'Bouwend Nederland,' the Dutch association of contractors in Zoetermeer NL could accommodate a market or even an auction where the 'demand and supply' market parties could meet and inform each other on future research projects. The building industry is composed of an enormous amount of smaller companies (some 80.000) with 400.000 to 500.000 employees. On average five to six employees. Only seven or eight Dutch main contracting companies are big in economy terms and count more than 5.000 employees. These companies normally have their own research development departments and hence also can be addressed. The other companies are regarded as (SME, in Dutch: 'MKB') small and medium enterprises and are difficult to address: by personal visits, branch organizations, regional organizations, professional publications, etc. The best entrance is through their cupolas or joint branch associations.

Societal problems and challenges

One of the problems at this stage is that the building industry has a history of lack in interest in research and development. Companies compete on the base of price and process optimization. Technical improvements, inventions and innovations are not as influential in the average project, still awarded on pricing. Only when price/quality ratio simultaneously is regarded with more interest, inventions and innovations will influence. However, there is a general awareness that the building industry increasingly is governed by consumer needs, by their demand side. It has enjoyed the virtues of a supply market since WWII, and kept that supply market artificially by building less (houses) than the market demands. The transition from supply production to a demand production makes the builders aware that there is an uncontrollable demand market to be regarded. In general terms the building sector sees the demands of society as the base of whatever is needed for interventions in the built environments, whether is would be new buildings and new infra structure or renovations, transformations of buildings and infrastructure. In order to direct a company to society needs, one needs to know, to analyze and design or at least to make educated guesses of future demands from society towards the built environment. This study starts by listing the aforementioned critical societal challenges, to study and analyze these, to have them informed by a number of specialists from economy, politics, socio-sciences and psychology. This is the complex future ahead.

Four themes and eight sub-themes for research

The idea is to define critical societal problems with an influence on the built environment of society, to analyze the building research aspects; after that the building university research challenges and to ask the professors and researchers whether they recognize the scientific challenges and to write and propose research projects on the same topics. In many circles people think along the same lines of societal challenges. Many of the mentioned subjects figure also in other lists: they are quite general. A number of brainstorms at the 3TU Building Faculties has resulted in four basic themes that bundle a number of different societal problems: MOBILITY, environment, health and ENERGY, each of them subdivided in two sub-themes, see Figure 48.

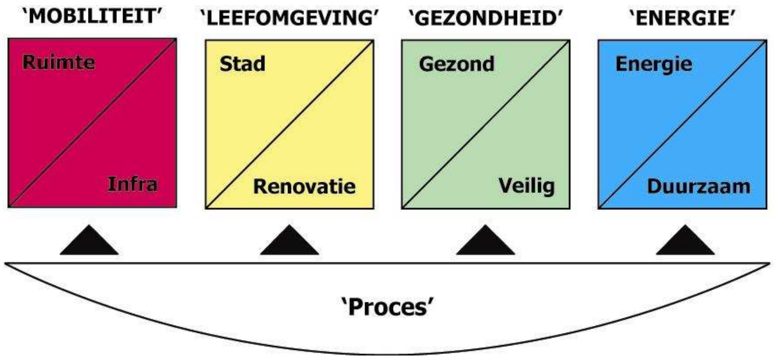


Figure 48: Scheme of four themes and eight sub-themes and one cross-theme.

Each of the eight sub-themes has been described in its critical content and important issues in the eyes of the academic researchers. They are described in full length in the 'Bridging the Gap' (Eekhout 2009).

Design is the tunnel between (fundamental) science and society. Design is application orientated and has much to do with applications in and for society. The global umbrella of the 3TU Spearhead Building from 2010 onwards requires the wider thinking of designers to design the relationships between aspects and subjects derived from the societal challenges. One of the characteristics of designers is a wide awareness, knowledge and insight or view, while researchers, their extreme counter-partners only have deep and intense knowledge, this according to Figure 49. In the scope of this conference on 'Research by Design in the Netherlands' it is obvious that designers and researching designers or designing researches are the core of the academic researchers designing a new future for the design portfolio of the 3TU Building Faculties.

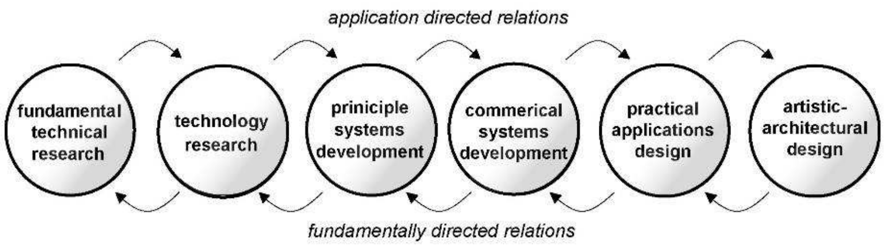


Figure 49: The six rings scheme of the relationship between fundamental research and a free design.

Examples for the eight sub-themes

Each of the eight sub-themes knows examples to give an image of the potentials of these sub-themes. 2010 will be used to detail each sub-theme into a programming of critical subjects; to invite the researchers to propose future projects; to initiate minimum eight pilot projects so that at the end of 2010 a catalogue of new proposals and projects is ready.

Theme mobility

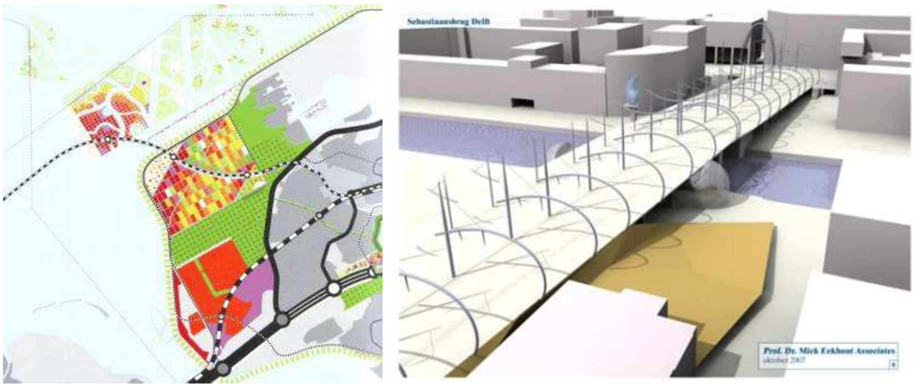


Figure 50: Space: new town of Almere Pampus; Sebastian bridge Delft, thin carbon fiber reinforcement without high society costs by closing the bridge off for fourteen months.

Theme environment

Figure 51: Town: high, deep, intense city living; renovation of apartment flats.

Theme health

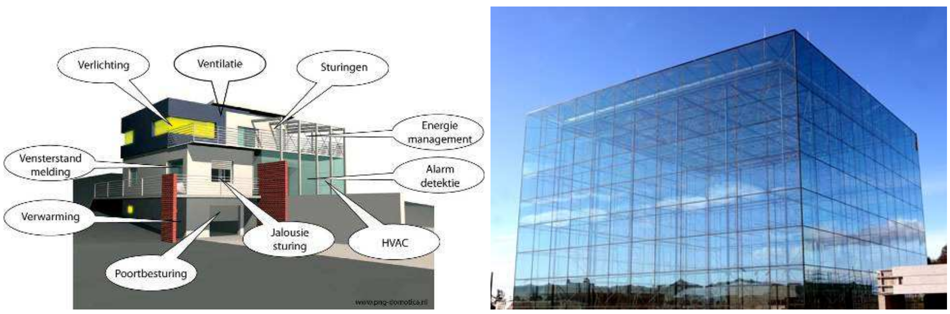
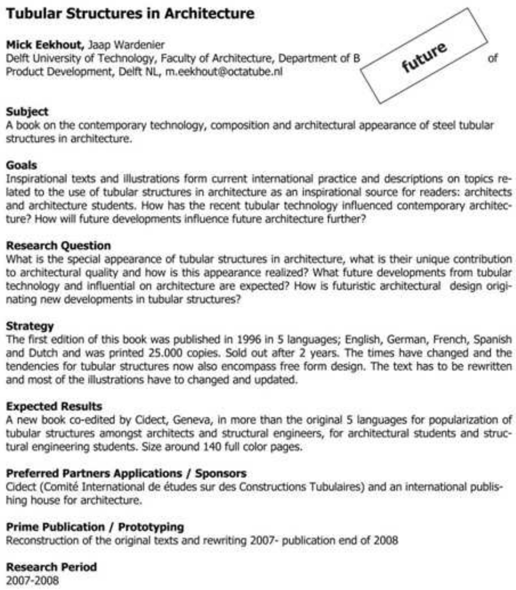


Figure 52: Domotics in a private house; safety in construction design: glass cube in Madrid.

Theme energy

Figure 53: Energy in renovation of a Bank Building in Ludwigshafen; proposal for a sustainable Concept House requiring zero energy during operation.

Figure 54: Overview of ‘Tubular structures in architecture’ publication.



Tubular Structures in Architecture

Mick Eekhout, Jaap Wardenier
Delft University of Technology, Faculty of Architecture, Department of B future of
Product Development, Delft NL, m.eekhout@octatube.nl

Subject
A book on the contemporary technology, composition and architectural appearance of steel tubular structures in architecture.

Goals
Inspirational texts and illustrations form current international practice and descriptions on topics related to the use of tubular structures in architecture as an inspirational source for readers: architects and architecture students. How has the recent tubular technology influenced contemporary architecture? How will future developments influence future architecture further?

Research Question
What is the special appearance of tubular structures in architecture, what is their unique contribution to architectural quality and how is this appearance realized? What future developments from tubular technology and influential on architecture are expected? How is futuristic architectural design originating new developments in tubular structures?

Strategy
The first edition of this book was published in 1996 in 5 languages; English, German, French, Spanish and Dutch and was printed 25.000 copies. Sold out after 2 years. The times have changed and the tendencies for tubular structures now also encompass free form design. The text has to be rewritten and most of the illustrations have to changed and updated.

Expected Results
A new book co-edited by Cidect, Geneva, in more than the original 5 languages for popularization of tubular structures amongst architects and structural engineers, for architectural students and structural engineering students. Size around 140 full color pages.

Preferred Partners Applications / Sponsors
Cidect (Comité International de études sur des Constructions Tubulaires) and an international publishing house for architecture.

Prime Publication / Prototyping
Reconstruction of the original texts and rewriting 2007- publication end of 2008

Research Period
2007-2008

Figure 55: Overview of ‘Tubular structures in architecture’ publication.

Future projects

It is clear that the new Spearhead research Programming is quite different from the existing 3TU Building Research programming. New programming under the afore mentioned sub-themes has to be set up in joined discussions with the research professors and staff. The researchers and professors can draw individual projects hanging under the programming and look for tender possibilities for external financing. All current projects are described in a standard format. The future projects should be described in a similar format, see previous pages. These examples are published in Eekhout (2008a).

Future laboratory for the Netherland built environment in 2040

Different parties in the Dutch building sector are mapping their future. Normally this refers to the immediate future of one, two to five years from to date. The Dutch cabinet has initiated the Dutch ‘Innovation Platform,’ chaired by the Prime Minister Mr. Jan Peter Balkenende. One of their initiatives is to issue the so-called ‘MIA’s, Societal Innovation Agendas. Currently discussions are defining the establishment of a MIA Bouw (Societal Innovation Agenda for the Building). A more accurate name would have been ‘MIA Built Environment.’ In order to make a stimulating agenda, a plan for the future in steps, one needs to know the future of the built environment, suited for the future society. Fitting preferably like a glove. Not only in steps of five years, as all companies and institutions are used to do, but far beyond the survey-able and calculable future: preferably in 20 or 30 years from now. The critical societal problems involved in the relationship between society and the built environment have to be studied and advised by the best professionals available on their fields of expertise. Together they could form an impossible mathematical formula with too many unknowns and hence it would be unsolvable. But through the process of study and research a far better insight may arise than ever before, after which all awake parties in the building sector and around it may draw their own conclusions. It would be not impossible that with a shrinking population, with graying (more elderly) and de-greening (less working younger people) and other critical influences the future of the building industry will totally depend on the demand side. The supply side of the building industry will become too big. The building industry better focuses on making the existing real estate and housing 'fit for future' (in Dutch: 'toekomstgeschikt') instead of new buildings. The profession of architect and contracting will become different in future. The gloom of heroism will, may be, disappear and 'doctors work' will be left.

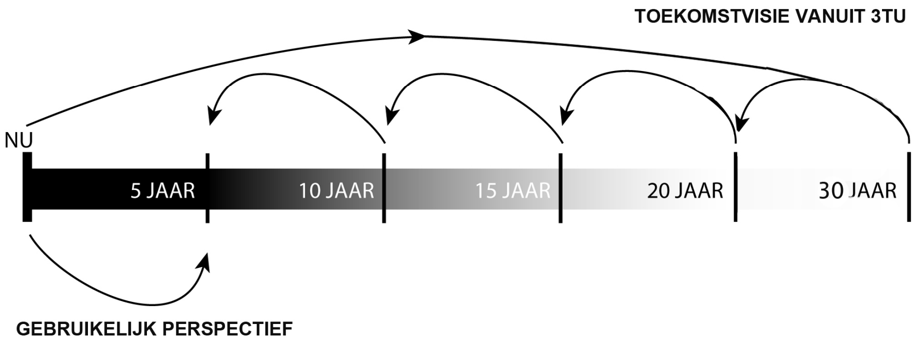


Figure 56: Reasoning to a far future and reasoning back to the short future.

The idea is to form an atelier of laboratory of thinkers, designers and engineers, who all have an umbrella look on the profession, the built environment and the societal influences on it. They have to analyze with the best advisors and professionals available in The Netherlands, the critical influences on the future built environment. And they have to interpret these critical leads to clusters of probable and improbable futures. This could happen by taking up extreme scenarios and estimating the future as floating between the extreme future scenarios. We are now able to look back at least in the experience of one generation of 50 to 60 years from the War onwards: the baby boom generation. The next generation has to look forward at least a period of 30 years. Hence the name of the laboratory: 'Netherlands 2040.' Derived from the long term scenarios will be shorter term scenarios, like 20 years and 10 years from now. In this think tank designers are the prominent thinkers as they have usually a vivid imagination, which has to be mixed with the professional future thinkers to come to a complete overview of the future of the built environment.

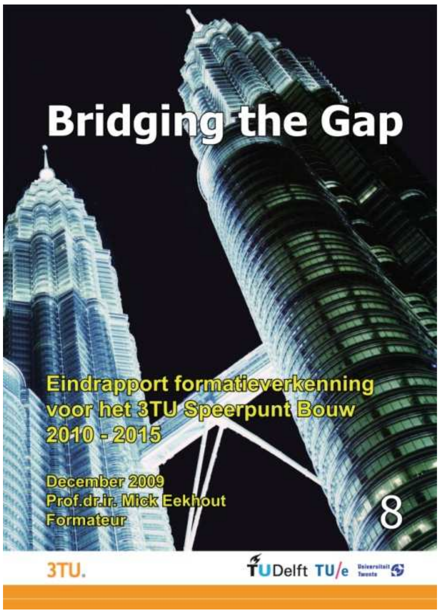


Figure 57: Bridging the gap publication.

Conclusion

In the new 3TU Building Research programming starting 2010 onwards and gradually substituting the existing building research programming, design has a major position for two reasons:

1. Design is an important part of the trio Design, Development & Research, as it connects research to society. Design is a tunnel between fundamental technical research and society.
2. In order to get a grip on the future the building sector in the coming generation of 30 years, the first activities would concern the Design, Development & Research Laboratory Netherlands 2040, targeting at scenarios of the built environment around the year 2040, suiting the then society. For that reason all society problems have to be taken up as societal challenges and combined into future scenarios. In these scenarios designers are leading the research.

INTEGRAL DESIGN METHOD FOR SUPPORTING CONCEPTUAL BUILDING DESIGN

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Word cloud of this chapter, created with http://www.wordle.net

Introduction

Many factors influence the sustainability of the built environment, however, man-made climate change and the measures that are needed to counteract such change seem to be by far the main problems of our time (IPCC 2007). To understand the impact of building design on the environment, recent research has shown that 40% of the total energy output of The Netherlands is consumed by the built environment, and this figure rises to 70% when social services such as healthcare are included (Uitdenbogerd 2007). Recent research in the Netherlands, from within the HVAC sector, for example, has shown the need to better integrate comfort and sustainable energy systems in buildings (Boerstra et al 2006, Opstelten et al 2007). It is our belief that this can best be achieved by rejecting current design practice, and by organising relevant disciplines into functional, multidisciplinary design teams. The unsatisfactory cooperation between building design disciplines has resulted in calls for better organization of the design process (Friedl 2000, Wichers Hoeth and Fleuren 2001). These calls gain more importance when we consider the increased complexity in current design processes arising from, amongst other things, growing sustainability demands. In this context, traditional approaches to organize and plan these complex processes may no longer suffice (Van Aken 2005).

One clear goal of improving teamwork in building design is the increased possibility to arrive at new building concepts, which may well prove essential in the development of a sustainable built environment. The research program aims to support multi disciplinary building design teams of architects and engineers as well as investigate the possibilities to include knowledge from builders such as installers and roofers especially within the conceptual design phase, as in this design phase the most important decisions are made (Buur and Andreasen 1989, Ullmann 2003, den Hartog 2003). The research is not only focussed on supporting the architect during the design process as often is the case (Reymen 2001, Segers 2004, Ivvaskov 2004) because in contemporary building design the role of architects and traditional discipline based consultants are changing (DGMR 2008).

Design research methodology

In order to approach the design problem in a systematic and scientific way we looked for a sound research methodology. Fully accepted research methodologies do not yet exist for design research (Reymen 2001, Cross 1998). As a result of what they saw as the lack of existing rigorous methods for design research, Blessing and Chakrabarti (2002) developed Design Research Methodology (DRM). They observed that since design research is currently conducted using a mixture of methodologies from different fields, it is very difficult to compare different instances of design research. DRM can be seen as a generic design research methodology that fits these research areas together, and provides a framework that connects research questions and addresses them in a systematic way. Several variations of the methodology are possible and necessary to suit the focus and constraints of a particular project. In our research we used the methodology as presented in Figure 58 (Savanovic 2009).

RESEARCH CLARIFICATION	DESCRIPTIVE STUDY I	PRESCRIPTIVE STUDY	DESCRIPTIVE STUDY II
Review →	Review →	Detailed →	Initial

Figure 58: The four DRM stages in our research.

To develop the method for the necessary new building design approach, both the design model and the setting had to be worked on. Following the DRM approach, this was done within the stages of the research. After the research clarification stage in which the problem was defined and measurable criteria were derived, the research proceeded on the basis of making assumptions on key variables to be manipulated. In this project these were the design team, the design tools, i.e. the morphological charts and overviews, the design model, and the setting. Key assumptions regarding these variables were made, on the basis of which research questions were derived and then tested. The results of each test fed into the design of the subsequent design and testing, the descriptive study II. This paper presents the results of the last study, the results of the earlier studies can be found in Savanovic (2009).

Tools as a systematic intervention: Integral Design

In the past a number of prescriptive design methods were developed, which were largely based on the view of design as an ill-structured problem solving activity (Simon 1969). Even though design undoubtedly includes stretches of 'normal' ill-structured problem solving (Dorst and Rooyakkers, 2006) any model or description method that tries to reduce design to ill-structured problem solving is bound to miss important aspects of the design activity (Hatchuel 2002). Recognizing the fact that design is not a scientific or merely a problem solving activity, we wondered if any of the existing and largely neglected prescriptive design methods could help us to understand design by using them for research, rather than (as originally intended) for design activities. The motivation behind this idea was that, being developed on the basis of a scientific approach to designing, these prescriptive design methods 'automatically' meet the requirements for being methodical – one of the key characteristics of valid design research (Cross 2002).

A specific design method, 'Methodical Design' (Van den Kroonenberg 1978), was developed at the University of Twente in the 1970s and theoretically elaborated by de Boer (1989) and Blessing (1994). Using the analogy of System theory (Bertalanffy 1951, Blanchard and Fabrycky, 2005) van den Kroonenberg thought of a design process as a chain of activities, which starts with an abstract problem and results in a solution. Methodical Design distinguishes three main phases or stages (the problem definition, the working principle determination and the detailed design), and four specific design steps (generating, synthesizing, selecting and shaping). Dividing a design process into stages and steps is important to decompose and structure the process around more manageable tasks. The transition between steps provides decision points, forcing review and evaluation of the results generated so far. The Integral design method, though based on methodical design, is an extended design method; the cycle (define/analyze, generate/synthesize, evaluate/select, implement/shape) forms an integral part in the sequence of design activities that take place, see Figure 59.

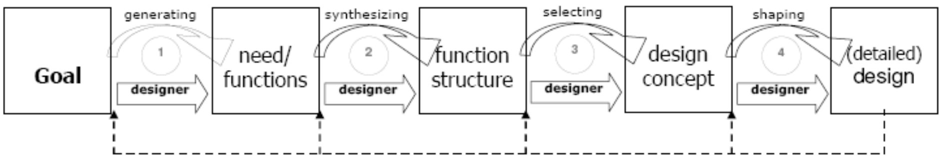

Figure 59: The four-step pattern of integral design with possible iteration loops.

So, a distinctive feature of the integral design method is the four-step pattern of activities (generating, synthesizing, selecting and shaping, see Figure 59), which occurs on each level of abstraction with the different phases of the design process. After each step in the design process a decision is made to either move forward in the design process or to go backwards via an iteration loop. Within the Integral Design method, like in the Methodical Design method, morphological charts are used to support the generation and synthesizing steps.

Morphological overview

Morphological charts were first used by Zwicky (1948). The morphological chart is formed by decomposing the main goal of the design task into functions and aspects, which are listed on the first vertical column of the chart, with related sub-solutions listed on corresponding rows. The functions and aspects are derived from the program of demands, Possible solution principles for each function or aspect are then listed on the horizontal rows. Different overall solutions are created by combining various solution principles to form a complete system combination (Ölvander et al. 2008). The main aim of using morphological charts is to widen the search area for possible new solutions (Cross 1994). The combination of functions on the vertical axis and sub-solutions on the horizontal axis leads to a combinatorial explosion of different combinations of sub-solutions. These possibilities include not only existing conventional solutions, but also a very wide range of variations offering completely new combinations. Morphological charts are often used to aid in developing solutions using a systematic method of developing and combining potential design solutions (Holt 1997, Marchal and Leany 2002, Ruder and Sobek II 2007).

The use of morphological charts within the integral design method supports step 1 and step 2 of the integral design method’s four step pattern, see Figure 60.

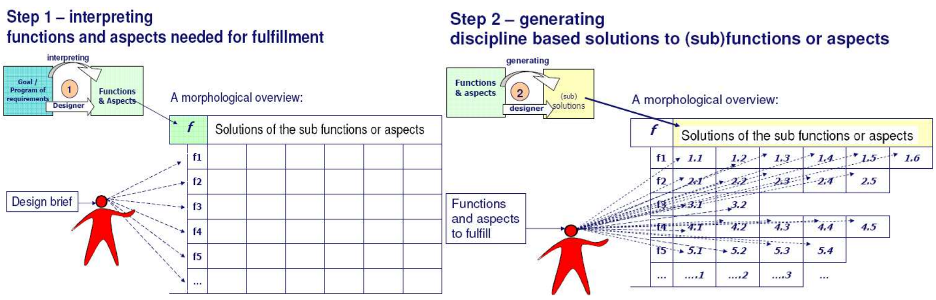

Figure 60: Step 1 and step 2 of the integral design method.

The morphological charts made by each individual designer can be combined into a (team) morphological overview, see Figure 61, after discussion on and the selection of functions and aspects considered important for the specific design. The advantage of this approach is that the discussion begins after the preparation of the individual morphological charts. As each designer uses his own interpretation and representation, in relation with his specific discipline based knowledge and experience, this gives an overview of different interpretations of the design brief resulting in a domain specific morphological chart from each design team member. Importantly, this encourages and allows engineering based disciplines to think and act in a more 'designerly' way than is common in the traditional design approach. In sum, this approach allows a greater freedom of mind of the individual designers and results in more creativity in interpretation of the design problem and generation of sub-solutions from the different disciplines. Such a morphologic overview can be used by the designers to reflect on the results during the different design process stages.

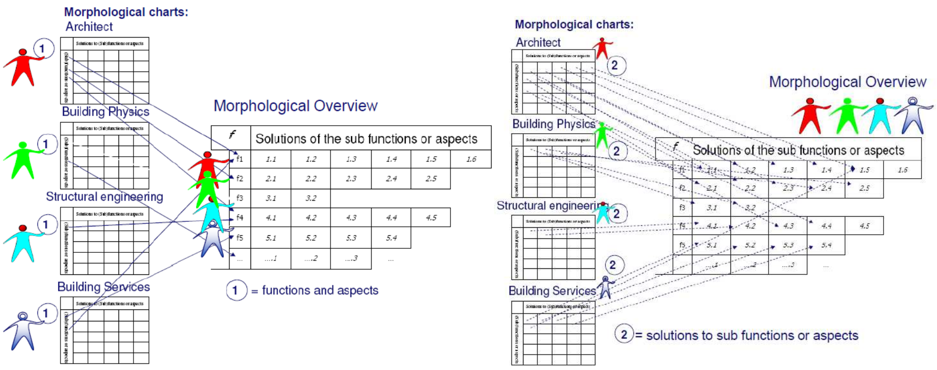

Figure 61: Building the morphological overview. Step 1: the Morphological overviews show the agreed functions and aspects (1) of the different morphological charts. Step 2: the Morphological Overview with the agreed on sub-solutions (2) from the separate morphological charts.

Applying C-K theory to the conceptual Integral design phase

The pragmatic view of Integral design, as well as existing design theories (Yoshikawa 1981; Suh 1990; Gero 1996; Braha and Reich 2003) define design as a (dynamic) mapping process between required functions and selected structures. Hatchuel and Weil argue that dynamic mapping is not sufficient to describe the generation of new objects and new knowledge, which, according to them, are distinctive features of design. Their statement that "*there is no design if there are no concepts*" (Hatchuel and Weil 2003, pp.5) underpins the logic of C-K theory and of the present research. The distinction between the known (knowledge) and the unknown (concepts) determines the core propositions of C-K theory (Hatchuel and Weil 2007).

Starting from the Integral design perspective C-K theory can be applied to define the initial object-design-knowledge, iODK that participants bring into design team as space K. From here, two types of synthesis are possible: either the representations are combined, using the K→K operator, or are transformed, using the K→C operator. The former possibility leads to ‘redesigns’ (RE), while the latter leads to ‘integral design concepts’ (ID-concepts). Ultimately, evaluation of RE-design can only result in the same object-design-knowledge, while from ID-concepts new object-design-knowledge, nODK, can be developed. This nODK represents possibilities for innovative design solutions. The focus in the design process can therefore be put on the possibility of expanding the solution space with integral design concepts (ID-concepts) in order to produce potential for the creation of new object design knowledge (nODK). What we want to test in our research is a supportive design method for the generation and structuring of knowledge (K) and the transformation of knowledge to concepts (K-C transformation).

Research methodology

To test our approach of the morphological overviews and to determine if the theory led to positive effects for the professionals, we arranged workshops as part of a training program for professional architects and consulting engineers (structural engineers, building services engineers and building physics engineers). The iterative development of the method results from housing the research within the Design Research Methodology framework (Blessing and Chakrabarti, 2009). Within the ID-method the structured presentation of object-design-knowledge is guided by morphological analysis. The first step of the ID-method is to record and structure the design team’s interpretation of the design task, resulting in a dynamic list of functions/aspects. The simultaneous generation of sub-solutions per defined function/aspect needs, in the first stage of the approach, to remain based on individual disciplines in order to result in an overview of the design team’s object-design-knowledge. Iterations are possible and this is where the added value of morphological overviews’ structuring is most apparent. Feedback can take place after each iteration, thus allowing the overviews to be amended. As the prescriptive model intends to structure and not to predict design behaviour, the iterative and recursive processes do not disqualify the model. In addition, morphological overviews represent a transparent record of the design process, which external parties can refer to in order to determine whether all necessary functions and aspects are adequately addressed. In this sense, the ID-method makes the team design process explicit and provides an audit trail. The next step of the ID-method concerns the combination of generated sub-solutions, resulting in redesigns, and/or transformation of generated sub-solutions, resulting in new concepts.

Test setting workshops in a professional context

One of the difficult aspects of conducting design research is finding suitable participants for experimental testing. Mostly verification and testing of a new method or tool is done by experiments with student groups (Segers 2002) or with design groups within one company (Blessing 1994). By using experienced designers we wanted to improve the relevance, as there is a major difference between the design approach of experts and novice designers (Kavakli et al. 2001, Ahmed et al. 2003, Kavakli et al 2003).

In the Integral Design project different concepts of workshops were tested (Quanjel and Zeiler 2003). An overall model was chosen in the form of design task workshops.

The workshops and case studies gave the possibility to evaluate the outcome of the theoretical model of the method to support the process for building design.

A key aspect of the proposed project is to test the ID workshop approach in the context building design. To that effect a series of different type of workshops with experienced professionals from the professional organizations of architects (BNA), engineers (NL Ingenieurs), installers (TVVL) and roofers (Hellenddak).

Experiments: workshops for professionals

After extensive experiments with different set ups, in which well over one hundred professionals participated (Zeiler et al., 2005), we concluded that a good way to test our design approach was a workshop setting for professionals. An essential element of the workshop, besides some introductory lectures, was the design cases, on the basis of which the design teams worked and presented their conceptual design at the end of each session to the whole group. These design exercises were derived from real practice projects and as such were as close to professional practice as possible. Since 2005 we have organized five series of workshops for experienced, professional architects and engineers, all of whom voluntarily applied to participate. These workshops typically included around twenty participants and lasted for two or three days. The final developed setting of the workshop was achieved in series 4 and was repeated once in order to investigate its prescriptive value. The average age of the 108 participants was 42 and they had an average of twelve years of professional experience.

The participants of each discipline were randomly assigned to design teams, which ideally would consist of one architect, one building physics consultant, one building services consultant and one structural engineer. Starting with a three day practice-like ‘building team’ concept, in which all disciplines are present within the design team from the start, the integral design method workshops have finally evolved to a two-day series. In the first workshops we also introduced the Kesselring method of decision support, upon which the VDI 2225 is based (Zeiler et al., 2008) but it proved to be an information overload for the participants. Therefore, we focused on the use of the Morphological Overview as a design tool. More information about the first three series of workshops can be found in (Zeiler et al., 2005, Savanovic and Zeiler, 2007, Savanovic 2009). The results and feedback from workshops series 3 led to adjustments for the final two-day workshops series. In the current configuration (Figure 62) stepwise changes to the traditional building design process type, in which the architect starts the process and the other designers join in later in the process, are introduced in the set up of the design sessions.

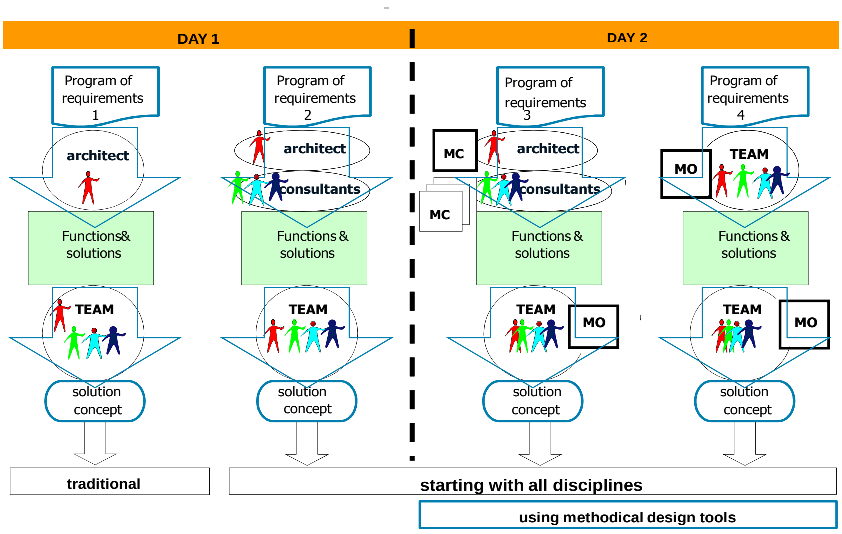

Figure 62: Workshops series 4 & 5, four different design set ups of participants.

To avoid a possible learning effect within a design team, after each session the participants were assigned to other teams so that no participants worked together more than once. Starting with the traditional sequential approach during the first two design sessions on day 1, which provide reference values for the effectiveness of the method (amount of integral design concepts), the perceived "integral approach" is reached through phased introduction of two major changes:

1. all disciplines start working simultaneously within a design team setting from the very beginning of the conceptual design phase,
2. the integral design model / morphological overviews are applied.

The second set up of the design sessions allowed simultaneous involvement of all design disciplines on a design task, which aimed to increase the amount of considered design functions/aspects. Additional application of morphological overviews during the set up of the third design session demonstrated the effect of transparent structuring of design functions/aspects on the amount of generated (sub) solution proposals. Additionally, the third setting provided the possibility of one full learning cycle regarding the use of morphological overviews. All sessions were videotaped and additionally photographs were taken every ten minutes. The end presentations and all used material, sketches etc. were also photographed.

DRM stage 4: Descriptive study II

This research has been housed within the framework of DRM. As such, after trying to establish a clear picture of the status quo in descriptive study I, the research design progressed on the basis of assumptions which were tested in this research via the observation of the workshops. The resulting findings led to iterative improvements of the research design. Descriptive study II represents the final stage of DRM research, in which validation is sought for the final research design. In other words, this stage represents the testing of the solution to the identified problem in the status quo. This section proceeds by stating the assumptions for the final design workshop.

At this point it is useful to restate the goals of the research project. Essentially, there are two main goals, one a short term, practical goal, and one more abstract, long term goal. The first goal is to integrate engineering disciplines into a team design process with the view to gaining access to their knowledge at the outset of the conceptual design process. Following the DRM approach, determining whether a goal has been reached is a matter of determining whether measurable criteria have been realized. The measurable criterion for the first goal is the amount of aspects and solutions generated within the conceptual design phase. If the assumptions in this research are correct, then the interventions should lead to a greater amount of aspects and sub-solutions than in the status quo.

In terms of the second goal, merging such knowledge is seen as a necessary precondition for the creation of innovative design concepts, which are desirable in the context of complex design tasks such as designing sustainable buildings. The measurable criterion for this goal is the emergence of integral design concepts. The final workshop set-up needed to be able to test for both of these measurable criteria.

In the fifth, final workshop series set-up, the same four design settings as in the fourth series workshop were used. Here, the first setting functions to simulate the status quo in building design in which the architect takes a leading role in the design process. In the second setting, in contrast to the status quo, individual disciplines are required to work on the design brief from the outset before integrating into multidisciplinary teams. A comparison of settings one and two will show the impact that a simultaneous approach had on the design task.

This comparison will serve the purpose of testing whether goal 1 can be reached with the method developed from the research design. Setting three essentially represents a learning phase for the participants of the workshops. What is to be learned here is how to structure the knowledge of the individual design team members into an integrated picture of the design team's knowledge. To do this successfully within the ID-method is a matter of mastering the use of morphological charts and overviews within the context of an integral design team. In the first design session of setting 3 the participants are given the opportunity to record their knowledge input in an individual morphological chart. In the second design session each team seeks to integrate these charts into a morphological overview, which represents the team's object design knowledge of the design task. At the end of the setting 3 / start of the setting 4 time was reserved for extensive feedback on the teams' application of morphological analysis. It was imperative that the teams became adept at this task in order that they could use the tool correctly from the outset in design setting four, where both of the research goals were to be tested. Therefore, setting four was considered to be the main area of interest in this research project. The analysis of setting four is the place to determine whether either or both research goals had been achieved.

Analysis I

The first goal of our research is to integrate engineering disciplines into a team design process and to share their knowledge at the outset of the conceptual design process. Therefore is it necessary to observe the actions by the participants during the conceptual design tasks. By this point in the research various observation methods and tools had been used (Savanovic 2009). Essentially, what was needed was a categorisation based only on functions/design aspects and solutions. Indeed, these are the things that participants needed to make explicit during the workshops. The idea appealed that the proposed design tool to structure these elements might just as well be used as a research tool to categorize them. Another advantage of using this tool is that it removes the need for live observation, which in early workshop set-ups had received consistently negative feedback from the participants and had also not yielded desirable results. For the sake of clarity, the tool in question is a morphological overview.

Here only a brief selection of all the results is given. The focus here is on the comparison of setting 1 session 2 (traditional building design setting) with that of setting 2 session 2 (where all disciplines work with the same information) and setting 4 (integral design setting with support of the morphological overview as design tool). As an example only the process steps of one design team (group 1) is presented, as the process went similar for the other groups.

The compilation of the design team was such that only the architect was part of group 1 in all settings, the other members changed each time. More information and results are presented in Savanovic (2009).

TABLE 13: Final two-day BNA-ONRI workshop. Workshop configuration February 2008, 5 teams.

Duration	Two days
Design sessions	4
Duration design sessions	2 x 2 x 120 minutes (total 480 minutes)
Design task	Day 1 ‘parasite’ & ‘office’; Day 2 ‘renovation’ & ‘school’
Number of participants	19 in total, (day 1 – 18, day 2 – 16) 14 same for all four tasks
Architects	5
Building physics con.	4
Building services con.	7
Structural engineers	3
Observations by	Questionnaires, photographs, videos, all produced material collected

1st Design setting, ‘parasite’ design task

In design session I: only architects, working individually - five architects. In design session II: team setting - five design teams. In design setting 1 each team was given the same design task: to design a ‘parasite’ structure to be placed on the building that the workshop was taking place in. For full description of the design task see Savanovic (2009). All teams proceeded with the task in the same way. Initially, in the first design session, which lasted approximately thirty minutes, the architect worked alone on the design. Basically, this was done to mirror the status quo in which the architect is responsible for the original design, which is then presented to engineering disciplines. Following this, the other engineering disciplines of the design team joined the architect in order to discuss the proposed design. In this sense, the design team members of the engineering disciplines adopted the reactive role that is the norm in the status quo, and gave their reactions to different aspect of the design proposal. On the basis of these reactions the architect made adjustments to his original design. These adjustments led to improvements of the design.

In order to demonstrate what occurred in design setting 1, the work and analysis of one team is presented below, while the work of the other four teams can be found in Savanovic (2009). After the initial design session I, in which the architect worked alone, all team members met in design session II, to discuss the design. Here, the architect led the discussion. He did so by first explaining the considerations he took into account while working on his design. Through analysis of the session, these considerations were recorded in the Table 14 below. The analysis of each team's work proceeded as follows:

- First, the architect's explanation of the initial proposal at the beginning of second design session is translated into a table of aspects and sub-solutions.
- This resulting sequential list is then structured in the architect's morphological chart.
- Then, on the basis of a review of the videotaped session, a table of aspects and sub-solutions considered by the design team is structured in the design team's morphological overview.

Design team 1 consisted of: architect (A), building physics consultant (BP), building services consultant (BS), and structural engineer (SE) (four members from four disciplines).

TABLE 14: Aspects and (sub) solutions as explained by architect 1 to design team 1 (session II)

Time (design session II)	Who	Aspect or sub-solution	Description	Text/sketch or verbally
00h04min	A	Aspect (1)	Form	Text (session I)
00h04min	A	Aspect (2)	Materialisation	Text (session I)
00h04min	A	Sub-solution (1-1, 2-1)	Contrasting to the existing building	Text (session I)
00h04min	A	Sub-solution (2-2, 3-1)	Wood	Text (session I)
00h05min	A	Sub-solution (2-3)	Open structure	Text (session I)
00h05min	A	Aspect (3)	Sustainability	Text (session I)
00h05min	A	Sub-solution (4-1)	On (the existing building)	Text (session I)
00h05min	A	Sub-solution (4-2)	Against (the existing building)	Text (session I)
00h05min	A	Sub-solution (4-3)	Loose (from to the existing building)	Text (session I)
00h06min	A	Sub-solution (4-4)	In the middle (of existing building)	Text (session I)
00h06min	A	Solution!	'Roof' on the existing roof…	Sketch (session I)
00h09min	A	Solution!	Loose, vertical spiral addition…	Sketch (session I)

In order to allow comparison between different design teams and settings, these tables were reconfigured into the form of morphological overviews. The analytically derived morphological overview of team 1 is presented in Figure 63. The aspects/functions and sub-solutions originally brought to the table by the architect can be found as {A} in Figure 63. After the discussion with the designer of other disciplines the team decided to work on different functions leading to the morphological overview of Figure 64, which represents the final result of the design session.

Design aspects/functions	Sub-solutions			
(1) Form {A}	(1-1) Contrasting {A}			
(2) Materialisation {A}	(2-1) Contrasting {A}	(2-2) Wood {A}	(2-3) Open structure {A}	
(3) Sustainability {A}	(3-1) Wood {A}			
(4) (Positioning)	(4-1) On {A}	(4-2) Against {A}	(4-3) Loose {A}	(4-4) In the middle {A}

Figure 63: Architect’s morphological chart.

Design aspects/functions	Sub-solutions			
(3) Sustainability{A}	(3-1) Wood {A}	(3-2) Heat pump {BP}	(3-3) Natural ventilation {BP}	(4-1-4) V-shaped columns {A/SE}
(4-1) On (positioning)	(4-1-1) 90° over the ex. building, on own legs {BP}	(4-1-2) 35-meter beams {SE}	(4-1-3) In line and partly over the ex. Building {BP}	
(5) Demountable {SE}	(5-1) flexible, prefab system {SE}	(5-2) plug-n-play building services {Team}		
(6) (Entrance)	(6-1) Independent {A}	(6-2) Extend existing entrance {A}		
(7) Flexibility {BS}	(7-1) Theatre at the end {A}	(7-2) entrance on west side {BP}		
(8) Orientation, sun {BP}	(8-1) roof wider than floor {A}			

Figure 64: Design team’s morphological overview.

2nd Design setting, ‘zero energy office’ design task

In design session I all disciplines worked separately (five architects, three building physics consultants, seven building services consultants, and three structural engineers). In design session II there were five design teams. The analysis of the second design sessions of the second workshop design setting is presented as follows: based on videotaped design team activities, a table of aspects and sub-solutions considered by design teams during session II is structured into the design team’s morphological overview.

The goal of setting two was to make minimal changes to the status quo and measure the effect on the design process and the final product. To reach this goal at the beginning of the design process in design session 1 all disciplines were asked to respond to the design brief, as opposed to only the architect in the previous setting. In practice the participants worked together with members of the other teams from the same discipline. In effect, this led to the creation of four mono-disciplinary teams. All of these teams ended up with one finished product. The individual disciplines took this product back to the multidisciplinary team. These discipline-based responses were then brought to a team discussion in design session two. How much of this product was used in the multidisciplinary team and in what way was down to the representative of each discipline.

The logic for following this procedure was to see if asking all disciplines to work on the task from the outset had any effect on the amount of aspects/functions and sub-solutions that were generated by design teams during design session II. The analysis of the team work in design session II is shown in Figure 65.

Design team 1 consisted of: A, BP and BS: three members from three disciplines.

Design aspects/functions	Sub-solutions			
(1) Keep sun out {A}	(1-1) Trees {BP}	(1-2) Overhangs with PV panel{BS}	(1-3) reflective glazing{BP}	
(2) Light {BP}	(2-1) High-frequency lighting {BP}	(2-2) Solar tubes {A}		
(3) Heating {BS}	(3-1) office to storehouse {BP}	(3-2) TES {BP}	(3-3) sedum roof {BS}	
(4) (cooling)	(4-1) Adiabatic cooling {BS}	(4-2) Night ventilation {BS}	(4-3) air intake underground {A}	(4-4) In the middle {A}
(5) Electricity {A}	(5-1) Wind turbin{BS}			

Figure 65: Design team 1 morphological chart.

In order to determine the effect of the set-up of setting two it must be compared to setting one. The main point of interest is to assess whether requiring individual disciplines to consider the task from the outset had any effect on the number of sub-solutions generated when the individuals came together as a multi-disciplinary team. The comparison is presented below: Table 15 contains the aspects and sub-solutions generated by each individual team in setting I; Table 16 contains the aspects and sub-solutions from each individual team in setting II.

TABLE 15: Aspects addressed and (sub) solutions produced by design teams (setting I)

	Team 1	Team 2	Team 3	Team 4	Team 5	Average
No. of aspects	5	7	2	5	7	5.2
No. of sub-solutions	13	16	12	16	17	14.8

TABLE 16: Aspects addressed and (sub) solutions produced by design teams (setting II)

	Team 1	Team 2	Team 3	Team 4	Team 5	Average
No. of aspects	5	2	3	3	3	3.2
No. of sub-solutions	13	5	7	8	7	8.0

As can be seen from the table, contrary to what one might have expected, the intervention of introducing other disciplines into the design process from the outset did not result in the generation of a greater number of aspects and sub-solutions. On the contrary, in setting two fewer aspects and sub-solutions were generated than in setting 1, which was meant to represent the status quo.

3rd Design setting, 'renovation' design task

The team setting for both design sessions were five design teams. Design setting 3 represented a learning-by-doing opportunity for the individual disciplines and the design teams. The ideal outcome would be that each team could clearly demonstrate successful use of the design tools during the design process. However, as a key part of learning is feedback, after the teams completed tasks set in setting 3, time was given to compare and appraise the teams' work and to answer any questions that arose. The results of this learning session are discussed in Savanovic (2009) but are not relevant in the context of this article.

4th Design setting, 'school' design task

Design setting 4 represents the very last stage in the cycle of research in this research project. All of the individual interventions that were used in the earlier research stages are combined so that in setting 4 the ID-method can be tested. To be explicit, is the elements that have been combined are: design team, design model, design tool and design setting. The analysis of the fourth workshop design setting, in which five design teams participated, is presented as follows: based on videotaped design team activities, a table of aspects and sub-solutions considered by design is structured into the design team's morphological overview. Design team 1 consisted of: A, BS, SE: 3 members from 3 disciplines). In this setting, all of the design teams' proposed sub-solutions were recorded directly on morphological overviews; see Figure 66.

Design aspects/ functions	Sub-solutions					
(1) Sustainability {Team}	(1-1) 'green' façade {A}	(1-2) PV/T shadings {BS}	(1-3) 'buffering' for humidity {A}	(1-4) roof garden {BS/A}		
(2) child-friendly, healthy {Team}	(2-1) Scale, identity {A}	(2-2) natural materials {BS/A}	(2-3) structure, protection {A}	(2-4) open façade, windows {A}		
(3) Natural ventilation {Team}	(3-1) HOLCOM ventilation {BS}	(3-2) higher classrooms {BS}	(3-3) walls for ventilation {BS}	(3-4) building orientation {BS}		
(4) Energy sustainability {Team}	(4-1) photo-voltaic thermal	(4-2) adiabatic cooling {Brief}	(4-3) air-inlet via underground {BS}	(4-4) CHP for winter {BS}	(4-5) floor heating {A/BS}	(4-6) sprinkler comb. cooling {A}
(5) Flexibility {Team}	(5-1) Columns {SE}	(5-2) Walls {SE}	(5-3) C/W Combination {Team}	(5-4) System plafond {A}	(5-5) 'Clear' plafond {A}	(5-6) HOLCOM floor {A}

Figure 66: Design team 1 morphological overview (design setting 4).

To conclude this section comparison is made between settings 1 and 4, and the research questions that were stated for setting 4 are answered. Table 17 contains information on the number of aspects and sub-solutions generated by the teams in the setting four. The tables clearly show that, as expected, more aspects and sub-solutions were generated in setting 4 than in any previous setting 1 and 2.

TABLE 17: Aspects addressed and (sub) solutions produced by design teams (setting IV)

	Team 1	Team 2	Team 3	Team 4	Team 5	Average
No. of aspects	5	11	11	5	10	8.4
No. of sub-solutions	24	26	39	20	46	31.0

Analysis II: integral design concepts

Morphological charts and overviews can be used to generate, define and record design aspects/functions and sub-solutions. Within the ID approach, after the first step of generating discipline specific morphological charts and discussing the results as a team, the individual charts are combined into one morphological overview containing all of the useful sub-solutions from the individual team members. The next step is for the team to take the knowledge and ideas from the overview and translate them into a proposed design solution, see Figure 67.

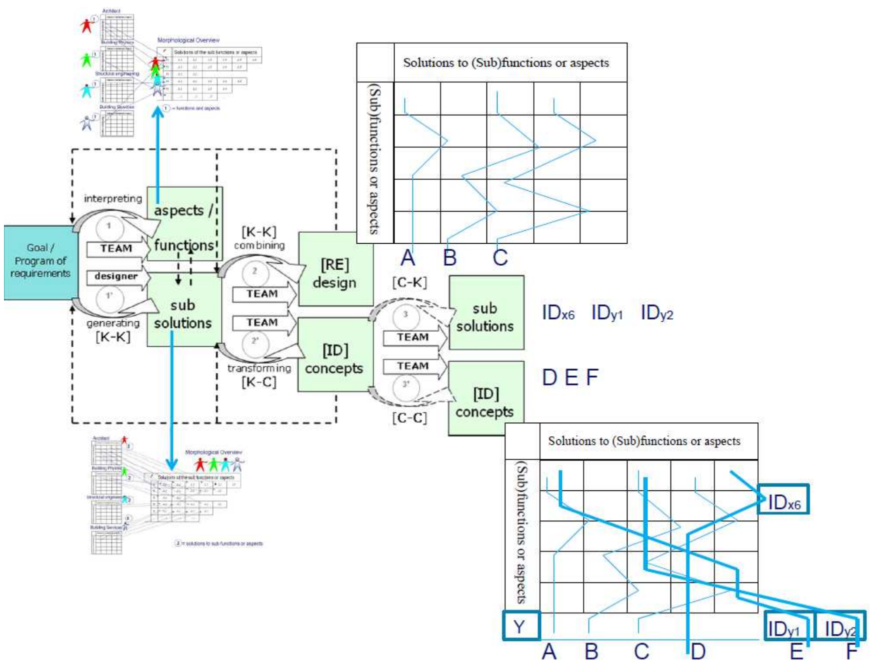

Figure 67: The ID-method steps according to the C-K theory operators.

This step can take two forms: either the design team combining sub-solutions into RE-designs or the design team transforming object-design-knowledge into ID-concepts.

The Integral Design model combined with the C-K theory forces the focus on the distinction between redesign (K-K transformation leading to RE) and integral design concept generation (K-C transformations leading to ID-concepts). The elements IDx6, IDy1 and IDy2 represent conceptual sub-solutions as a result of the concept generation K-C, see Figure 67. This distinction is crucial since, we firmly believe, that the development of new concepts is essential if we would like to generate creative solutions to the highly complex contemporary design problems that our societies face. In this research the main area of interest lies in the conceptual phase of the design process. Here, the focus is on K-K and K-C relations. Nonetheless, C-K theory also offers value in subsequent building design stages, where it can be used to focus on C-C and C-K relations. In essence, in the current research ID-concepts are seen as essential for the creation of new, innovative building designs, which increase the possibility to ultimately realise sustainable building solutions. Perhaps more importantly, ID-concepts represent the potential for the definition of new object design knowledge, which can then be exploited to solve future design problems.

Result I

The use of the design tools and the team approach confirmed that the goal was realised. The comparison of design setting 1 and 2 presents the effect of introducing all the different designers from the start without using support. This led to a decrease of the number of aspects and sub-solutions, indicating a less effective design process.

From the analysis of the workshops it could be concluded that the solution space, resulting from the number of functions and aspects considered, was significantly increased by applying the morphological overviews. A good example of this increase can be seen from the results from session 1 (without morphological charts and morphological overview) compared with the results of session 4 (with use of morphological charts and morphological overview). The increase of the number of considered functions and aspects leads to a larger number of partial solutions, which implies an increased problem-solution space, defined as the number of aspects times the number of solutions, see Figure 68.

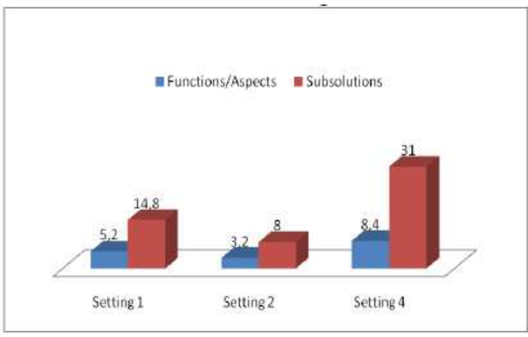

Figure 68: Comparison of the number of aspects/functions and the number of partial solutions being generated by the design teams in design session 1 & 4 and as an overall indication the 'problem-solution' area.

Result II

The results of analyzing the transformation of initial design knowledge into design concepts with the help of morphological charts and morphological overview showed that the Integral Design method did prove successful in facilitating the inclusion of engineering knowledge from the outset of the conceptual design phase. This in itself rendered the design process more efficient as it removed an unnecessary iteration, that is, the architect beginning the design task on his own before receiving input from engineering disciplines. However, what the disciplines within design teams ended up doing in many instances amounted to no more than seeking to fit solutions to design tasks. In essence, the design teams' approaches could best be categorised as 'integrated' rather than the desired 'integral' design, leading to redesigns (RE) rather than the desired integral design concepts (IDC). This research therefore cannot claim to have realised the aim of using the ID-method to arrive at integral design concepts. Nonetheless, the Integral Design method is a helpful method with the morphological charts and morphological overview to focus on the creation of integral design concepts as the result of K-C transformations.

Discussion and further research

The morphological charts can also be used in conjunction with other design tools such as 6-3-5, brain writing, reverse engineering and redesign method (Bohm et al. 2008). Morphological charts are essentially tools for information processing, and as such they are not confined to technical problems but can also be used in other fields, for example in the development of management systems (Pahl, Beitz et al., 2006).

By facilitating combinations of sub-solutions the classic technique of applying morphological charts leads to an increased number of overall solutions compared to other tools. In addition the use of the morphological overview leads to an increased number of functions and aspects generated from the different disciples and listed in their individual morphological charts, each with their own related sub-solutions. Thus, this design tool, the morphological overview leads to an increase of the problem space as well as the solution space, which logically results in a larger number of possible sub-solutions.

Research has shown that a highly promising way to get different disciplines truly working together is in a face-to-face setting (Abadi 2005, Emmitt and Gorse, 2007). Our experiences through the workshops and the feedback from the participants confirmed this. In addition, creating a workshop environment allowed professionals to work openly and freely, without the burdens that a laboratory setting would bring with it.

The reason that there was no creation of IDC during the design sessions of the four design settings during the final workshops series might be caused due to time limitations, the lack of an authentic design task, artificial surroundings or to a fixation on the morphological overview as such. As we preformed test with different time frames we think this is not the main reason. As we took design tasks from practice in a setting as near to practice as possible we also think that the authenticity of the design task and the artificial surroundings may well not be main reasons. We argue that the main reason might be that the present culture of thinking within the disciplines still needs further change. After all, the engineering disciplines seemed content to simply fit sub-solution based on previous experience. How to stimulate the design team to expand the morphological overview is an important aspect for further research. In the next stage of the research the use of so called C-constructs will be investigated to stimulate the creation of new concepts. These C-constructs, sometimes called C-projectors, are used by Hatchuel and Weil in their KCP (Knowledge-Concepts-Proposition) workshops (Hatchuel et al., 2009) to stimulate the forcing of concepts. The KCP workshops were held in different companies in France and more recently in Volvo in Sweden (Elmquist en Segrestin, 2008, 2009). The use of C-constructs could lead to increased effectiveness of the Integral Design workshop approach and especially to an increase of the solution space by stimulation the transformations of K-C and C-K.

Conclusions

The goal of our design research program is to link product and building design by developing a supportive collaboration methodology, as a framework for integral design derived from customer demands and wishes. This methodology allows designers/engineers to collectively (re)design products/systems, employing decision support models and a dedicated workflow process, in relationship to the requirements from the building principal. The potential of this methodological framework was tested in workshops with architects and engineers. It proved useful for the generation and structuring of knowledge, however it needs to be extended with additional elements to be able to stimulate the transformation of knowledge to concepts.

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THE DEATH OF THE ARCHITECT

The need for integral design teams in the generation of concepts for a sustainable built environment

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Word cloud of this chapter, created with http://www.wordle.net

Introduction

The position that this paper takes is as follows: In order to provide adequate design solutions to the highly complex present and future problems in the built environment, the traditional approach to building design need to be overthrown in favor of new, “Integral” design approaches. The paper begins by describing the traditional approach to design for the built environment, in which the architect dominates proceedings, and demonstrating its failings by referring to recent data regarding the inefficient use of energy within the building environment. The paper moves forward by presenting a useful alternative to the traditional approach to design, the Integral Design approach, as described in (Savanovic 2009), in which multidisciplinary team of designers replace the dominance of the architect. The paper then discusses future research directions and applications of the integral Design approach before ending with a short conclusion.

The traditional approach to design and its effect on the built environment

Within the traditional approach, the design process begins when a client expresses the need for a new building. At this stage the requirements are rather general and need to be further worked out and translated into an adequate design solution by the end of the design process. Nonetheless, the design process for real, so to speak, begins with the client handing over this generic and ill-defined list of requirements to an architect. After discussion of these elements with the client, the architect proceeds to develop an initial concept for the design. It is not until after this concept has been developed and sketched on paper that other disciplines are invited to enter the process. These disciplines, largely understood as engineering disciplines, are essentially brought into the design process in order to optimize the proposed solution of the architect.

Literature addressing the traditional approach raises many concerns about its efficacy. One clear point from the literature is that as the complexity of design tasks increase due to the need to integrate complex technologies in order to achieve better performance for our buildings, the usefulness of traditional design approaches decreases (van Aken 2005).

Research from within The Netherlands has shown that at present the approaches used to integrate complex HVAC (Heating, Ventilation & Air-conditioning) components to achieve comfort and sustainability requirements are inadequate. Late integration of these components led to non-optimal designs in some cases and to rejections of designs in others (Boerstra et al., 2006).

Frustration with the current process has led to many calls for further cooperation between building disciplines (Friedl 2000, Wichers, Heeth and Fleuren 2001, Cross, Christiaans and Dorst 1996). The urgency of these calls can be understood by looking at current figures on energy use of the built environment and at the targets set for improvement of these figures.

Many factors influence the sustainability of the built environment, however, man-made climate change and the measures that are needed to counteract such change seem to be by far the main problems of our time (IPCC 2007). To understand the impact of building design on the environment, recent research has shown that 40% of the total energy output of The Netherlands is consumed by the built environment, and this figure rises to 70% when social services such as healthcare are included (Uitdenbogerd 2007). The scale of change required for energy use in the built environment becomes clear when the European 2020 targets are considered. Three of the key targets here are: 1: at least 20% of energy used in the EU will come from renewable sources by 2020; 2: at least 10% of the fuels used in transport will be biofuels by 2020; 3: EU emissions will be reduced to 20% below 1990 levels by 2020.

Reaching these goals, many now agree, will only be possible by generating innovative new concepts that allow better integration and performance of components and systems. The growing complexity of such systems and components and the huge challenges associated with successfully integrating them into the built environment logically dictate that building design can no longer be centered around one discipline, architecture: Rather, what is required are team based approaches that integrate the knowledge of the various disciplines involved in the realization of building concepts. For more than five years, Zeiler, Quanjel and Savanovic have worked on such an Integral Design approach at the TU/e.

The Integral Design approach

The Integral Design (ID) approach began with the work of Zeiler and Quanjel in the year 2000 and was motivated by the failure costs that were seen to arise from the knowledge gaps resulting from poor interdisciplinary cooperation in the early phases of the construction design process. Essentially, this early work on the ID approach aimed to engender and study interdisciplinary team design in the way it was envisaged by Le Corbusier as far back as 1960. The ID approach sought to integrate and synthesize the different cultural perspectives of the architect and the engineer in the conceptual design phase by arranging workshops in which Integral Design teams worked on the design task together from the outset. This first, general, investigation was considered so successful that Quanjel and Zeiler went on to apply and further refine the approach in a specific research project aiming to integrate sustainable technologies into roofs. This integration proved to be a problem because within the traditional approach a concept for the roof generally preceded consideration of the components to be integrated. In essence, the integration of the components amounted to add-on solutions in an attempt to optimize existing designs. This process often led to components being rejected due to the complexity of integration, which resulted in lost opportunities to reduce energy use. Alternatively, those integrations that did take place often resulted in unforeseen problems and failures such as leakage or condensation, which effectively represented energy waste. The latest results of this work are reported in (Quanjel and Zeiler 2009). The most developed description of the ID method, however, can be found in Savanovic (2009), a recently completed thesis on the ID approach in the context of a sustainable environment. The ID method as described here exploits the morphological tools from earlier approaches, but the design model used, based on (Kroonenberg 1974), the integration of C-K Theory (Hatchuel and Weil, 2009) to distinguish ‘Knowledge’ (K) from ‘Concepts’ (C) and the amount of data yielded within the research represent a well developed formulation of the approach and a sound basis for future research. The approach is described in brief below.

The Integral design approach sought to remedy the problems noted above by achieving two main objectives:

- Including all of the required disciplines from the outset of the design process.
- Providing tools to structure the knowledge of these disciplines in a systematic and exploitable manner.

The first objective required the identification of the core disciplines needed to complete a design task for the built environment. These core disciplines were concluded to be, in addition to architecture, Structural Engineering, Building Physics and Buildings Systems. To achieve the second objective, the ID method sought to adapt tools primarily associated with engineering disciplines but which were also usable for architects. Zwicky's morphological box (Zwicky 1948) was chosen as a starting point. In the Id approach the morphological box is present in the form of a Morphological Chart, which is used by each team member to structure their individual discipline knowledge relating to the task. The ID approach has also developed the Morphological Overview, which is used to combine the knowledge contained in the individual morphological charts. This combinatory step is done on the basis of discussion with the entire ID team, ensuring a clear and shared picture of the design problem under consideration. Figure 69 illustrates the use of the morphological tools within the ID approach.

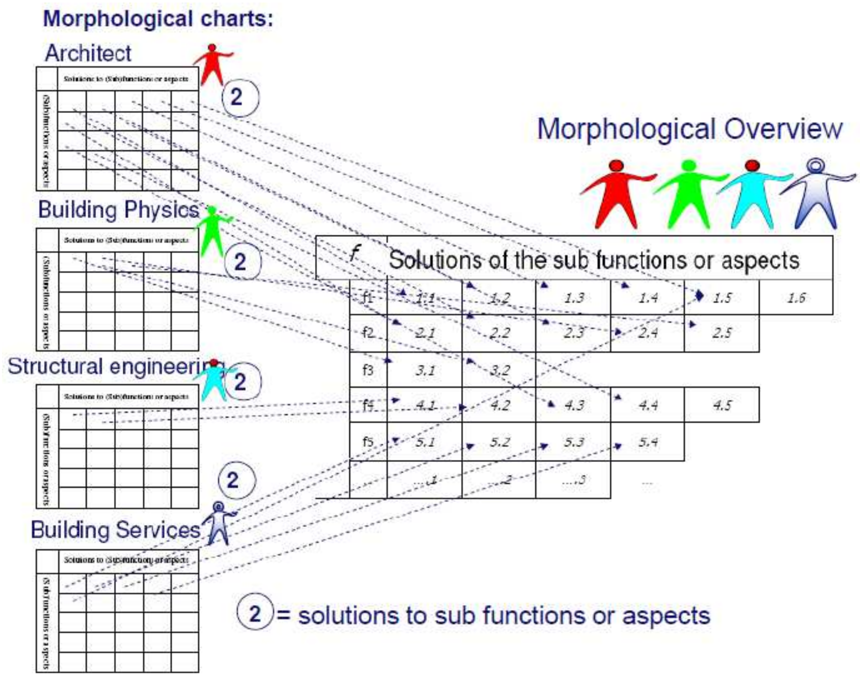

Figure 69: Morphological tools as used by ID teams.

Savanovic (2009) demonstrated two key benefits from the use of the morphological tools. First, all of the individual disciplines effectively contributed to shaping the problem and solution spaces by suggesting sub-solutions from their own perspective. Second, due to the increased number of sub-solutions generated, there is an exponential increase in the number of possible combinations of solutions available to the team. What was not found, however, was that the teams sought or managed to use the knowledge in front of them to arrive at innovative concepts. It appears that they attempted to find solutions to the design problem by thinking of combinations of solutions that had worked for them in the past. Effectively, in terms of C-K theory, this meant that the teams did not use the knowledge to extensively explore the problem space in order to identify opportunities for invention, rather the knowledge was brought to bear on the solution space in order to provide quick, and minimal solutions to the problem. The research did note that this may have been a result of the non-authentic setting of the research and suggested ways to drive concept generation in future research.

Future research directions and applications of the integral Design approach

Recent research has highlighted the need to further investigate communication (Dong 2007, 2009) argumentation (Stumpf and McDonnell, 2002) and reasoning strategies (Dorst and Royakkers, 2006) within multidisciplinary teams in order to develop protocols to steer the teams towards more desirable outcomes. How each of these aspects relates to ID teams will be discussed in brief below.

Communication between members of an ID team is primarily task based, i.e. it is geared to understanding and working on the task at hand. Although the task at hand requires the knowledge of all of the disciplines involved, since the design task can be understood as an ill-structured or “wicked” problem, there is no defined or fixed procedure to integrate or combine this knowledge. Rather, this comes down to a process of negotiation within the team. In such a process of negotiation, it is important to ensure that all parties have an equal and meaningful voice. Methods to investigate power relations within the group include protocol analysis and politeness theory (Brown and Levinson, 1987)

An ID approach is particularly interesting from both a design and an argumentation perspective because it instantiates argumentative episodes, which are a valuable source of data. Argumentation analysis could be used not only to triangulate the findings of a politeness analysis; it could also provide answers to questions such as:

- Where exactly do argumentative episodes appear within the process?
- How is the forwarding of standpoints distributed throughout the team?
- How is doubt expressed towards standpoints?
- Are disputes resolved according to normative standards of argumentation?
- What argumentative schemes and structures are used to support standpoints?

The answers to these questions will allow the development of communication and argumentation protocols with an ID approach or other approaches that rely on integrated teams. Due to its analytic tools and normative guidelines, the Pragma-dialectical theory of argumentation could be very useful here (van Eemeren and Grootendorst, 1984).

Some of the results from the argumentation analysis, particularly relating to structures and schemes, may well complement research into modes of reasoning within the group. As recently noted, professionals who have used the ID approach tended towards combining knowledge into workable solutions based on previously known solutions. They did not manage to transform the knowledge into the creative concepts that were desired. Providing a clear picture of the modes of reasoning at play would allow the design of interventions to help force the team to develop creative concepts.

Results in any of the above areas would be of particular interest to the ID approach, but would also be relevant to other fields of research including design, group theory and various fields of communication. A number of these results can be pursued thanks to the considerable data yielded by the extended research of Savanocic (2009), but to increase confidence in any of the findings, future research must also be done with design teams in real practice. A key objective of the current research is to apply the ID approach on an authentic task with a real design team. This would allow observation of real phenomena as they occur in practice. These phenomena can be discovered through careful analysis of the gathered data via the methods described above. Once understood, it is possible to conceive of further interventions that would improve the status quo. Of course, the ultimate goal of this research is to integrate new interventions into the existing ID method/approach.

Conclusion

Producing the next generation of energy efficient buildings requires the careful integration and management of highly complex building components and systems from a variety of disciplines. Building design then has now reached the point where it is simply too complex an endeavour for a single designer or even design discipline. However, current building design practice has retained a traditional approach in which the design process is restricted by the dominant role of the architect. The Integral Design approach has demonstrated that the systematic inclusion and structuring of team knowledge leads to a significant increase in the possible sub-solutions. The next challenge for the ID approach is to better understand how the team may use this knowledge to arrive at the creative concepts that are required to solve the wicked problems in the built environment.

DESIGN SYSTEMIZATION

Adjusting and developing a process model for a complex architectural design

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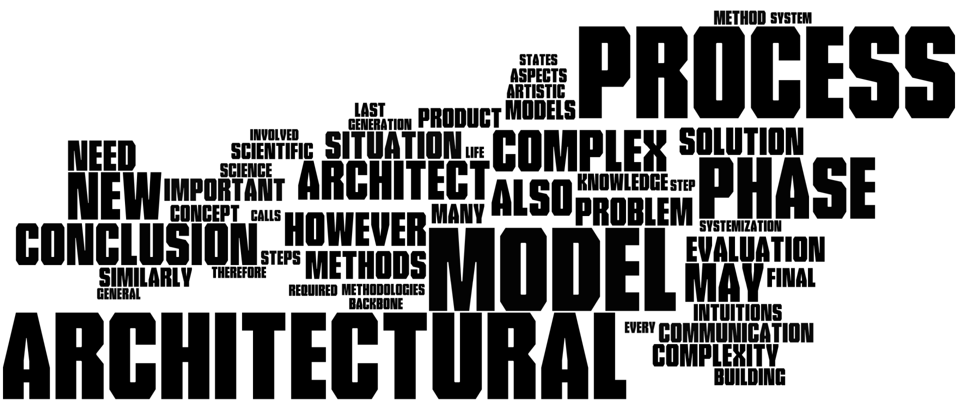

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Introduction and argumentation

Most building related problems (e.g. social, environmental, and economic), such as cases of huge collapse and fatalities in earthquakes, and consequent evacuation of desert habitats, derive from design inappropriateness. This may be relating to the lack of information and knowledge prior to the actual design, design methods, or design concepts. Theories are strong supports for objectivity and rationality of design procedures (Bunge, 1967). Methodologies that include systematic design processes and cover objective methods are prominent for a generic design. Regarding the required appropriate design method, Van Doesburg (1923) also states "*in order to construct a new object we need a method, that is to say an objective system.*" For such methodologies rationalization, integration, and systemization, rather than limiting the freedom of design, are important theoretical bases. Design can be founded on scientific principles, analogous to structural laws in theoretical physics and biology (Salingaros, 2007). Theories are important as they form the core of sciences (Bunge, 1967).

On the other hand, it has very often been observed that theories specially for building design have been avoided or not established. According to Krabbendam (2001) "*architects are not used to theories that can be tested and discussed, they may be afraid that the design will be limited by the theories.*" "*Many designers continue to prefer to see design as an intuitive, largely visual, and artistic process*" (Punter et al., 1997). Irrespective of this obvious need for structuralization and systemization, many architects generally reject theoretical or scientific supports. Even well-known architects such as Hertzberger (2002) states: "*Inventiveness is an inverse proportion to knowledge and experience. Knowledge and experience keep forcing us back into the old grooves of the old record of meaning.*" However, research shows that organization and planning are very important in architectural and engineering design; but many designers tend to underestimate the potentials of professional design processes (Van Aken, 2005). This leads to the conclusion that without systemization of the design processes the reliability of the interpretations and conclusions is seriously hampered. Besides, organizing and planning these modern design processes significantly differs from traditional approaches (Van Aken, 2005). Modern architectural projects are often multidisciplinary and of large scale. To which involvement of several experts in decision making stage adds extra complexity (Van Loon, 1998): "*as the scale of design processes increases, as well as their knowledge's intensity and organizational complexity, the traditional approaches may no longer suffice.*" When the number of involved elements has become too large, relying on traditional methods becomes insufficient and risky (Van Aken, 2005). Hence, Cross (2008) adds: "*there are also too many errors made with conventional ways of working, which are not very useful where team work is necessary too.*"

Traditionally a product, and particularly a building, followed an evolutionary pattern; every new product was in most aspects similar to the previous one. In modern design products tend to be rather revolutionary than evolutionary, thus, there are no experiences or knowledge from the past to assist designing of such a new product. In architecture this newness of designs and incompleteness of the traditional ways is also occurring. Lots of new functions have been added to the field (e.g. in interior design, cladding and façade…) while new methodologies for construction and design have not been equally established (Kalay, 1997). This unbalance is a clear indication for requirement of new methods, as the old habits would decrease the positive effects of contemporary building design that creates opportunities for the transfer of new technologies and methods.

The idea that science and theories are to the opinion of many architects in conflict with creativity is discussed in several studies (e.g. Cross, 1984, 2001; De Vries, 1993; Jones, 1992; Klassen, 2003). Their main argument is that every design is unique and cannot be seen as a process of problem solving and therefore not be described in methodology. This argument leads to the conclusion that architectural solutions are the result of intuition and visualizations and problems are dealt with likewise. This is very unfortunate for all those people on the planet that have to suffer from inappropriate design solutions.

Objective deduction leads to the viewpoint that architectural design is a complex and sophisticated skill as it is composed of art, science and technique (Sariyildiz, et al., 2003; Achten, 2000; Lawson, 2006; Carrara et al., 1994). These suggestions lead to the idea that the complexity will be further risen by any circumstantial complication that interferes with well known solutions. Such complications might be referred to as design constraints (Shahnoori, 2006), when they interfere with all aspects of design (e.g. use of sources, selection and prioritization). In case there are two or more design constraints interfering with a specific design project the resulted complexity might become too high to reach for any conclusion. This interference could go up to the point that the design utterly and completely fails. There are several models available that describe design processes (e.g. Table 18). However, currently no model provides an accurate support for architectural design in a complex situation that faces constraints. Nevertheless, studies as den Otter (2000) indicates this complexity, but as a side issue. Furthermore, these models sometimes have been categorized in different typologies. For instance, model of Van Aken (2000) is domain independent while model of Bax & Trum (2000) is set according to domain theory.

TABLE 18: Examples of available models for design process by the name of developers (method applied by Tate & Nordlund (Tate & Nordlund, 1996) has also been incorporated)

Proposed process model	
Action-based	Phase-based
Archer	Asimow
Cross	Clausing
Harrsi	French
Jones	Hubka
Kirck	Pahl & Beitz
Marples	Pugh
Wilson	Ullman
Roozenburg & Eekels	VD2221
Leupen et al.	Watts
Buijs	Bax & Trum
van Aken	Ertas

However, because in architectural design the role of intuitive and artistic aspects is generally more intense than in most fields, this aspect needs to be incorporated in models differently to insure architects that their artistic wishes are not neglected. Hence, architectural design (e.g. urban, building and construction design) plays a significant role in human's life, "*designers in this field generate objects or places, which have major impact on the quality of life of many people. Mistakes can cause seriously inconvenience, may well be expensive and can even be dangerous*" (Lawson, 2006). Designers of districts, neighbourhoods and buildings are not only constructing objects, but are contributing to conduct the life of dwellers (Duijvestein, 2005). This substantially differs from other design fields and should therefore be addressed differently in new methods and models.

These two later subjects are important to show that the existing models that do not generate from the direct field of architecture and do not concentrate on extremely complex design situations are not sufficient for such application. Thus new methods that can be developed also based on available methods are crucially required for a demanding situation

Problems in current situation, main requirements for systemization

As a consequence of twentieth century, technology has advanced in a rapid pace during the last decennia. Collins (1965) and Benson (1996) have both indicated that technological development of the last century is comparable to all previous technological developments. Benson specifies that the improvements from 1850-1950 are bigger than those in the previous 2000 years. It can be argued that the improvements after 1950 are bigger than those of the previous 100 years.

Enormous developments in technologies, allowed designers to experiment and innovate, thus consequently the complexities in design grew at a huge pace. The complexity and the newness of the designs initiated the search for new design tools such as graphical computer programs. Because the complexity of products has outgrown the brain capacity of most designers, they immensely trusted in the supporting computers. This resulted in unwanted failures sometimes, such as with the Apollo 13 space module (Ferguson, 1993).

The vernacular architecture changed into more daring and radical architecture, the distance between the builder and the architect has been enlarged. Furthermore the new architectural styles (e.g. Free Form Building) have more innovative design elements than one builder can handle, teams specialist builders are needed to realize the designs. This change in professions of builder and architect might lead to a significant rise of miscommunications or misinterpretations (Van Loon, 1998; Lawson, 2006). The role of architects changed from cooperative craftsman into directing designer. In the more extreme cases the artistic inspiration of the individual architect overgrew other aspects like functionality and human well being. Thus, the buildings gradually lost their human scale and generally became architect and sometimes technology centered. This central position of architect, gives an enormous freedom that seems not to be limited by anything than his intuitions (Lawson, 2006). This unlimitedly acting and intuitions is actually sometimes the starting point of emerging possible mistakes. Although intuition is crucially important for an innovative design (Alexander, 1964; Johnes, 1992; Schon, 1984; Simon, 1977), generalizing it as the 'everything we need' creates a random-wise risky design conclusion. Hence, in addition to high dependency of the succession or failure of the design conclusion on the designer in this method, team work is problematic (Cross, 2008). However, as intuitions are necessary but not sufficient, the design methods can not guarantee a great design conclusion themselves (French, 1999). Therefore, new design methodologies are essential for any architectural design and unavoidable for a complex situation, but need to incorporate intuitions and visionary aspects appropriately within the design processes.

Towards modelling the architectural design

For supporting a design in complex demanding situations, developing a process model is a useful method. This model should be operational and precise, it needs to be concrete enough and specific enough so that it functions practically (Alexander, 1964). However, in the architectural design field a fixed detailed model does not survive (Lawson, 2006).

Therefore, this study develops a process model on the bases that have already been argued by Roozenburg and Eekels (1995), and more directly by Cross (2008). In the model introduced by Cross (2008), assumed as a back-bone model, four key stages are: (i) exploration, (ii) generation, (iii) evaluation, and (iv) communication. In such models iterative returns to earlier stages that are frequently necessary are shown with feedback loops. In the backbone model introduced by Cross (2008), the feedback loop connects the “evaluation” stage (iii) to the “generation” stage (ii). The strength of this concept relies on its potential for generalization and its comprehensiveness. It is also flexible and open to incorporate the artistic freedom of architects, thus can be adjusted to architectural design process for a complex situation, but requires rearrangements. Phases of the resulted new model are arranged according to the numbering in Table 19. However, regarding the nature of architecture, these phases are the steps in which most of related activities are done, but may not be completed; these activities are evolutionary and may be final at the end of the design. Hence, necessary iterative inter-connections of these phases are shown in the conclusion.

TABLE 19: A backbone summary process model for architectural design in a complex situation

Phases	Actions	
1	Need	
2	Exploration	Investigation
		Analysis
		Theoretical synthesis
3	Generation, creating alternative concepts	
4	Evaluation, finalizing alternatives according to the criteria	
5	Optimization, communication and detailing	
6	Conclusion	Design solution
		Knowledge conclusion

Assessment of the phases and steps in the backbone model

Because in Cross’s (2008) model the product, its function, user… may not be stated at the beginning of the design, the process starts with explorations for such items. However, comparing design with science, a scientific research always starts with a problem (Bunge, 1967). Instead, an architectural (scientific) design normally starts with a need (French, 1999). In the science, formulating the problem is essential (Bunge, 1967), while in the design recognition, awareness, and studying the real need (Ertas et al., 1995). This is crucial for a complex design situation, in which because of extreme number of involved items the actual need may become tacit. The problem formulation in an architectural design comes after the need, and the problem may be caused by the ways of acquiring the need or even from the consequences of alternative solutions. In the cases that the need can be named a problem, then the process may start with the problem. Similarly, Archer (1984), Leupen et al. (1997); French, (1999), Erden (2004), and Zeiler (2009), van Aken (2000) start their model with the need. Pahl & Beitz (1984) also start their model with task instead of problem. The general order in an architectural design is shown in Figure 70.

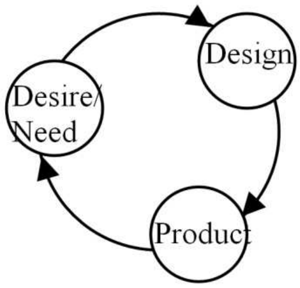

Figure 70: The order of general processes in architectural design.

Although Cross's (2008) model starts with "exploration," content-wise there is no conflict, but, in an architectural design, following the desire/need investigations and explorations in the relevant domains, disciplines, and criteria start (Leupen, et al., 1997). This is essential to ground a strong foundation for a design (Alexander, 1964; French, 1999; Bunge, 1967 but for research). Similarly, investigations and explorations are in the second phase of science. This is also similar to the reflective processes of Schon (1984). Similarly, in a complex situation many things are not clear at the beginning and may be completed at the end of the design. However, in the second phase of the process the crucial, recognizable, and possible exploration can be set; these may be (gradually) completed later.

In the proposed model in this study, similar to Cross (2008), the next phase after the "exploration" is "generation." In generation phase alternative concepts are created. For an architectural design conceptualization is very important as it is the core of the design (Leupen, et al., 1997). Lawson (2006) even calls it 'ability to design,' and Ertas (1995) calls it 'the preliminary design.' Similarly, Roozenburg et al. (1995) calls this phase as 'embodied' design because "*it embodies decisions on the geometry and material of the new product.*" The talented designers are more identified at this step as intuitions are more involved in this phase (Ferguson, 1993). This conceptual stage of any design is concerned with (action) synthesis (Pugh, 1991). If a design process is a solution finding process then the design concept is the phase of introducing the preliminary solutions. In which "*a solution principle is being worked out to the extend that important properties of the product- such as, appearance, operation and use, manufacturing and costs- can be assessed in addition to the technical- physical functioning*" (Roozenburg & Eekels, 1995).

Cross (2008) arranged the "evaluation" phase to be done after the generation. Similarly in a scientific research, after selecting the hypothesis solution for the problem, its value should be tested (Bunge, 1967; March & Smith, 1995). The values that a design is aimed at and the unpredicted values coming from the intuition in the selected concept are tested in the "evaluation" phase. The requirement for evaluation phase in the general design process has been mentioned by a number of studies including Schon (1985), Ferguson (1993), Roozenburg et al. (1995), Buijs (2003); Galavan et al. (2008), Simon (1969), March et al. (1976), Kalay, 1991; Leupen et al. (1997). In the impression of Ferguson (1993) evaluation is the qualitative and quantitative judgment of human for a successful design, and states "*computerized illusions of certainty do not reduce the quantity or the quality of human judgment.*" However, type and frequency of evaluation that differs from one case to another is another relevant issue for the design process. For example, Leupen et al. (1997) calls it testing against requirements for rejection or adjustation that at every step the designer examines the possible consequences for sequent steps and creates margins for solving whatever unforeseen problem may occur. At every step he or she also looks back to see whether the original concept holds or requires modifications. The way of evaluating depends also on the number of the involved items. Similarly, Pugh (1991) states "*depending on the complexity of the project, it is not untypical to carry out five or six evaluations and comparisons in all, before a single concept emerges, which is then carried through to final design, detailing and manufacture.*" The required modification by evaluation, mentioned by Leupen is optimization of the design, locating after the evaluation in this study.

The last phase of Cross's (2008) model is "communication." Although this is not stated in most of architectural design steps, it is also an important phase. However, some designers take it into account, although not directly with this name (e.g. Schon, 1985; Alexander, 1985; Salingaros, 1998). By mentioning "*there is no place in an ideal engineering system for unpredictable actions, either by machines or by people,*" Ferguson (1993) not only involves the importance of the evaluation but also indicates the communication phase. In this way he includes the communication as a part of the evaluation phase. However, after experiencing some failures in designs, many architects evolved a final phase in their design as optimization. Therefore, the communication, the last phase of Cross's model, can be transferred into complex architectural design process model as "Optimization" phase, locating after the evaluation phase. As the language of the conceptualization phase can be for instance drawings, the language for "optimization" (i.e. communication) may be prototyping. This prototyping is detailing and a sampling of the product before the building is made. In either case the communication phase, called "optimization" phase in the complex design process is the final step before the design conclusion. Ending the process model up with the "design conclusion" is referable to the final "solution" in the Archer's (1984) model. Similarly, Roozenburg et al (1995) include a final phase as approved design. Moreover, new knowledge as an indirect conclusion of the whole process is also of final achievements.

Conclusion

According to the arguments in the first and second section, new methodologies for architectural design are required. Transferring methods into the architectural design can be very useful, especially for a complex design situation, but it needs to be adjusted with the nature of architecture. Main issues in such adjusting include flexibility and openness of the design process model, freedom of the architect, importance of intuitions, being value (instead of market or user …) centre. The last issue can be appointed as relevant to the human's life.

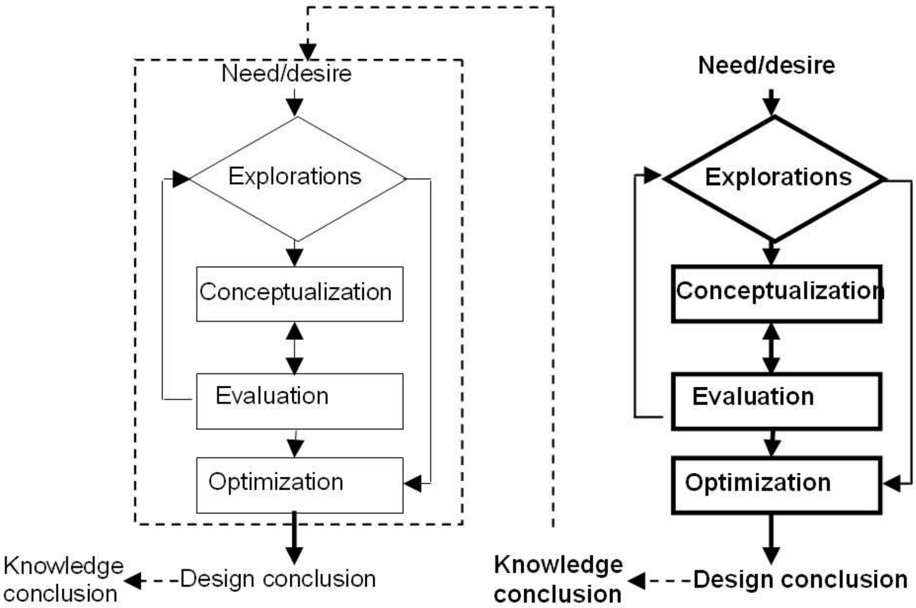

Figure 71: Design process model for a complex demanding situation.

A general summarized model of processes for application in a complex architectural design acts as a backbone to bind other elements. For which the basic steps introduced by Cross (2008) have been adjusted as an initial process model. Figure 71 shows the compositional structure of this system. In this system the approved design is one conclusion, the other conclusion is the deducted new knowledge. From these two, the design concept is mostly a conclusion for local applications. However, in the design with a scientific approach the created knowledge is the conclusion for a global application. Therefore, this design process model for a complex design situation will be called Glocal Process Model (GPM), as a global local model.

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