Improving Design Processes through Structured Reflection: A Domain-independent Approach

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Abstract
This report includes the Ph.D. thesis of Isabelle Reymen, which has been defended at the Technische Universiteit Eindhoven on April 3, 2001. The thesis can be positioned in the field of design research. The goal of the performed research is to decrease the gap between design research and design practice in order to improve design processes. To reach this goal, the development of support for structured reflection on design processes and the development of domain-independent design knowledge is combined in a broad explorative study. Structured reflection on design processes can help designers to improve their design process, its results, and the designer’s proficiency. Domain-independent design knowledge (as distinguished from domain-specific knowledge) is useful to improve design processes in various design disciplines. The Ph.D. thesis describes a domain-independent approach to improve design processes through structured reflection. The results are a design philosophy and a design frame, offering concepts, a vocabulary, and a structure to describe design processes in a domain-independent way, and a design method, being a first proposal of a method that supports structured reflection on design processes. The results are starting points to improve the effectiveness and efficiency of design processes in practice.

Keywords
Design research / design theory ; domain independence / design method ; reflection / design process ; description / multidisciplinary engineering design
Introduction to this report

This first SAI Report includes the Ph.D. thesis of Isabelle M.M.J. Reymen. The work in the thesis has been paid by the Stan Ackermans Institute, Centre for Technological Design and has been carried out under the auspices of the research school IPA (Institute for Programming research and Algorithmics). The Ph.D. thesis is already published under the same title as ISBN 90-386-0831-4, which is also part of the IPA Dissertation Series (2001-4).

The Ph.D. thesis has been approved by the supervisors prof.dr.Dipl.Ing. D.K. Hammer and prof.dr.ir. P. Kroes. The thesis has been made to obtain the degree of doctor at the Technische Universiteit Eindhoven under the authority of Rector Magnificus, prof.dr. M. Rem and for a commission designated by the “College voor Promoties”. It has been defended in public on Tuesday April 3rd 2001 at 16 o’clock by Isabelle Marcelle Marie Jeanne Reymen, born in Elsene, Belgium.

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GLOSSARY

SUMMARY

SAMENVATTING (DUTCH SUMMARY)

CURRICULUM VITAE

SAI REPORTS
To Twan
Preface

After I finished my Master’s thesis at the Department of Architecture, Urban Design, and Planning (ASRO) of the Faculty of Applied Sciences at the Katholieke Universiteit Leuven (KULeuven) in Belgium, prof. Herman Neuckermans, head of the Department of ASRO, told me of the possibility of doing a Ph.D. research at the Technische Universiteit Eindhoven (TU/e) in The Netherlands. He received a vacancy for a Ph.D. position from a colleague professor in Architecture, namely prof. Thijs Bax. At that moment, Thijs Bax was working at the Stan Ackermans Institute (SAI), the Centre for Technological Design at the TU/e. The aim of the Ph.D. project was to compare design processes in several disciplines in order to develop a multidisciplinary framework for design. Because I had already seen the practice of architecture in my father’s office and I had already studied the theoretical side of it at the KULeuven, I was very enthusiastic about looking into other design disciplines.

Instead of first starting a two-year traineeship to become an independent architect and taking over the architect's office of my father, I changed my career plan: I applied for the Ph.D. position and I came to the SAI to do research about designing. The start of my Ph.D. research implied moving from Belgium to The Netherlands. Because research activities were just being set up at the SAI, after a few months, I moved from the SAI to the Department of Computing Science of the Faculty of Mathematics and Computing Science at the TU/e. There, I became a member of the Section Technical Applications (Sectie TT) of prof. Dieter Hammer, the initiator, and first promoter of my Ph.D. project.

I have been feeling very well in the Computing-Science Department and, after a while, although my research topic was not a computing-science one, I even became the representative of the Ph.D. students of computing science in the board of the department and in the AiOOE (AiO consultative body Eindhoven). For a number of years, I also organised, first, with Richard Kelleners and, later on, with Tim Willems, Tao meetings in which Ph.D. students of the department present their work to their colleagues. From the Tao and other meetings, I learned very much and I made a lot of friends. One person of the department, namely Twan Basten, has become very special to me. To him, I dedicate this thesis.

Many people contributed to the development of my Ph.D. thesis. It is impossible to mention them all, but the following persons get my special thanks. First of all, I want to thank Herman Neuckermans for teaching me the principles of design methodology during my study in Leuven and for initiating my interest in design research. I want to thank Thijs Bax and Dieter Hammer for offering me the opportunity to come to Eindhoven. I am also very grateful for all facilities and support I got from the SAI and the Faculty of Mathematics and Computing Science; I especially want to thank the managing director of the SAI, Marloes van Lierop.

Four supervisors, Dieter Hammer, Thijs Bax, Peter Kroes, and Joan van Aken, guided me through the four years of my Ph.D. research in more than fifteen meetings we had together and in many bilateral discussions. I am very thankful for their participation in my research project and for their belief in me. Having four (professors as) supervisors was a privilege, although it was not always that easy.

I am indebted to the junior and expert designers for the input they gave me in the case studies I performed at the beginning of my research project and for their feedback on the results of my research at the end of my project: the junior designers Wilbert Alberts, Chris Arts, Janneke Bierman, Paul de Crom, Sander de Jonge, Douwe de Vries, Raymond Habets, Edwin Hautus, Albert Hofkamp, Marcel Renkens, Nicole Segers; the expert designers Jan Brouwer of XX Architecten, Astrid Dobbelaar of Philips Design, Henk Dolf of Mecano, M. Koster of Philips CFT, Jan Kruithof of Daf, Tinneke Reijbroek of Paper Design, Piet Sanders of TU/e, Bart van den Hoge of Paper Design, Migiel van der Palen of XX Architecten, Wim van der Sanden of Panfox, and Karel Verhulst of Philips Medical Systems.
I also want to thank the people that helped me with the implementation of a prototype software tool: Elisabeth Melby for programming and Jack van Wijk and Huub van de Wetering for their supervision and technical advice.

Important for the development of my results were also the discussions I had with colleagues I met at conferences and at meetings of the Stichting Toekomstbeeld der Techniek (STT) and the Dommelgroup, and the discussions I had with Ph.D. students and staff from the Faculties of Mathematics and Computing Science, Architecture (DDSS Group), Mechanical Engineering, and Technology Management at the TU/e. I especially want to thank the colleagues from Industrial Design at the TU Delft for their constructive criticism of my work and for their confidence in me.

The final realisation of this Ph.D. thesis took place under the supervision of Dieter Hammer, Peter Kroes, Joan van Aken, and Kees Dorst, being the core members of my graduation committee. I like to thank them for their advice and for the time they invested to give comments on several versions of this thesis. I want to thank especially Kees Dorst for his willingness to participate actively in the last phase of the project. I also want to thank Thijs Bax for his many suggestions for improving the thesis. Twan Basten did a great job in correcting my English, helping me with the consistency of the thesis, and suggesting other improvements. Patricia Reymen helped me with the layout of the thesis.

I also want to thank prof. Jan Buijs, prof. Herman Neuckermans, prof. Koos Rooda, prof. Paul Rutten, and dr. Kees van Overveld for being a member of my graduation committee and prof. Jan-Karel Lenstra for being chairman of the committee. At this point, I also already want to thank Ann Heylighen and Patricia Reymen for being my paronymphs on April 3rd.

During my first months in The Netherlands, I was received very well by the SAI, by Corry Kolk and the OOTT's, and by the secretary Marja de Vroome and the other members of Sectie TT. The following people were a great help to me during the past four years: my roommates Paul and Maarten; Richard, Roy, Tim, and many other Ph.D. students; Huub, Michel (x2), Rob, Tineke, and all other (former) members of Sectie TT and the other groups of the department. Important were also other friends I made in The Netherlands, in particular Bram, Miranda, Petra, and ‘de Introgroep’. I also want to thank the archi’s in (far) Belgium for their support, especially Ben and Ann, colleague Ph.D. students in Leuven.

And last but not least, I want to thank the people being close to Twan and me for all the support they gave and for their continuous interest: my parents Marcel Reymen and Gabriëlle Hermans, who also have been giving me a broad education and an example of multidisciplinary thinking and who supported my choice to come to Eindhoven; Patricia and Yves, who have been a real sister and brother to me; Theo and Marga Basten, Eveline and Chiel, and oma Bouten who supported us, also in more difficult times. And finally, Twan, there are so many things you did for me and for which I want to thank you; perhaps I can summarise them as follows: Thanks for all your love!

1 Introduction

In the world of designing, three fields of attention can be recognised, namely design practice, design education, and design research. The ambition of this research project about designing is, on the one hand, to contribute to design research and, on the other hand, to develop support for design practice and design education.

Design processes in practice can be improved by increasing the effectiveness and efficiency of activities in the design process; part of this involves improving communication in multidisciplinary design teams to obtain a better integration and co-ordination of important aspects. Structured reflection on the design process can help designers to improve their design process, its results, and the designer’s proficiency. By reflecting explicitly on the current design situation and on the performed design activities, in a systematic way and on a regular basis, designers can plan suitable next design activities: design activities that are performed effectively and efficiently given the design goal at that moment.

To support designers from several design disciplines, domain-independent design knowledge (as distinguished from domain-specific design knowledge) can be useful. It can help designers to improve communication in multidisciplinary design teams: By using terminology and concepts that are independent of a specific design discipline and that are based on similarities in design processes in different disciplines, team members with different backgrounds can use this terminology and these concepts as a tool to understand each other. (Designers can, for example, use such common terminology and concepts to compare and discuss results of their individual reflection processes.) Domain independence can also improve design processes in a single discipline: The development of domain-independent design knowledge, based on a comparison of design processes in several disciplines, may make implicit concepts of the design process in a certain discipline explicit and may give rise to new views on the traditional design process in that discipline. In addition, concepts used in other disciplines may be translated to a specific discipline.

The goal in this thesis is to develop domain-independent design knowledge for supporting structured reflection on design processes. The research project (described in this thesis in Chapter 2) was set up as a broad explorative study. This study includes empirical research in three design disciplines (software engineering, mechanical engineering, and architecture), the development of some theoretical results, and the development of support for design practice. The results of the research project are a domain-independent design philosophy (Chapter 3), a design frame (Chapter 4), and a design method (Chapter 5). The results are put into a broader perspective in the conclusions and the recommendations for further research (Chapter 6). Appendices A and B illustrate the use of my design method and propose software support for facilitating its use. Appendices C and D describe the approach and results of the empirical research I performed to explore the design practice and to get some feedback from a first confrontation of my results with design practice. At the end of this thesis, a glossary including a definition of the most important concepts of this thesis can be found. An extensive overview of the thesis is given in Section 2.9. A general reader can start with the summary and with Chapter 2 describing my research project. The most interesting chapters for designers are probably the results of my research, described in Chapters 3, 4, and 5, Appendix A and B, and the conclusions. The introduction to Chapter 1 can offer educators and design students an overview of the field of design research and references to the literature. Design researchers might be interested in the whole thesis. The reader should be aware that, because of the explorative nature of this study, the results of the project are only a first step towards the improvement of design processes through structured reflection.

The goal of the first chapter is to offer an introduction and an overview to the reader who is not familiar with the world of designing or with one or more of the specific topics in this thesis; it also offers a framework in which my research about designing can be positioned. Given the goal of my
research project, it is important to discuss literature about domain-independent design knowledge (theories and methods) and literature about reflection on design processes (including support for reflection on design processes). An overview of current research topics and of research methods for doing design research is important to position my research. The presentation of an introduction to the world of designing, and introduction to design research, and an introduction to main characteristics of designing (common in different disciplines) also helps to fulfil the goal of this chapter.

The chapter starts in Section 1.1 with a general introduction to the world of designing. The chapter continues in Section 1.2 with an introduction to design research. The definition and history of the field and disciplines working in this field are mentioned to get an impression of its breadth. Research topics, definitions of different kinds of results, and literature overviews of results in design research offer the reader insight into the basic knowledge of the field, knowledge that is used to develop my results. Two important paradigms that can be recognised and research methodologies that are used in the field give an impression of the choices concerning my research process and its resulting products that I had to make. The chapter goes into more detail in Section 1.3 with a description of characteristics of designing. This overview of characteristics of design tasks, design processes, and designers offers basic knowledge to start from when doing design research. Common characteristics of several disciplines are an essential starting point for the development of my domain-independent design knowledge. Common characteristics of designing can also be recognised in the literature on domain-independent design theories and methods. These theories and methods, summarised in Section 1.4, together with the domain-independent design knowledge I developed, form the basis for the development of support for design practice. The chapter ends in Section 1.5 with a definition of reflection in general and of reflection on design processes.

1.1 The world of designing

Design practice, design education, and design research are the three fields of attention that can be recognised in the world of designing. The current state of the world of designing in The Netherlands and Belgium is presented in [Korbijn (ed.), 1999]. An overview of the current state of the three fields in the entire world, with an emphasis on the U.S.A., can be found in [NSF, 1996].

Design knowledge links the three fields in the world of designing: all three have a relation with design knowledge; design practice applies and generates design knowledge, design education transfers this knowledge, and design research produces this knowledge (together with design practice). Ideal relations between the three fields are the following:
- Design research gets input from design education and practice and develops theories and support for future use in design education and practice;
- design education uses results of research, gets inputs from design practice, delivers good designers for practice, and gives feedback to design research;
- design practice uses support developed in research and taught in education and gives input for design education and design research.

Interaction between the three fields is thus very important (see Figure 1.1).

![Figure 1.1: Interactions between the three fields of attention in the world of designing.](image)
However, these ideal relations cannot be recognised yet in the world of designing: The interaction between the three fields and even interaction within the fields themselves is not yet very strong. Gaps between the different fields can be recognised. The gap between design research and practice is, for example, described in [Norman, 1996], [NSF, 1996], [Dorst, 1997], and [Van Handenhoven, 1999]. Many results of design research are too theoretical to be used in practice; others are too much focussed on specific problems in the current practice and forget to take into account important characteristics of design processes that are already described in the design literature. [De Vries, 1994] gives an overview of researchers who observed this gap in the discipline of architectural design. Also in other design disciplines, these gaps can be recognised. To decrease these gaps, interaction between the various fields must get more attention. My research project aims to decrease the gap between design research and design practice by performing research in close interaction with design practice.

1.2 Design research

This section describes one of the fields in the world of designing, namely design research, in more detail, because this thesis intends to contribute to this field. I made an attempt to offer an overview of the field of design research, mainly by referring to important literature. My structuring of the field is certainly not the only possible one; another division can, for example, be found in [Oxman, 1995].

1.2.1 Definition

Design research is often referred to as design methodology, science of design, or design science. Many definitions of these terms have already been given. Nigel Cross gives a definition of each of these.

Following [Cross, 1984], design methodology includes the study of how designers work and think, the establishment of appropriate structures for the design process, the development and application of new methods, techniques, and procedures, and reflection on the nature and extent of design knowledge and its application to design problems. Following [Roozenburg, 1987], design methodology is the scientific study of methods that are or can be applied to designing. It is thus a more critical and normative activity; design methodology is strictly just a sub-field of the philosophy of design.

Science of design refers to that body of work which attempts to improve our understanding of design through ‘scientific’ (i.e., systematic, reliable) methods of investigation [Cross, 1993].

Design science refers to an explicitly organised, rational, and wholly systematic approach to design; not just the utilisation of scientific knowledge of artefacts, but design in some sense as a scientific activity itself [Cross, 1993].

The two definitions of design methodology differ in the sense that the first one is much broader than the second one. The definitions of design methodology (following Cross) and science of design are similar. The definition of design science deviates from the definition of science of design and design methodology in the sense that not the study of design but design as a scientific activity is meant; however, design science is often used with the meaning of science of design and design methodology. For all these reasons, the whole field of research about designing, as meant in the definition of science of design, is called in this thesis design research.

The position of science of design related to other sciences is not yet clear. Many issues about the science - design relationship, about design research, and about types of (design) knowledge can be found in [De Vries et al. (eds.), 1993] and [Simon, 1970]. [Owen, 1998] compares design research to classical forms of scholarly and scientific research. A discussion on design - science interactions can be found in [Willem, 1990]. The main question in the discussions on the nature of design research in the 1960’s and 1970’s was “What is the distinction between science and design and between research methodology and design methodology?”. Answers to this question express dichotomies between each

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1 Science of design and design science must both be distinguished from scientific design, which refers to modern, industrialised design - as distinct from pre-industrial, craft-oriented design - based on scientific knowledge but utilising a mix of both intuitive and non-intuitive design methods [Cross, 1993].
of these pairs; a possible answer is, for example, that science tries to find out the nature of what exists, whereas design tries to invent things which do not yet exist. Later on, the question “Can design and science be distinguished?” was asked. As a result, the dichotomies have been replaced by discussions on the interaction between science, research, and design.

1.2.2 History

Design research has a history of more than 35 years. An overview of the history of design research can be found in [Cross (ed.), 1984] and [Cross, 1993]. [Hubka et al., 1996] offers a description of the history, split up in different language area’s and countries all over the world. In [Rinderle (ed.), 1990], international perspectives on design theory and methodology are given in four papers (Eastern Europe, Japan, UK and Swiss, and West Germany).

In the light of this thesis, the following evolution in design research is relevant: Design research started in the 1960’s with general theories about design (based on operations research and management decision-making techniques); these theories were meant to be useful in several design disciplines. In the 1970’s, critique was given on these theories: Among others, they failed to be successful in design practice. As a reaction, research concentrated and mainly still concentrates on individual design disciplines. An example of a relatively recent general design theory is described in [Takeda et al., 1990]. An overview of domain-independent design theories and methods that are important in the context of this thesis is given in Section 1.4. As in the 1960’s, my research focuses on general design theory that is useful for several design disciplines; it differs for from earlier design research in the sense that it starts from the design practice in these disciplines and that it has an explicit goal of improving design practice.

1.2.3 Disciplines

Design research is a very broad field of research in which scientists from very different disciplines are involved. Research is being done in typical design disciplines like architecture, industrial design, and mechanical engineering, but also in technical disciplines like software engineering, electrical engineering, and management, in natural sciences, in philosophy, and in social sciences like psychology, pedagogy, and history.

1.2.4 Research topics

In this subsection, a brief overview of research topics\(^2\) in the field of design research is given, based on [Dorst, 1997], [Kroes, 1998], [Love, 2000], [NSF, 1996], [Oxman et al. (eds.), 1995], [Reyment, 1999b], and [De Vries et al. (eds.), 1993]. The field is subdivided according to the kind of studies performed in the field, namely descriptive, prescriptive, and philosophical studies and studies focussed on design education. In the research practice, these separations are not that strict and many combinations are made. I have chosen for the given subdivision because it is most appropriate to position my study, namely as a combination of a descriptive and prescriptive study. Another subdivision of the field can be found in [Behesti, 2000].

Descriptive studies: This kind of research tries to answer the questions “What is design?” and “How do people design?”. The design process as well as the product being designed is subject to research. Design theories describe the cognitive processes of designers, important design skills and attitudes, design activities, the structure and organisation of the design process, and/or the context of designing. Part of the research focuses on different types of products, on the kind of design problems, specifications, and solutions, and on necessary design knowledge.

Prescriptive studies: This type of studies focuses on the questions “How to design?” and “How to support designers?”. Prescriptive studies concentrate on the development and application of strategies, methods, techniques, and tools to use for designing. The aim is to support the organisation and the activities of the design process. The development of different kinds of computer support is an

\(^2\) Note that these kinds of research topics also appear in other sciences.
important topic. Researchers also look at the communication between different stakeholders in a design process and think about how collaboration between designers and disciplines can be organised.

**Philosophical studies:** These studies concentrate on (based on [Kroes, 1998])
- foundational problems (like the different views on technology and the difference between the natural and the artificial);
- epistemological problems (like the nature and extent of design knowledge, the difference between technical and scientific knowledge, the relation between science and technology, and the role of natural sciences in the design process);
- methodological problems (like types of methods, types of problems and constraints, normative implications of used methods);
- ethical problems (like responsibilities of designers).
The technological practice itself is also being studied. To do so, the empirical studies of the former two kinds of studies are taken as a starting point for critical analysis or reflection on this practice, with the goal to achieve conceptual clarification. Philosophy of design focuses also, for example, on the following questions: “What, in general, is design?”, “What are the characteristics of a valid theory of design?”, and “How might a theoretical design concept be tested for coherency with other concepts?”.

**Research focused on design education:** This category focuses on the question “How to teach designing?”. The research concentrates on the contents to teach as well as on the teaching methods. Other topics of research are the role of designing in the education of engineers; designing as a pedagogic aid for the integration of different kinds of knowledge (scientific, technical, marketing-technical, economical, and others); the role of computers in design education; the influence of new technologies like multimedia or international networks on design education; new possibilities for lifelong learning.

Several other topics that do not fit precisely in the above classification are being studied; a few examples are the following: research focusing on the history of designing in which the evolution of a concept, product, or technology over a large period of time is being studied; research on the profession of ‘designer’ by the social sciences; research on a research methodology for design research, answering the question “How to do design research?”; research on the history of design research itself.

### 1.2.5 Research results

The results of design research are design philosophies, theories, methods, strategies, and models. The first two describe how people design and may be called descriptive; the following two include guidelines how to design and may be called prescriptive. Models can be descriptive as well as prescriptive. A definition for each of these kinds of results is given below.

A **design philosophy** is a school of thought expressed by designers and researchers as regards how design is, might be, or should be done [Evbuomwan et al., 1996].

A **design theory** is a collection of concepts, principles, and experientially verified relationships useful for explaining the design process and providing a foundation for the basic understanding required for proposing useful methods (based on [Evbuomwan et al., 1996]).

A **design method** is a set of guidelines that can be followed during the design process in order to arrive at a realisable product (based on [Evbuomwan et al., 1996]); or following [Cross, 1994], a design method is any procedure, technique, aid, or tool for designing. Design methods represent a number of distinct kinds of activities that the designer might use and combine into an overall design process.

A **design strategy** describes the general plan of action for a design project and the sequence of particular activities (i.e., the tactics, or design methods) which the designer or design team expect to take to carry through the plan [Cross, 1994]. To have a strategy is to be aware of where you are going and how you intend to get there [Cross, 1994].

A **design model** is a representation of a philosophy or strategy proposed to show how design is and may be done [Evbuomwan et al., 1996].
1.2.6 Literature overviews

A selective overview of recent English-language publications in design research is given in [Banse, 1999]. (This paper gives also an overview of the conferences and periodicals about designing.) [Evbuomwan et al., 1996] gives a survey of design philosophies, models, methods, and systems. An overview of recent design research in The Netherlands can be found in [Oxman et al. (eds.), 1995] and [Achten et al. (eds.), 2000]. An extensive review of research in mechanical-engineering design is given in [Finger et al., 1989a] and [Finger et al., 1989b]. All results described in these overviews focus on one or more research topics as defined in Section 1.2.4. An overview of domain-independent design theories and methods that are related to the results of my research is given in Section 1.4; this overview is used in Section 6.1 to position my results. Important common characteristics of designing that are described in the literature are mentioned in Section 1.3; these have been the basis for the development of my results. Important research methodologies used in design research for obtaining these results are summarised in Section 1.2.8; this overview gives also more information about the research methodology that I have chosen. In the next subsection, Section 1.2.7, the two paradigms in which these methodologies and results are developed are described.

1.2.7 Two paradigms

In the philosophy of science, two dominant scientific belief systems are distinguished. The traditional view on science within technology and the natural sciences is called positivism. Constructivism emerged in the social sciences in the second half of the previous century. Both paradigms are summarised in [Eide, 1997] (after [Easterby-Smith et al., 1995]) as follows:

“Basic beliefs in the positivist paradigm are that the world is external, the observer is independent, and science is value-free; a researcher should focus on facts, look for fundamental laws, reduce phenomena to elements, and test formulated hypothesis; preferred methods are operationalising, measuring, and taking large samples. Basic beliefs in the constructivist paradigm are that the world is socially constructed, the observer is part of the observed, and science is driven by human interests; a researcher should focus on meanings, try to understand, look at totality, and inductively develop ideas; preferred methods are establishing different views on phenomena and investigating small samples in depth.”

Design research is primarily conducted within the frames of the positivist worldview [Eide, 1997]. However, in the last decade, more research based on the constructivist paradigm was performed. Some discussions on the change of paradigm and proposals for using social-science methodology for studying design are given in [Eide, 1997], [Kennedy, 1997], and [Lloyd et al., 1997].

In [Dorst, 1997], two paradigms for describing design that are based on the two paradigms in the philosophy of science, namely rational problem solving ([Simon, 1970] and [Newell et al., 1972]) and reflective practice [Schön, 1983] are described. Both paradigms are summarised in Table 1.2. They are described in [Dorst, 1997] as follows:

“In the paradigm of rational problem solving, design is seen as a rational search process: The design problem defines the ‘problem space’ that has to be surveyed in search of a ‘satisfying’ design solution. Seeing design as a rational problem-solving process entails adopting a positivist view of science, taking natural sciences like physics as the model for a science of design. There is a strong emphasis on de rigour of design research: ‘Objective’ observation and logical analysis should lead to general, formal models of the design process. Simon quotes ‘hard’ models and methods, as are used in optimisation, as prime examples of what a real science of design could and should be. In the reflective-practice paradigm, design is described as an activity involving reflective practice. This constructivist theory is a reaction to the problem-solving approach, specifically made to address some of the shortcomings that Schön perceived in mainstream design methodology. Schön particularly objects to training programmes for design that are defined in terms of generalities about design processes. He stresses the uniqueness of every design problem, and identifies the core skill of designers as their ability to determine how every single problem should be approached. Schön calls this the essence, ‘the artistry’ of design practice, and finds it unacceptable that this cannot be described in the prevalent analytical framework. To describe the tackling of fundamentally unique
problems, Schön proposes an alternative epistemology of design practice, which describes design as ‘reflective conversation with the situation’. His view on design research is modelled in accordance with the social sciences.”

<table>
<thead>
<tr>
<th>Designer</th>
<th>RATIONAL PROBLEM SOLVING</th>
<th>REFLECTIVE PRACTICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design task</td>
<td>Information processor (in an objective reality)</td>
<td>Person constructing his or her reality</td>
</tr>
<tr>
<td>Design process</td>
<td>Ill-defined, unstructured</td>
<td>Essentially unique</td>
</tr>
<tr>
<td>Design knowledge</td>
<td>Knowledge of design procedures and ‘scientific’ laws</td>
<td>Artistry of design: when to apply which procedure or piece of knowledge</td>
</tr>
<tr>
<td>Example or model</td>
<td>Optimisation theory, the natural sciences</td>
<td>Art, the social sciences</td>
</tr>
</tbody>
</table>

Table 1.2: Two paradigms for describing design (based on [Dorst, 1997]).

In the dual-mode model of design, also elaborated in [Dorst, 1997], Dorst summarises the choice between the two paradigms that researchers that want to study designing have. The choice depends on the kind of design activity they want to study.

### 1.2.8 Research methodologies

In the field of design research, a growing attention for the need to make a research design can be recognised. Possible research strategies depend on the chosen paradigm of science. Some important strategic choices are the following:

- **explorative research** or **research in depth**;
- **empirical research** (based on observation) or **theoretical research** (based on reflection);
- **qualitative research** or **quantitative research**;
- **general or specific** and **concrete or abstract research**.

Fully accepted research methods do not yet exist for design research. A widely used empirical research method in the nineties of the previous century are protocol studies [Dorst, 1995]. An example of a well-known constructivist qualitative research strategy that seems useful for studying designing is ‘grounded theory’ [Eide, 1997]. The latter research method stipulates a systematic set of procedures to develop an inductively derived theory about a phenomenon; a main feature of grounded theory is that it emphasises that the theory should emerge from the collected data.

To define my research methodology, I started from the basic beliefs of the constructivist paradigm. Given my background as an architect, this is the paradigm I have been feeling most pleased with. The constructivist paradigm, and the reflective-practice paradigm in particular, also suits best the goal in this thesis, namely supporting the reflection process of designers. I have chosen for explorative research, for doing qualitative empirical research, and for research aiming to be general and concrete. The choice for this research strategy is motivated in Section 2.6. To explain the research method I followed, a description of the research process I performed is given in Section 2.8. Below, important characteristics of explorative research are described, translated from [De Groot, 1972]. Also, the distinction between qualitative and quantitative research is explained, based on [Kennedy, 1997], and the suggestion in [Tomiyama, 1997] to focus in design research on general and concrete problems is illustrated.

[De Groot, 1972]:

“Explorative research is empirical research that is appropriate when the researcher is, on a relatively broad domain with little useful theory, confronted with an amount of observations or variables for which relatively few relevant facts are known. The researcher is, however, aiming at a certain type of relations, with corresponding ideas and relatively vague expectations. This aim determines which facts will be taken into account, what will be measured, and which kinds of relations will be studied. The goal of this kind of research is mainly not the ordering of facts or the creation of an overview of ‘the existing’, but it aims at establishing relations that are
considered to be relevant for a certain theoretical or practical goal. The researcher starts from certain expectations, from a more or less theoretical frame: He is trying to find relations in the material, but these are not defined by him in advance in the form of sharp hypotheses that can be tested; these hypotheses can thus also not yet be tested as such. Exact theory and/or hypothesis forming and testing must follow explorative research.”

I have chosen for a practical goal, namely developing support that can improve design processes in practice; I have been aiming to support designers with structured reflection.

[Kennedy, 1997]:
“For a social scientist, quantitative research is about testing theories3; research questions are defined at the outset of the study. Questionnaire, survey, and experimental methods are used with a representative sample of a given population so that data can be analysed using statistical methods. Results are usually presented in the form of tables; the aim is to confirm or deny the theories and hypotheses defined at the beginning of the study. Qualitative methods in the social sciences focus on the subjects of the research4. A sample is selected purposively. Subjects are selected by how much they know, or how close to the action they are; research questions and theories emerge as the study continues. Participant observation and partially-structured interviews are used and results are presented as case studies, rich in description and quotation; the aim is to provide the reader with enough information so that he can come to a shared understanding with the subjects of the study.”

[Tomiyama, 1997]:
“General research can be applied to a variety of artefacts; specific research can only be applied to a particular artefact. Abstract research does not deal with concrete entities and is difficult to apply; concrete research is useful and can help practitioners. General and concrete theory can thus be applied to a variety of artefacts and is useful because the descriptions are concrete; good research results tell practitioners how to conduct a design process of a specific type of artefacts.”

The study of research methods for design research is important for the development of the field; research methods strive for certainty and for controlling the research process. In [Blessing et al., 1998], a general design-research methodology that aims at a more rigorous approach to design research by piecing together the various existing design-research areas and by encouraging collaboration with other disciplines is presented. (I agree with the main conclusions of this paper, namely the importance of descriptive studies and the need for involvement of the social sciences in design research.) Despite the fact that there are not yet standard research methods for design research, a piece of academic research (thus also design research) should be [Cross, 1998]:
- purposive: based on identification of an issue or problem worthy and capable of investigation;
- inquisitive: seeking to acquire new knowledge;
- informed: conducted from an awareness of previous, related research;
- methodical: planned and carried out in a disciplined matter;
- communicable: generating and reporting results which are testable and accessible by others.

How my research project fulfils these criteria is discussed in Section 6.2.

In the previous subsections, a general overview of design research is given to introduce to the reader the field I intend to contribute to. The next section concentrates on characteristics of designing: these characteristics offer the basic knowledge to start from when doing design research. For my research project, which aims to develop domain-independent design knowledge, especially characteristics that are common for several disciplines are important. Common characteristics of designing can be recognised in domain-independent design theories and methods; an overview of the most important domain-independent design theories and methods is given in Section 1.4.

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3 The term ‘theories’ must be understood in a broad sense: it can include classification systems, taxonomies, a system of concepts, or empirical theoretical systems [Wester, 1991, pp. 134].
4 The subjects of the research are the persons observed or interviewed.
1.3 Characteristics of designing

In this section, some characteristics of design tasks, design processes, and designers are highlighted, without having the intention to be complete; only characteristics that are important for a global understanding of the results in this thesis are mentioned. The section starts with definitions of ‘designing’. These definitions make clear that designing can be studied from different perspectives. In the remainder of this thesis, the verb ‘designing’ is used to refer to the activity of designing (technical systems). The noun ‘design’ is used to refer to a representation of the product being designed.

1.3.1 Designing defined

Many authors have been giving definitions of designing; for an overview, see, for example, [Hubka et al., 1996] and [Ebvomwan et al., 1996]. Some definitions are focussed on a specific design discipline, others are formulated in general and focus on a certain design method or on certain characteristics of design processes. Two main types of definitions can be recognised: ‘designing is …’ and ‘designing as …’.

The structure of the first type of definitions can be summarised as follows. The definitions contain (at least) one or more of the following three parts: perform one (an act) or more (a process) activities - upon a defined ‘something’ - for a certain purpose. Examples of such definitions are:

- Engineering design is - the process of applying various techniques and scientific principles - for the purpose of defining a device, a process, or a system in sufficient detail to permit its physical realisation (Taylor, 1959) in [Hubka et al., 1996]. (first and third part)
- Engineering design is - a purposeful activity - directed towards the goal of fulfilling human needs, particularly those which can be met by the technology factors of our culture (Asimow, 1962) in [Hubka et al., 1996]. (first and third part)
- Designing is - relating product with situation - to give satisfaction (Gregory, 1966) in [Hubka et al., 1996]. (first and third part)
- Designing is - to initiate change - in man-made things [Jones, 1970]. (first and second part)
- Designing is - an act to create - artificial things which have not existed in the real world [Yoshikawa, 1981]. (first and second part)
- Designing is - the execution of cognitive actions - upon information [Schön, 1990]. (first and second part)

Some examples of the second type of definitions are designing as

- a cognitive process, 
- a creative process,
- a decision-making process,
- a dialectical process,
- a dynamic process,
- an explorative process,
- an information-processing activity,
- a rational process,
- a problem-solving process,
- a process of reflection-in-action,
- a refinement of abstract representations,
- a social process.

Designing can also be defined by distinguishing it from related activities like engineering and project management or art, research, and science. A fundamental discussion on engineering can be found in [Vincenti, 1990]; in [Kroes et al., 1992], the nature of technological knowledge and the role of design in engineering theories is discussed. Discussions about the question “Is design art or science?” can be found in [De Vries et al. (eds.), 1993], [Eder, 1995], [Foque, 1999], and [Zeisel, 1997]. Some terms closely connected to designing are intuition, ‘feel for design’, creativity, innovation, inventing, and heuristics. Each of these terms is discussed, for example, in [Hubka et al., 1996].

As it can be seen from the above, it is very difficult to give one general definition of designing; each definition emphasises only certain aspects of designing. Each definition also reflects the design

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5 This type of definitions offers no real definitions of designing, but each of the mentioned activities and processes appears in definitions of designing.
philosophy of its author. I define, in Section 3.6, designing as the activity of transforming the state of the product being designed or of the design process into another state towards the design goal. This definition is a result of the choice I made in my design philosophy (Chapter 3) to see a design process as a sequence of state transitions. I have chosen for the viewpoint of state-transition systems because it offered me general concepts and a terminology that are very useful to describe design processes in a domain-independent way and to describe my ideas about reflection (see Section 3.1). In my definition of designing, the first type of definition of designing can be recognised: Transforming - the state of the product being designed and of the design process - with the goal of creating a desired representation of the product being designed having a desired state.

1.3.2 Design tasks

Designers are faced with design problems that must be solved. These problems, however, do not stand alone, but are part of a larger context and must be solved under certain conditions (for example timing constraints). This means that characteristics of the specific design context and design process influence the solutions to the problems. The combination of the set of characteristics of the product being designed, the design process, and the design context is called in the remainder of this thesis a design situation (for a more precise definition, see Section 3.2.2). In this thesis, a design task is a task that includes solving design problems, taking into account the whole design situation. (These terms are also used and discussed in [Dorst, 1997].) In this subsection, important concepts related to design tasks, like problems, solutions, products, and design goals, are described in more detail and their use in this thesis is discussed.

Design problems are often called ‘wicked’ or ‘ill-defined’ problems. Characteristics of ill-defined problems are given in [Cross, 1994]; [Rittel et al., 1984] describes ten properties of wicked problems. The most well-known characterisation of ‘design’ problems in the field is given in [Lawson, 1980]:

- Design problems cannot be comprehensively stated.
- Design problems require subjective interpretation.
- Design problems tend to be organised hierarchically.

More characteristics of design problems can be found in [Evbuomwan et al., 1996]. A possible categorisation of engineering design problems is given in [Rückert et al., 1997]. In my thesis, the concept of a design task replaces the concept of a design problem because the concept of a design task has a broader meaning (see Section 3.5.1).

The design situations that must be taken into account when planning a design task can be very complex: They can consist of many related factors. A solution often needs an integration of technical, economical, environmental, ethical, and many other considerations and an integration of the demands of different stakeholders. (For a more in depth discussion on integration, see [Dorst, 1997].) In [Lawson, 1980], the following two characteristics of solutions are described: There is an inexhaustible number of different solutions and there are no optimal solutions to design problems. Designers develop many proposals and alternatives to come to a solution. In this thesis, the concept of a solution can be recognised in the concepts ‘design’ and ‘final state of the product being designed’ (see Sections 3.2.2 and 3.4.2).

Solutions to design problems usually lead to new products. Many types of products can be distinguished; for an overview, see, for example, [Hubka et al., 1996]. In [Meijers, 1998], an ontological analysis of properties of design products (technical artefacts) is made. In Section 3.2.2, a distinction is made between a product and a product being designed to make clear that, during a design process, the product does not yet exist.

The product that must be designed is of course not well defined at the beginning of a design process. Also, the design goal is often not yet clear at the beginning of a design process. This means that this goal can evolve during the process. A design goal can be defined as the purpose for design actions and decisions taken in each design step [Evbuomwan et al., 1996]. A design goal guides the choice of what to do at each point during the design process. For my definition of a design goal, the reader is referred to Section 3.3.2, for the goal of a design activity, and to Section 3.4.2, for the goal of a design process.
As illustrated in [Nidamarthi et al., 1997], designers seem to understand the given problem and they achieve the final solution through simultaneously evolving requirements and solutions. The symmetrical relationships between problem/sub-problems and solution/sub-solutions in design are also illustrated in the design model of Cross [Cross, 1994]. The viewpoint of simultaneously evolving requirements and solutions can be recognised in my design philosophy as simultaneously evolving current and desired properties (see Section 3.4.2).

1.3.3 Design processes

A design process is in a wider sense related to planning, project engineering, developing, and organising [Hubka et al., 1996]. In [Roozenburg et al., 1994], the design process is seen as a sub-process of a product-development process. Characteristics of design processes are already mentioned in Section 1.3.1 in the second type of definitions of designing. More characteristics of design processes can be found in [Hubka et al., 1996] and [Lawson, 1980]. An important characteristic of design processes, described by Lawson, is that the process involves finding as well as solving problems. Many empirical studies delivered characteristics of the design process; however, these results were obtained in specific settings and are rarely transferable to other settings. This was one of the reasons for [Eris et al., 1999] to set up an initial ontology for the product-development process. This initial ontology is a description of the objects, concepts, entities and relationships that exist in product-development projects in order to develop a unifying set of variables relating one study to another. The common characteristics of design processes form a basis to develop my domain-independent description of a design process.

In Section 3.4.2, I define a design process as a finite sequence of design activities necessary to obtain the design goal. A design process in this thesis includes the design activities, but also the people performing these activities and the means for performing these activities. The design processes considered in this thesis can be executed by one person or by several persons (possibly having a background in several disciplines), working together as a team or working individually in parallel sub-processes.

Design processes are represented in design models. An overview of the most important models, classified as descriptive, prescriptive, and computational models, can be found in [Evbuomwan et al., 1996]. Many of these models include several phases and feedback-loops. Representative (domain-independent) models of the design process are mentioned in Section 1.4. My model of the design process can be found in Section 3.7.

Design activities, performed in parallel or in sequence, constitute a design process. In practice, designers execute activities like analysing, brainstorming, calculating, choosing, communicating, deciding, decomposing, defining, developing, discussing, documenting, drawing, evaluating, exploring, generating, integrating, inventorying, judging, justifying, managing, modelling, negotiating, observing, optimising, presenting, reading, reflecting, searching, selecting, simulating, solving, specifying, structuring, taking initiatives, talking, testing, thinking, unifying, validating, verifying, and writing. Design activities can occur as mental or physical activities, as creative or rational activities, can be performed consciously or unconsciously, by a group or by an individual, in the context of discovery or in the context of justification [Kroes, 1996], for knowledge acquisition, application, or communication, or involve objective or subjective interpretation [Dorst, 1997]. Some activities occur more often in the design process than others and some actions always occur in a certain sequence. The occurrence and sequence of the specific design activities in design processes may depend on the design task, on the specific design discipline, on the method or strategy used, and on the design style of the individual designers.

Many attempts have been made by researchers to find patterns in design activities and many different terms have been introduced. Two important mechanisms of design are compared in [Dorst, 1997]. The first mechanism, called ‘basic design cycle’ and, for example, described in [Roozenburg et al., 1994], includes the following four activities: analyse-synthesise-simulate-evaluate. The second mechanism, called the ‘mechanism of reflective practice’ and described in [Schön, 1983], includes the activities
name-frame-move-evaluate. In my thesis, I do not name specific design activities and I do not describe patterns in design activities; during my research process, I only used the list of concrete design activities as a support for thinking about designing.

1.3.4 Designers

Designers execute design activities in (multidisciplinary) teams and/or they work individually. In [Cross, 1995b], it is stated that there exist ‘designerly’ ways of knowing, thinking, and doing. For Cross, design ability can be regarded as a distinct form of intelligence that everyone possesses. More about natural design ability can be found in [Cross, 1995]. Experienced designers possess many design skills; for an overview, see, for example, [Hubka et al., 1996]. Despite of the fact that design ability and design skills are important concepts for designing, it is outside the scope of this thesis; they are only mentioned here to be complete.

Design knowledge can be regarded as implicit knowledge obtained through experience or explicit knowledge about design theories, methods, strategies, design patterns, types of designs, and earlier design projects. The same functions of design knowledge recognised in the world of designing (knowledge production in design research, knowledge transfer in design education, and knowledge application in design practice) can be found in the design process, namely applying existing knowledge, generating new knowledge, and communicating this knowledge to different stakeholders.

1.4 Domain-independent design theories and methods

In Section 1.2.4, an overview of research topics is given. In this section, two of these research topics, namely descriptive and prescriptive results of design research, are discussed in more detail because they are the kinds of results of my research project; my results are compared to the descriptive and prescriptive results of design research in Section 6.1. Given the approach of my research project, only domain-independent results are described. Domain-independent design theories and methods are, in contrast to domain-specific results of research, not specific for a certain design discipline; they abstract from domain-specific aspects, are based on the study of several design disciplines, and can be useful for many design disciplines and for multidisciplinary design teams. Some theories, however, are called ‘domain independent’ but do not abstract from all domain-specific aspects and examples given to illustrate these theories are often taken from only one discipline. (For example, in [Hubka et al., 1996], all examples are taken from mechanical engineering and the existence of non-material products (like software) is not considered.) Many general design theories are also often based on the study of one design discipline or are made with no practical goal in mind. Domain-independent design knowledge is possible because designing in different disciplines has much in common. Common characteristics of a design process are, for example, the occurrence of design phases in almost all design processes and the ill-defined nature of design problems.

The need for a domain-independent design theory has been discussed since the beginning period of design research. In 1995, the Design Research Society sponsored a discussion meeting, ‘design dialogues one’, on the question whether the search for domain-independent theory of designing is a reasonable or realistic goal. Nigel Cross mentioned that a primary goal of the Design Research Society since its founding in the 1960’s has been a domain-independent theory of design within the context of a science of design. A summary of the discussion can be found in [McDonnell, 1995]. The discussion led to the role of design research, showing a clear division between those who want to study design per se and those who want to improve design practice and design education (the latter is called an instrumental view). Arguments for a domain-independent design theory are that such a theory can facilitate interdisciplinary communication and that it can support multidisciplinary design. Arguments against a domain-independent design theory are the incommensurability of different views of design and the fact that the elimination of context necessary for a universal theory would result in a theory about an activity unrecognisable as design. Because the goal of my research is to develop domain-

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6 ‘Domain independent’ is sometimes also called ‘general’ or ‘generic’.
independent support for designers, my position in this ongoing debate is an instrumental one: domain-independent design theory is useful for the improvement of design education and practice.

In the following subsections, only theories and methods that are important in the light of this thesis are discussed. First, descriptive theories and, second, prescriptive methods about designing are mentioned. In the literature, a distinction is made between theories and methods (both are represented in models) that can be situated within the paradigm of positivism and within the paradigm of constructivism; the same distinction is made in this section. An overview of descriptive models of design can be found in [Akin, 1997]. An overview of descriptive and prescriptive results can also be found in [Cross, 1994] and [Evbuomwan et al., 1996].

1.4.1 Descriptive theories

Some design theories are based on general, not design-specific, theories, like systems theory, structuralism, evolution and transformation theory, logic, and others. A good overview of general theories is given in [Hillier et al., 1972].

Within the paradigm of positivism, the following theories and models are important in the light of this thesis:

- The rational problem-solving theory, as described in [Newell et al., 1972]. In that theory, humans are represented as information-processing systems. The theory combines a cognitive system (i.e., the design-problem solver), characteristics of design problems, the environment in which design-problem solving takes place, and the design process itself. They postulate that problem solving takes place by searching in a problem space.
- The ‘basic design cycle’, for example explained in [Roozenberg et al., 1994]. This model includes the following steps: analysis, synthesis, simulation, and evaluation.
- The transformation approach to the design process, for example explained in [Hubka et al., 1996].
- An evolutionary process model of design, as presented in [Hybs et al., 1992].
- A general design theory based on axiomatic set theory, as presented in [Yoshikawa, 1981], [Tomiyama et al., 1986], and [Takeda et al., 1990]. The theory clarifies what designing is, how to formalise a design process, and how to describe design knowledge.
- A domain-independent design theory using aspects of linguistic modelling as a symbolism, as proposed in [Korn, 1996]. In this theory, design is seen as a process of completing an incomplete situation.
- A stepping stone for the development of a domain-independent design theory to support the design of large-scale, complex design processes, as provided in [Van Aken, 2000].

Within the paradigm of constructivism, the following theories and models are important in the light of this thesis:

- The mechanism of reflective practice, as described in [Schön, 1983]. Based on a description of design processes of professionals, the following steps are observed in design processes: name, frame, make a move, and evaluate. Schön sees designing as a ‘reflective conversation with the situation’: Designers work by naming the relevant factors in the situation, framing the problem in a certain way, making moves toward the solution, and evaluating those moves.
- The definition of object world and process world as important elements of a design theory, in [Bucciarelli et al., 1987] and [Bucciarelli, 1994].
- A description method, as described in [Valkenburg et al., 1998] and [Valkenburg, 2000]. It is based on Schön’s theory of reflective practice and used to describe the nature of team designing.
- The social language for the description of design processes, as proposed in [Friedrich, 1999].
  Design processes are seen as social, interactional, and interpretative processes.

I believe that sound descriptive design theories should be based on more than one design discipline. This is, however, not always the case. The descriptive results I developed are based on three design disciplines. My design philosophy (described in Chapter 3) is related to the descriptive theories and models within the paradigm of positivism. The theories and models in the paradigm of constructivism,
including concepts about reflection, were important for the development of my design method (described in Chapter 5). My results are positioned in the literature in Section 6.1.

1.4.2 Prescriptive methods

Within the paradigm of positivism, several systematic methods and models have been developed:

− An early example of a systematic design method, proposed in [Jones, 1970], suggests the following basic structure of the design process: analysis, synthesis, and evaluation. [Jones, 1970] also contains descriptions of 35 methods, including methods for exploring design situations, methods for searching for ideas, methods for exploring problem structure, and methods of evaluation.

− The VDI Guidelines 2221 [VDI, 1987] suggest a systematic approach in which ‘the design process, as part of product creation, is subdivided into general working stages, making the design approach transparent, rational, and independent of a specific branch of industry’. The structure of this general approach is based on seven stages, each with a particular output.

− The model described in [Pahl et al., 1988] proposes the following design stages: clarification of the task, conceptual design, embodiment design, and detail design.

− The design model of Cross [Cross, 1994] contains six stages within a symmetrical problem-solution model. For each of the stages, a design method is used to achieve the objective in that stage.

− A training method that intends to enable a designer – as individual and as member of a group – to reflect on his own design process is developed by a German research group. Literature about the design studies performed by this group can be found in a special issue of Design Studies [Frankenberger et al. (eds.), 1999] and in [Wallmeier et al., 2000].

Within the paradigm of constructivism, I only found a domain-independent prescriptive method in a Ph.D. thesis [Robbins, 1999]. This thesis describes a tool that is inspired by the theory of reflection-in-action of Schöen; the tool includes design critics, checklists, non-modal wizards, a dynamic ‘to do’ list, clarifiers, etc. [Robbins, 1999]:

“The theory of reflection-in-action implies several requirements for design support:

− The designer should be allowed to easily alternate between synthesis and analysis activities;

− the designer should not be forced to complete a synthesis activity without analysis; likewise, the designer should not be locked into an analysis mode;

− furthermore, a tool should support the natural integration of synthesis and analysis by providing the designer with prompts to recall relevant design knowledge.”

The relation between these prescriptive methods and my design method is given in Section 6.1.

1.5 Reflection on design processes

The goal in this thesis is to develop domain-independent support for structured reflection on design processes. That is the reason why I concentrate, in this last main section of the introduction, on reflection. Because not yet much literature about reflection in the world of designing can be found, I start in the following subsection with general definitions of reflection and a general description of a reflection process. Then, in Section 1.5.2, concepts about reflection in other domains are discussed. Finally, Section 1.5.3 concentrates on reflection in the world of designing and, more specific, on reflection on and within design processes.

1.5.1 Reflection in general

Following [Webster, 1993], reflection is

1. a thought, idea, or opinion formed, or a remark made as a result of meditation;

2. a consideration of some subject matter, idea, or purpose, often with a view to understanding or accepting it or seeing it in its right relations;
3. introspective contemplation of the contents or qualities of one’s own thoughts or remembered experiences;
4. turning back.
My definition is based on the third definition (see further on in this subsection).

Etymologically, the original meaning of reflection is ‘turning back the image of another object’; since the phenomenon was usually used to see oneself with mirrors (the alternate spelling ‘reflection’ is preferred for the optical phenomenon), it has come to mean ‘applying to oneself’ (see reflexive). From there, it has come to mean not just to see oneself’s physical image, but also to examine one’s own mental state (early 17th century); it quickly applied to thinking in general (late 17th century), and it has been used for well-considered thought in general, although still keeping as an alternative this meaning of thinking about one’s thoughts (from [Tunes, 2001]).

In [Bax et al., 2001], reflection is defined as an inter-relational process of research, design, and cultivation (in my terms, research, designing, and education). This definition of reflection is an application of the pragmatism of Charles Pierce to reflection. Charles Pierce’s phenomenology, one of the constituting elements of his pragmatism, consists of the three categories potential, actual, and intentional\(^7\). In [Bax et al., 2001], it is argued that the activities research, design, and cultivation constitute the overall activity of reflection in a pragmatistic way. Research is defined as a process of discovering (in an existing world) what is possible (the potentialities). Designing is a process of inventing a new actuality (a not-yet-existing world); designing presupposes several potentialities. Education is a process of justifying potentialities for actualities; education presupposes potentialities and actualities and learns to make connections between both. This viewpoint on reflection is used in Section 1.5.3 to link the main activities in the world of designing to reflection.

My definition of reflection is based on the third definition of Webster. Reflection is seen in this thesis as an introspective contemplation of the contents or qualities of one’s own thoughts or remembered experiences. What people remember are, for example, the experiences that were striking, the experiences when they reached a boundary, when they did something wrong or failed, or when they found a breakthrough. I describe a reflection process as a process that consists of three main activities that are called preparation, image forming, and conclusion drawing. These steps are related to the steps of the basic design cycle [Roozenburg et al., 1994], to the mechanism of reflective practice, as described in [Schön, 1983] (see also Section 1.4.1), to the major stages in creative problem-solving processes, as described in [Isaksen et al., 1985] and [Isaksen et al., 1994]\(^8\), and to the stages of a reflection process described in [Daudelin, 1996] (see Section 1.5.2). The preparation step consists of the preparation of an initial question and of a critical analysis of the facts in relation to this question. For this critical analysis, the following evaluation criteria can be important: coherency, completeness, consistency, reliability, and validity of the facts\(^9\). The facts are the thoughts and remembered experiences. The image-forming step makes a selection and synthesis of the facts and their analysis; this step results in an image of the situation. During the conclusion-drawing step, the image is analysed; the questions “Why is the situation like that?”; “What does the image teach me?”; and “What must be changed?” should be answered; these questions are related to learning. The preparation and image-forming step mainly look back in the past. The conclusion-drawing step starts from the results of the first two steps and looks forward to determine the next activities. It is desirable that, after the reflection process, action takes place to perform the planned activities.

I defined reflection as a personal process as distinguished from a team process. In Section 5.8, it is shown how a team can partially perform this reflection process (for reflection on design processes).

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\(^7\) More about the philosophy of Charles Pierce and about its implications for interdisciplinary design can be found in [Bax et al., 2000].

\(^8\) Main stages in these kind of processes are mess-finding, data-finding, problem-finding, idea-finding, solution-finding, and acceptance-finding. In further developments of the model, the first three stages are called problem exploration; idea finding is called idea generation; the last two stages are called action planning.

\(^9\) These are similar to the criteria defined by Schön: coherence, accordance with performance specification, and problem-solving value. I refined ‘accordance with performance specification’ to ‘completeness, consistency, and reliability’; ‘problem-solving value’ is interpreted as ‘validity’.
The described reflection process must also be distinguished from a related process, called reviewing. A review process starts from official documents, follows formal rules or procedures, and is performed to advise other persons.

1.5.2 Reflection in other domains

When searching for literature about reflection, I found most of the literature in physics (reflection); this kind of reflection, however, is outside the scope of this thesis. Surprisingly, I also found much literature about reflection in the field of computer science. Reflection is also a commonly used word in theories about learning in business management.

In *computer science*, reflection is the domain of programs that describe or manipulate ‘themselves’ or other related programs. This notion extends to programs the philosophical notion of reflection, namely human thought that can be applied to itself. Applications of reflection as a conceptual tool in computer science are, for example, expert systems that reason about their own behaviour and dynamic (runtime) evolution of programming systems [Tunes, 2001].

In *business management and human-systems engineering*, the *Deming Cycle* [Deming, 1986] is known as a four-step process for continuous improvement. It consists of the following steps:

- **Plan**: establish a plan for improvement based upon a study of the current situation;
- **do**: test the plan on a small scale;
- **check**: check to see if the trial produced the expected results;
- **act**: act to implement changes on a larger scale if the experiment is successful.

A model that might be a source of inspiration for studying design processes and for developing support for reflection (of individuals working in design teams and possibly for reflection in teams) can be found in [Bos, 1974]. Starting form a question, the *judgement model* (in Dutch: ‘oordeelsvorming’) distinguishes between a way of cognition (in Dutch: ‘kenweg’) and a way of choice (in Dutch: ‘keuzeweg’), between experiencing (living through) and judging. Polarity and rhythm (between facts and ideas, goals and ways to meet goals, insights and decisions, words and actions) characterises this process of judgement.

Reflection and learning are related, as illustrated in the *experiential learning cycle* of [Kolb, 1984] and given in Figure 1.3. Learning takes place through action and reflection, as also stated in [Drath et al., 1984]. Kolb also inventoried different learning styles; each learning style focuses more on certain and less on the other activities in the experiential learning cycle. This means that some people pay less attention to reflection than others do. When people are aware of their learning style, they can correct their behaviour to balance the activities of the experiential learning cycle.

![Figure 1.3: Experiential learning cycle ([Kolb, 1984]).](image)

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10 The Deming Cycle is also called Shewhart Cycle after Deming’s teacher, who developed a three-stage cycle of activities, on which the four-step cycle is based.

11 The correspondence between the experiential learning cycle and the Deming Cycle may be as follows:

- ‘observation and reflections’ may correspond to ‘plan’,
- ‘formation of abstract concepts and generalisations’ to ‘do’,
- ‘testing concepts in new situations’ to ‘check’, and
- ‘concrete experiences’ to ‘act’.
Reflection also plays a key role in enabling managers to learn from experience [Daudelin, 1996] and [Seibert, 1999]. Daudelin describes the following about reflection and learning:

“When a person engages in reflection, he or she takes an experience from the outside world, brings it inside the mind, turns it over, makes connections to other experiences, and filters it through personal biases. If this process results in learning, the individual then develops inferences to approach the external world in a way that is different from the approach that would have been used, had reflection not occurred. … Two important conditions for learning from experience are the development of insights from past events and their application to future actions. … Reflection is the process of stepping back from an experience to ponder, carefully and persistently, its meaning to the self through the development of inferences. Learning is defined as the creation of meaning from past or current events that serves as a guide for future behaviour.”

She continues:

“A reflection process can be described in the following four stages: articulation of a problem, analysis of that problem, formulation and testing of a tentative theory to explain the problem, and action (or deciding when to act). … Reflection can be called a simple and time-tested tool. To use it effectively, managers need only recognise that it has value and then create an amazingly small amount of time and structure for it to take place. … One of the techniques for increasing the power of reflection is the posing and answering of questions. The types of questions that are most effective in enhancing reflection vary depending on the stage of reflection. In the four stages of a reflection process, the following kinds of questions are most helpful: what, why, how, and what, respectively. Questions are one of the most basic and powerful elements of the reflection experience. They are used in the process of learning from challenging work situations in three ways: to open up possibilities, to clarify meaning, and to structure the progressions through the four stages.”

More about the stages of a reflection process and about characteristics of reflection can be found in [Daudelin, 1996]; the paper also includes a very good selected bibliography about learning from experience in organisations, about the use of reflection in traditional education settings, and about the underlying mental processes that guide reflection and learning. The research described in [Daudelin, 1996] shows that providing managers with a one-hour reflection session, using structured questions and guidelines, significantly increases the learning from their experience.

The structured approach to reflection, as proposed by Daudelin, is called ‘coached’ reflection in [Seibert, 1999]:

“Coached reflection is distinguished from reflection-in-action. Coached reflection involves providing learners with formal tools to help them think through an experience in order to identify what they learned from it. … Reflection-in-action involves the way managers try to make sense of what they are experiencing while they are in the midst of experiencing it. … The two types of reflection represent two different means to learn from experience.”

In my design method, only structured reflection (on design processes) and no reflection-in-action is supported (see the next subsection). My design method also makes use of questions, in the form of checklists. Because only the preparation step (the first stage) of a reflection process is supported, (almost) only ‘what’ questions are included in the checklists.

1.5.3 Reflection in the world of designing

The definitions, concepts, and ideas about reflection in general and in several domains as described in the previous subsections might be useful for the world of designing. In the world of designing, not yet much literature about reflection can be found. Descriptive theories about reflection and designing are

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12 The four stages Daudelin defined for a reflection process correspond to the steps I defined as follows (see Section 1.5.1): my preparation step corresponds to the combination of ‘problem articulation’ and ‘analysis of that problem’; the combination of my image-forming and conclusion-drawing steps correspond to her ‘formulation of a tentative theory’. In my model, action is defined as a desirable next step after performing a reflection process; this next step corresponds to the combination of Daudelin’s ‘testing of a tentative theory’ and ‘action’.
described in [Schön, 1983] and [Schön, 1990]. Attempts to extend Schön’s ideas in a design theory, to apply it, and to address some of its limitations can be found in [Schön et al., 1992], [Schön, 1994], [Valkenburg et al., 1998], and [Valkenburg, 2000]. Prescriptive methods are described in [Grushka, 1997], [Robbins, 1999], and [Wallmeier et al., 2000]. Some of these prescriptive methods have been discussed briefly in Section 1.4.2. In [Schön et al., 1996], a distinction between three kinds of reflection is made, namely reflection-in-action, reflection-on-action, and reflection-on-practice; this distinction is often used in the literature (see, for example, [Seibert, 1999] and the previous subsection). I have chosen to concentrate in my research on reflection-on-action; this type of reflection is most appropriate for supporting structured reflection (for a definition and advantages of structured reflection, see below and in Section 5.1).

My general definition of reflection, given in Section 1.5.1, is adapted to reflection on a design process as follows: Reflection on a design process means an introspective contemplation of the designer’s perception of the design situation and of the remembered design activities. The general description of a reflection process is adapted as follows: The facts in the preparation step are the properties, factors, and relations of the design situation (for a definition of properties, factors, and relations, see Section 3.2.2) and the design activities performed during the design process. During the preparation step, these facts are collected and analysed critically, using the criteria mentioned in Section 1.5.1. The goal of the image-forming step is to form an image of the design process as a whole, based on the information collected and analysed during the preparation step: The designer has to lean back for a while and form an image of the design situation and the performed design activities. During the conclusion-drawing step, the image of the design process and the goal of the design process are taken into account to determine the next design activities in the design process. This description of a reflection process is used in Chapter 5 for describing some of the main steps of my design method.

Reflection on a design process is defined above as a combination of reflection on the design situation and reflection on the remembered design activities. Together, these two kinds of reflection can help to reach the goal of reflection on a design process, namely to determine the next design activities in the design process. A design situation offers a static perspective on the design process; design activities offer a dynamic perspective on the design process: Reflection on the design situation can, for example, offer information

- about the difference between current and desired properties of the product being designed, which is useful for checking if all important aspects are taken into account;
- about the difference between the current and the desired state in the design process, which is useful for judging its progress;
- about important factors in the design context, which is useful for determining next interactions with the design context.

Reflection on the performed design activities can, for example, learn which activities were not successful for reaching the design goal.

The relation between reflection and learning is already mentioned in Section 1.5.2. Reflection is vital in any learning process. Learning is an important activity to improve a design process, its results, and the designer’s proficiency (designers can learn from their experiences in the design process). Reflection on a design process, performed within or after the design process, may thus improve the design process. It may increase the effectiveness and efficiency of activities in the design process; part of this involves integration and co-ordination of important aspects. By reflecting explicitly on the current design situation and on the performed design activities, in a systematic way and on a regular basis, designers can plan next design activities that are both effective and efficient with respect to the design goal at that moment. By performing reflection in a systematic way, the chance of overlooking important design aspects may be decreased. A systematic way of reflection that is performed on a regular basis is called in this thesis ‘structured reflection’ (see Section 5.1). Reflection may not only improve the current design process, but it may also have effect in subsequent design processes. I have chosen reflection on design processes as a means to reach the goal of my research, namely improving design processes (see Section 2.3). My design method is developed to support structured reflection on design processes within these processes, with the goal to improve the current as well as subsequent design processes.
In the world of designing, *design research, design practice, and design education* can be seen as activities linked to the three constituting elements of reflection, namely research, design, and cultivation (see Section 1.5.1). This means that, in the world of designing, reflection can be defined as an inter-relational process of design research, design practice, and design education. These three fields are also related to learning: Design research is a form of learning about the existing world; designing is a form of learning about the non-existing world; design education is a form of learning to learn.

*Reflection* plays thus an important role in this thesis in two ways: First, my design method is developed for supporting (structured) reflection in practice. Second, by concentrating on the three fields in the world of designing, the thesis focuses also on reflection in the world of designing.

### 1.6 Conclusions

As mentioned in the introduction to this chapter, the goal of the first chapter is to offer an introduction and an overview to the reader who is not familiar with the world of designing or with one or more of the specific topics in this thesis; it also offers a framework in which my research about designing can be positioned. This goal is reached in the sense that the reader can find in this chapter an introduction to the world of designing and a more detailed overview of the field of design research. Common characteristics of designing are summarised and an overview of domain-independent design theories and methods is given. Finally, the chapter focuses on reflection in general and on reflection on design processes, the main topic of this thesis. My research project can be positioned in the given framework as a combination of a descriptive and prescriptive study, resulting in a design philosophy, some kind of design theory (a framework for design), and a design method. The study is a broad explorative study, starting from the basic beliefs of the constructivist research paradigm, including qualitative empirical research, and aiming to be as well general as concrete.

Based on this chapter, the following four conclusions related to the ambition of this research project and the goal in this thesis can be drawn. First, gaps between design research, design practice, and design education are identified. Given my ambition to contribute to these fields, it is preferred to do so in such a way that the gaps between the fields decrease; one possible way is to create good interaction between the fields. Second, design research that results in domain-independent design knowledge (knowledge that is based on an investigation of several design disciplines and that has an explicit goal of being useful for many design disciplines in practice) is a new topic in the field of design research. Third, almost no support for reflection on design processes has been developed so far and even not much literature that concentrates on theories about reflection on design processes can be found. Fourth, standard research methods do not yet exist for design research.

Summarising, the goal in this thesis, namely contributing to design research by developing domain-independent design knowledge for improving design processes through structured reflection, seems a challenging one. My approach to reach this goal is described in the next chapter.
2 Research Project

The goal of this chapter is to offer the reader insight into my research project. The chapter answers the following questions: “In which context is the research defined?”, “Which problems are studied?”, “What are the goals of the research?”, “Which questions are investigated?”, and “Which strategy is followed?”. The chapter also summarises which results are obtained (in Section 2.7; the results are described in more detail in Chapters 3, 4, and 5) and how these results are obtained (in Section 2.8, describing my research process). The last section of this chapter, Section 2.9, gives an overview of the thesis.

2.1 Context

The research proposal for this Ph.D. project is defined in the context of the Stan Ackermans Institute (SAI) at the Technische Universiteit Eindhoven (TU/e) in The Netherlands. The SAI is a centre for technological design that co-ordinates 10 post-graduate design programs leading to the degree of Master of Technological Design. Part of the two-year full-time programs is a multidisciplinary design project in industry. The SAI also supports students to pursue a Ph.D. on design. Halfway the nineties, the SAI defined two research projects to support its design courses with design research. The first project, entitled ‘Development of a Design-History System’, has been executed by Silvan Wiegeraad and is presented in [Wiegeraad, 1999]. My project was entitled ‘Towards a Multidisciplinary Framework for Design’. Because the research activities of the SAI were just being set up, we did our research at the faculties of our promotors: Silvan Wiegeraad in the Faculty of Mechanical Engineering and I at the Department of Computing Science of the Faculty of Mathematics and Computing Science. My supervisors, Dieter Hammer, Thijs Bax, Peter Kroes, and Joan van Aken, had a background in computing science, architecture, philosophy of technology, and organisation science respectively. The TU/e is situated in the Eindhoven Region. The latter name refers to a bundling of many companies and institutions in and around Eindhoven that are active in the field of product development and industrial design. The research context offered a unique source of inspiration and a unique testing environment.

2.2 Problems

In the world of designing, gaps between the different fields can be recognised. Given my ambition to contribute to these fields, it is preferred to do so in such a way that the gaps between the different fields decrease. In this thesis, I focus on the gap between design research and design practice. To decrease this gap, I concentrate on problems in design practice and on topics of design research that are related to these problems, that can improve design processes in practice, and that deserve more attention in the field of design research.

Designing in practice is performed in many design disciplines, like architecture, industrial design, mechanical engineering, software engineering, electrical engineering, and organisational science. Ever more, designing is also performed in multidisciplinary teams. However, most of the designers working in these teams are specialised in just one discipline and know very little about the other disciplines. The main problems in multidisciplinary teams are therefore the communication between designers with a different background and the integration and co-ordination of the different aspects during a design process ([NSF, 1996]). More in general, design processes in practice can be improved by increasing their effectiveness and efficiency.

Design research mainly tries to find answers to the following questions: “What is design?”, “How do people design?”, “How to design?”, “How to support designers?”, and “How to teach designing?”. Researchers usually concentrate on a single design discipline. The study of similarities and differences between design processes in several design disciplines is a topic of research that can improve the
design practice and that deserves more attention; the same holds for the development of support for reflection on design processes. How both kinds of studies can improve the design practice is explained in Section 2.3. The relatively low attention for both kinds of studies in the field of design research is already mentioned in the first chapter. As shown in Section 1.5, not yet much support for reflection on design processes has been developed. Sections 1.2.2 and 1.4 show that the development of domain-independent design knowledge, based on the study of similarities and differences between design processes in several disciplines, is a relatively new approach in design research.

### 2.3 Research goal

This section describes the final goal of my research and the final goal in this thesis. The evolution of my research goals can be found in Section 2.8. My research goals are determined by my exploration of the world of designing, by my research context, and by the problems I recognised in the different fields. The distinction between the goal of my research and the goal in this thesis corresponds to the following: the goal of a research project defines the problem that must (ultimately) be solved. The goal in a research project defines how this problem is solved in the research project; it describes thus the specific direction that is chosen in the research project to solve the problem.

**The overall goal of my research is to decrease the gap between design research and design practice in order to improve design processes.**

I assume that the gap between design research and design practice can be decreased by performing design research in close interaction with design practice: In order to develop results that are useful for design practice (and design education), I start from the current design practice (and design education) and the knowledge developed in design research. Besides improving design processes in practice, the goal of my research includes, of course, contributing to design research.

Learning during a design process is an important activity to improve design processes in practice and reflection is vital in learning processes (see also Section 1.5.2). In the context of designing, reflection on design processes is important. Through learning, reflection on a design process is a step towards the improvement of a designer’s own design activities: Reflection on a design process, for example, includes checking if progress is made towards the design goal and checking if the important aspects are taken into account. Reflection helps to generate the next design activities in a design process. The execution of these design activities is again evaluated. Through this cycle, designers can learn from their experiences. Reflection on a design process, during this process, can help designers to learn from their experiences in the design process, from the specific product being designed, and from the interaction with the design context. The results of the reflection process can improve the effectiveness and efficiency of current as well as subsequent design processes. Because reflection on design processes is thus a possible way to improve design processes and because not yet much support for reflection on design processes is developed, I have chosen to improve design processes by stimulating designers to reflect on their design process. In order to decrease the chance of overlooking important aspects during reflection, I propose designers to perform reflection in a systematic way. To be effective, explicit reflection must take place regularly during a design process. In this thesis, the combination of systematic and regular reflection is called structured reflection.

To improve design processes in several design disciplines in practice, the study of similarities and differences between design processes in several disciplines can be useful. A first result of this kind of study can be that the (implicit) choices made in each discipline, which must be made explicit for this study, can be discussed in the own discipline. Differences between the processes can be the cause of difficulties in collaboration between designers of different disciplines; to improve collaboration, these differences must be taken into account. Similarities between design processes are the basis for domain-independent design knowledge; this knowledge can consist of concepts and a terminology that are general for the different disciplines. Domain-independent design knowledge can be useful for improving multidisciplinary design processes and even for designing in individual design disciplines. Multidisciplinary teams can use the general concepts and the domain-independent terminology in a
common language. To improve the communication between team members from several disciplines and for the integration of important aspects, abstraction from domain-specific details can be a good technique. Also, individual design disciplines can profit of this domain-independent design knowledge. Specific disciplines can tailor and translate the general concepts (perhaps new for them) and the general terminology to their specific concepts and terminology. The comparison with concepts and approaches developed in other disciplines can offer new points of view for the own discipline: Disciplines can learn from each other because, among others, “A fish does not know what is water, because it does not know what is ‘no water’.” (a Japanese proverb). Because domain-independent design knowledge can improve design processes and because not yet many studies concentrated on similarities and differences between design processes in several disciplines, I have chosen to study a few design disciplines in order to develop domain-independent design knowledge. The possible use of domain-independent design knowledge in practice is shown in Figure 2.1.

![Figure 2.1: Possible use of domain-independent design knowledge.](image)

I have chosen to combine the development of support for structured reflection on design processes and the development of domain-independent design knowledge to reach the goal of my research project, namely improving design processes. The study of similarities and differences between several design disciplines, more specific the development of domain-independent design knowledge, and the study of reflection on design processes can be a step towards the improvement of design processes in practice and towards the solution to some of the problems in practice; these studies may help to decrease the gap between design research and design practice. By supporting designers from a certain discipline with structured reflection on design processes, the designers can learn from their design processes and the effectiveness and efficiency of their design processes can be improved. When the support is also domain independent, reflection can be supported in several design disciplines and in multidisciplinary teams. Domain-independent design knowledge has also the advantage that it can improve the communication between designers with a different background (for example, the communication about the results of individual reflection processes) and improve the integration and co-ordination of the different aspects during a design process. To be domain-independent, design knowledge may not be specific for a certain discipline, it must be based on several disciplines, and it must be useful in several disciplines in practice; in other words, it must be general and concrete. The resulting goal in my research project is given below. The main terminology of my research goals, also part of the title of this thesis, is explained in the following section.

The specific goal in this thesis is to develop domain-independent design knowledge to support structured reflection on design processes.
2.4 Terminology

Design processes: In this thesis, design processes of (complex) technical products are envisaged; for example, the design process of a production machine, of a building, or of a software program. A precise definition of a design process is given in Section 3.4.2.

Reflection on design processes: Reflection on design processes is seen as an introspective contemplation on the designer’s perception of the design situation and on the remembered design activities (see also Sections 1.5.3 and 2.7.2).

Structured reflection: Structured reflection refers to systematic reflection that is performed on a regular basis (see also Section 5.1).

Domain-independent design knowledge: Domain-independent design knowledge is, in contrast to domain-specific knowledge, not specific for a certain domain (or design discipline). Domain-independent design knowledge abstracts from domain-specific aspects and contains only aspects that are also valuable for other domains (or disciplines). Design knowledge is domain-independent if the knowledge is, for example, valuable for the disciplines architecture, software engineering, and mechanical engineering. Topics of such knowledge are, for example, common characteristics of the design processes in these disciplines, like the occurrence of design phases and the ill-defined nature of design problems.

Domain-independent approach: A domain-independent approach is an approach based on the study of and intended to be useful for several domains (design disciplines). For example, it is an approach based on the study of design processes in the disciplines electrical engineering, software engineering, and mechanical engineering to compare the communication processes in the design processes in these disciplines; the study can be intended to improve collaboration between designers of these disciplines, for example, in mechatronic projects.

2.5 Research questions

To reach the goal in this thesis, I need to know how to support structured reflection on design processes in a domain-independent way. To develop domain-independent support, I need to know how to describe design processes in a domain-independent way. The resulting research questions are thus:

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<th>Research questions</th>
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<tr>
<td>How to describe design processes in a domain-independent way?</td>
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<tr>
<td>How to support structured reflection on design processes in a domain-independent way?</td>
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2.6 Research strategy

To answer the research questions, domain-independent design knowledge useful for supporting structured reflection on design processes must be developed. The planned process for achieving this knowledge is described in my research strategy. The choices I made during my research process to develop this strategy were based on my research goals, on the literature I encountered, and on the contacts I had with several people; a description of my research process is given in Section 2.8. A preliminary version of the research strategy can be found in [Reymen, 1998]. In this section, the main concepts of my research strategy are explained.

The research has been set up as a broad explorative study. The study is broad because it contains some empirical research in several disciplines, the development of some theoretical results, the development of support for the design practice, and the confrontation of the results with design practice. An explorative study was necessary because design research across several disciplines is a relatively new approach in the field of design research; the literature does not yet contain much domain-independent design knowledge that is based on several design disciplines. An explorative study was also necessary...
because the study of design processes in several disciplines is rather difficult: These processes have many common aspects but are also very different; the exploration was necessary to find out which concepts, terminology, and kinds of support are useful for meeting the goal in this thesis. I chose a practical goal for my explorative research, namely trying to improve design processes by developing support (for helping designers from several disciplines with structured reflection on design processes). Because I did not start with sharp hypotheses that could be tested (which is characteristic for explorative research), my research must be followed by a study in which the results of my research are tested. The empirical research performed at the end of my project was only a first test, meant to derive some preliminary conclusions. Characteristics of explorative research are summarised in Section 1.2.8.

I chose to develop domain-independent design knowledge based on the following three disciplines: software engineering, mechanical engineering, and architecture. I chose architecture because it has already played an important role in design research and it is the discipline I am most familiar with. Mechanical engineering has also contributed much to design research and is a typical engineering discipline. Software engineering is a new evolving discipline that only recently started to reflect on its design process. Together, these three disciplines are responsible for a wide range of products and for many different design approaches.

I chose to first answer the first research question, mentioned in Section 2.5, by developing domain-independent descriptive knowledge about designing. For this purpose, I studied the three design disciplines to inventory characteristics of design processes. I did a literature study as well as empirical research and I compared the results in each of these studies for similarities and differences. The similarities have been a basis for the development of domain-independent descriptive design knowledge about design processes. The developed descriptive knowledge, in turn, has formed the basis for developing domain-independent prescriptive knowledge, namely support for structured reflection on design processes. I confronted the descriptive and prescriptive knowledge with the design practice in another empirical study, to get feedback on the results; I also compared the results to the design literature. The relation between the main concepts of the research strategy is illustrated in Figure 2.2.

![Figure 2.2: Relation between the main concepts of the research strategy.](image)

2.7 Results of the research project

This section summarises the descriptive and prescriptive domain-independent design knowledge resulting from my research project and indicates relations between these results. The summary is given to facilitate the understanding of the description of my research process, given in Section 2.8. The summary may also facilitate the reading of the chapters about my descriptive results (Chapters 3 and 4) because it gives information about the usefulness of the descriptive results for the prescriptive results.

2.7.1 Resulting descriptive knowledge

The descriptive design knowledge includes concepts, a terminology, and a structure to describe design processes in a domain-independent way. The comparison of design processes in the three disciplines
resulted in the definition of the concepts ‘design situation’ and ‘design activity’. A design situation at a certain moment during a design process includes all properties describing the product being designed and the design process, and all factors influencing this product being designed and its design process. (A precise definition of a design situation is given in Section 3.2.2.) Design activities change the product being designed and/or the design process towards the design goal at that moment. (A precise definition of a design activity is given in Section 3.3.2.)

The resulting descriptive knowledge is (part of) a domain-independent design philosophy and a domain-independent design frame. In the design philosophy, terminology and concepts are introduced to describe design processes in a domain-independent way. To describe design situations (states on a certain moment) and design activities (changing the design situation), I have chosen to base my concepts on a general theory, namely that of ‘state-transition systems’; in this theory, states and transitions between states are the main concepts (see Section 3.1). The design philosophy is a set of domain-independent concepts and terms for describing a design process from the viewpoint of state-transition systems. It is used to describe the other results of my research project and it can be used to improve communication between designers of several disciplines.

The design frame is a domain-independent aid to position properties, factors, design tasks, and other design-related concepts; it offers a structure to position these concepts in order to integrate and co-ordinate them. The design frame helps to describe (and analyse) design processes in a systematic way (one of the concepts on which the support is based, see Section 2.7.2); the structure facilitates the process of describing (and analysing) design situations and design activities (see Section 4.1). The domain-independent concepts and terms, defined in the design philosophy, are used to describe the design frame. The concepts of the design frame are used as a basis for the development of prescriptive support.

### 2.7.2 Resulting prescriptive knowledge

To answer the second research question, (domain-independent) support for structured reflection on design processes must be developed. I have chosen to support explicit reflection on a design process by supporting a combination of reflection on the design situation and on the design activities (being the two main concepts developed in my design philosophy). Together, these two kinds of reflections can help to reach the goal of reflection on a design process, namely to determine the next design activities in the design process. Reflection on the design situation can offer, for example, information about the difference between current and desired properties of the product being designed, about the current state in the design process, and about important factors in the design context. Reflection on the performed design activities can show, for example, which activities did not (sufficiently) contribute to reaching the design goal.

To support structured reflection on design processes, designers are supported to describe and analyse the design situation and design activities in a systematic way and to do so regularly during a design process. Only support for the preparation step of a reflection process (see Section 1.5.1) is developed. Checklists and forms are developed to support systematic reflection; the concept of design sessions is introduced to let designers reflect regularly during a design process. The structure of the design frame is used to support the description and analysis of the design process. The terminology of the design philosophy is used for describing the support in a domain-independent way.

The resulting prescriptive knowledge is a design method and a prototype software tool facilitating the use of the design method. The developed design method stimulates designers to reflect on design situations and design activities in a structured way by letting them describe and analyse the design situation and the design process regularly during a design process. The prototype software tool was developed to explore the benefits of using a software system to facilitate the use of the design method. The resulting prescriptive knowledge is a step towards domain-independent support for structured reflection on design processes. It may help to increase the effectiveness and efficiency of design processes in practice.
2.7.3 Relations between the results

To describe each result in this thesis, I used the previously described result: The description of the design frame is based on the design philosophy; the description of the design method is based on the design frame (and the design philosophy). The design philosophy is described first because it introduces my terminology. In the conclusions at the end of this thesis, my results are placed in a broader perspective, their value for the world of designing is discussed, and recommendations for further research are given.

2.8 Research process

In this section, a summary of the research process I performed is given. Although it is unusual to describe the performed research process (including the changes in direction) in a Ph.D. thesis, I believe that such a description can help to interpret the results adequately, to judge the quality of the results, and to see how the results can be extended. A description of the performed research process can help when it gives a description of the development of the results in the specific context of the research project. Or, in other words, when it describes the search process that resulted in the changes in direction and when it describes when which (preliminary) result is developed and which factors influenced the results. For example, the description of my research process demonstrates, among others, that the development of the design frame preceded the development of the design philosophy. Because in the field of design research fully accepted research methods do not yet exist, a description of the performed research process also describes the research method that is followed. The research method that I followed is the process of my explorative study, with a justification of this process based on the factors leading to the changes in direction. These changes in direction finally shaped my thesis in its current form. In the next subsections, the research process I performed is described. The description starts, in Section 2.8.1, with an overview of my research process. Arguments for the main decisions that I made about the final results are mentioned in the parts of this thesis where these decisions are mentioned.\textsuperscript{13} Conclusions about my research process can be found in Section 6.2.

2.8.1 Overview of the research process

I started my research process with a literature study in which I explored general design literature and literature specific for the three design disciplines. The goal of the literature study was to find domain-independent characteristics of design processes. I also consulted literature about research methodology (in the social sciences): [Verschueren et al., 1995], [Yin, 1994], and [Wester, 1991].

To explore design practice and to find the most important characteristics of design processes in several disciplines, I chose qualitative research based on an empirical approach. I performed case studies in the three chosen disciplines because the literature did not offer enough information to develop domain-independent design knowledge that is based on several disciplines. I first interviewed junior designers at the end of the design process of one of their design projects and I analysed their documents made during these projects. In a cross-case analysis, I compared all junior cases. Then, I performed the same activities for expert designers: interviewing the expert designers, analysing their documentation, and performing a cross-case analysis.

The literature and the case studies were the basis for the development of descriptive knowledge, namely a design philosophy and a design frame. I based the development of prescriptive knowledge on the descriptive knowledge, namely a design method and a prototype software tool supporting the use of the design method. When the design frame and design philosophy became stable, I developed (in parallel) a design method and a prototype software tool. Because the goal of the explorative study was

\textsuperscript{13} A more complete version of the description of the performed research process could also include argumentation for decisions about the preliminary results. This kind of argumentation is not given because it is less important for understanding the final results and the description of the performed design process would become very extensive.
a practical one, namely the (fast) development of support for design practice, the choices I made during my research process were more pragmatic.

In the empirical study I performed at the end of my research process, expert designers gave feedback on all results; junior designers gave only feedback on the design method and prototype software tool. The expert designers gave comments on my results in an interview; the junior designers used the design method and the prototype during one day and evaluated both at the end of the day. The feedback is only a first confrontation with design practice, to judge the generality (domain independence), the relevance, and the potential usefulness of the results for design practice. At the end of the research process, I performed again a literature study: I explored literature related to my results in order to position my results. I ended the research process with the writing of this thesis, which was an iterative process in itself. An overview of the contents of my research process is given in Figure 2.3.

![Diagram](image)

Figure 2.3: Overview of the contents of my research process.

In the next subsections, a chronological description of the important changes of my research goals during the four years of my Ph.D. research is given. Also, the main activities I performed, the main evolution of the concepts of my results, and the main factors influencing my research process and results are described, in periods of one year. Note that this description corresponds to a description of the three parts of a design situation, namely the design process (my activities), the product being designed (the preliminary results), and the design context (the factors influencing my research process and its results). An overview of the evolution of my results is given in Figure 2.4. Figure 2.5 gives an overview of main activities in my research process. To fully understand all changes in the concepts of my results, it may help to return to this section after reading the chapters containing my results.

![Diagram](image)

Figure 2.4: Evolution of the most important results.
2.8.2 First year

The starting point for my research activities, in September 1996, was the research proposal, entitled ‘Towards a Multidisciplinary Framework for Design’, written by Dieter Hammer, Peter Kroes, and Thijs Bax. The first research goal I defined included the development of a domain-independent design framework (to be developed by searching for the greatest common denominator of the effective approaches to design in different design disciplines) and the development of discipline-specific approaches. Important aspects of designing in different disciplines would be inventoryed, described, and modelled. I planned the following four phases in my research process:

- Phase 1: making a research design, doing a literature study, preparing the case studies in practice, following some education;
- Phase 2: executing the case studies and following education;
- Phase 3: analysing and modelling the different cases;
- Phase 4: synthesis.

After half a year, I defined the following objectives: The first goal was to inventory, describe, model, and compare the most important aspects, generic methods, and problems of design situations in different design disciplines in practice. The second goal was to consider in detail one aspect in relation to a bottleneck in a design situation to develop support for the design practice. The planning of the second year included performing a literature study and case studies. The first two years of my Ph.D. research would be broad: doing cases studies and analysing these. The case studies would deliver problems in practice. The last two years would be in more depth: I would synthesise case studies into a general framework and into differences. One problem would be chosen and analysed more in detail. Support related to this problem would be developed, evaluated, and improved. The support would be an application to test the general framework.

During the first year, my ideas about a framework for design changed as follows. My first idea of a framework was a design model based on existing models. Then, I saw the framework as a structured list of important aspects that could be general for designing in different disciplines; important concepts in the structure of the framework were: designing, design process, design space, project management, and project context. I decided to develop a framework by following the ‘grounded-theory approach’. This is a systematic procedure for qualitative research in which theory is developed step by step, based on systematic obtained and analysed research data. The procedure of the grounded-theory approach is described in, for example, [Wester, 1991] and [Verschueren et al., 1995].
The main results of the first year were the following:
- a literature study about design research and research methodology,
- summary reports of two pilot case studies,
- a protocol to perform case studies,
- a research document describing my research methodology,
- a list of possible cases studies in the three disciplines,
- a preliminary framework for design.

Important factors that influenced the research process and its results in the first year were the following:
- I participated in a course about designing (of the SAI program Architectural Design Management Systems), in which I did case studies in architecture and in which I was forced to think about doing case-study research.
- My supervisors offered me references to the literature and supported me to go to the ICED conference. The literature and the people I met at the ICED conference influenced my ideas about what would be a good direction for research.
- My supervisors Dieter Hammer and Joan van Aken stressed the importance of the case studies, whereas Thijs Bax emphasised the importance of an extensive literature study.

2.8.3 Second year

In the second year, I mainly performed the case studies. The framework was used to structure the question lists for the interviews, to transcribe the data of the cases, and to compare the cases of the junior designers. Then, I made a cross-case analysis and I developed a new version of the framework (based on similarities between the junior cases). I did the same after the cases with the expert designers. The framework transformed into a structure that offered a common terminology for describing and comparing design situations in different disciplines; I saw it more as a means than as a theory. The most important aspects of the framework were design situation, process, and product. A design situation was defined as all the aspects related to designing during a design project.

The most important research question during the second year was “What are the most important characteristics of design situations in practice?”. To answer this question, I compared the cases for similarities and differences, I studied literature about designing in different disciplines, and I made a description of design situations in the three chosen disciplines.

The goal of the case studies included finding problems that could be solved. Furthermore, Dieter Hammer wanted that an application would be developed to support designers in practice; an application could also test the theory (my framework for design). However, the case studies did not reveal a number of clear bottlenecks. As a consequence, at that moment\(^{14}\), I did not find a general problem in the different disciplines that I could solve. I decided to develop a general tool, useful in all disciplines. The first idea for an application was to base it on the concept of design histories (see, for example, [Wiegeraad, 1999]) or on the principles of TRIZ\(^{15}\) [Altshuller, 1996], or to support the documentation process in a design process. The research goal was then defined as decreasing the gap between design theory and design practice by describing design situations in practice and by translating the theory to practice. For the third year, I planned to perform a cross-case analysis and to design a design method and a design tool, based on the design method. At the end of the third year, I would test the tool.

The main results of the second year were the following:
- reports of the case studies,
- preliminary results of a cross-case analysis,
- a new version of my framework for design,

\(^{14}\) Later on in the research process, I recognised the need for supporting reflection on design processes.

\(^{15}\) A methodology for creative problem solving, depending on three major principles, namely resolution of contradictions, the evolution of systems, and the ideal result.
first ideas for an application,
- a paper about my research methodology and the first results of the cross-case analysis [Reymen, 1998].

Important factors that influenced the research process and the results in the second year were the following:
- At the beginning of the second year, I read in the Ph.D. thesis of Kees Dorst about design situations and picked up this concept.
- Thijs Bax influenced my ideas about a framework for design in the many discussions we had together.
- Dieter Hammer stressed the importance of an application for designers. The consequence of my choice to develop an application was that I had to stop the procedure I followed to develop the framework for design, namely the ‘grounded-theory approach’. It was not possible to combine this procedure with the development of also a design method and an application in an explorative study of four years.

2.8.4 Third year

At the beginning of the third year, I wrote a first version of the introduction to my thesis. At that moment, I decided that the discipline-specific approaches I planned as a result of my research (see in the first year the definition of my first research goal) would not be developed anymore. I also introduced then the concepts design session and reflection. I introduced the concept of a design session because I observed that main structuring principles of design processes in practice are design phases; design phases take long periods in time (usually some months). Shorter periods in time seemed to be desired to me (see Appendix C Section C.4). I defined a design session as a short period of time during which designers are designing, for example, one afternoon. Because I recognised a general need for supporting reflection on design processes, I decided to include support for reflection in my tool for design practice. A first proposal of a design method included the following main steps for each design session: first, describing the design situation, then, performing design activities (defining problems, specifications, and solutions in an iterative cycle), and, finally, reflecting on the results of the design process. The design method was supported by forms to fill out and by checklists. For the design sessions at the beginning and end of a design process, different kinds of forms and checklists were developed.

After four months in the third year, a written version of the framework for design was ready including a possible use of the framework for describing design situations. The description of the framework for design was split into a static and a dynamic description. The static description included the dimensions time, level, and view and a distinction between a framework for describing processes and one for describing products; a distinction was made between factors (about the process) and properties (about the product). The dynamic description included a description of the transformation and evolution of design situations. The framework was described as a matrix: time, level, and view as rows and kind of factors, relation between factors, and description of factors as columns.

During the next months, I worked on the design method and the design tool in parallel. The design method was elaborated as a list of questions that could be used to make a description of a design situation. The example of a garden house was also introduced. The ideas about the tool became more concrete. The tool would test the design frame and support the design method (support making a description of a design situation, sustain transforming a design situation, support administrating all information of a design situation, and ask questions about the design situation to the user). The challenge of the design process of the tool was to develop something useful.

Halfway the third year, I decided to split off a design model from the framework for design. The design model was a domain-independent representation of designing that offered a common vocabulary about designing. I made a distinction between general definitions and definitions for the context of designing. Among others, definitions of a state, an activity, an object, a product, a design process, a design task, and a design context were given. The definition of designing was transforming
the state of a design task into another state with the goal of changing an abstract product representation into some desired direction. A design situation was defined as a set of important factors influencing a design task. The design model evolved into a *design philosophy*. The design philosophy is based on a further elaboration of the design model and on some general concepts in the literature. The (remainder of the) framework for design, at that moment renamed to *design frame*, offered a domain-independent structure for describing design situations during the design process of one product. To describe design situations, factors and relations were introduced. The description of the design frame included sections about a definition of a design situation, about describing design situations, about dimensions, and about representations. Finally, I improved the design frame in several iterations, based on a comparison between the design frame and the design theory of Bax and Trum (see, for example, [Bax, 1986] and [Bax, 1989]); the result is the current design frame.

The *design method* was split into three different methods: the first one based on the idea of design sessions, the second one on how to describe design situations, and the third one on asking questions and giving answers. Forms and checklists for describing factors and relations supported the method. Predefined types (attributes) with predefined choices (values) were proposed in the forms. Some of these predefined types were the dimensions of the design frame. The distinction between product, design process, and design context was also made in the design method. The checklist was structured into parts concerning the design task (including the product being designed and the design process), the interaction with the design context, and the context. The distinction between different kinds of design sessions in a design process (one at the beginning of the process, one at the end, and the design sessions in between) was still made; a different checklist was made for each kind of session. Because new ideas resulted from the interactions between the development of the design method and the design of a prototype, the three methods were again integrated in one method, later in the third year.

I made a description of the desired *prototype*, the design process of the prototype, and its design context, using my design method. I also made a description of the implementation task for a programmer. Halfway the third year, the implementation process of a prototype of a tool started. From that moment, the design and implementation of the tool were performed in parallel. A team consisting of Jack van Wijk, Elisabeth Melby (programmer), and I, worked together and had regular meetings in which important decisions were taken (choice of programming language, use of a database or not, etc.). Huub van de Wetering offered technical advice. The prototype was being developed to reach two goals, namely, first, the development of a methodological aid to investigate the suitability of the design frame and the design method in practical situations and, second, the development of a design aid to support (student) designers. The prototype should combine the benefits of the design frame and the design method with the possibilities of the medium (software). The prototype would concentrate on storage of information (description of all properties and factors of a design situation) and on searching for information. The prototype was developed via rapid prototyping; however, the development of the prototype still took a lot of time. When it became clear that the prototype could not include all desired properties, only a subset was implemented; the remaining subset could be realised in further versions of the prototype.

The *main results* of the third year were the following:

- a first version of the introduction to my thesis,
- a description of the design model,
- a list of definitions,
- a first description of my design frame,
- a first description of a design method,
- ideas for the implementation of a prototype software tool,
- a paper at the ICED conference about my design frame [Reymen, 1999a],
- a publication about design research, in a book of the Stichting Toekomstbeeld der Techniek (STT) [Reymen, 1999b].
Important factors that influenced the research process and its results in the third year were the following:

- The design process of the prototype of a tool stopped for a while, because it seemed that no programmer or student was available to help me with the implementation of the tool.
- I worked with Kees van Overveld on a separate research subject: on representations, states (actual, obsolete), actions, and different kinds of transformations. The influence of this work, based on state-transition systems, is recognisable in the design model and in the design philosophy that is based on the design model.
- My supervisors stressed the possible importance of a design session. I gave this concept an important place in the design method.
- My participation in a workgroup of STT about design education and design research offered me important references to the literature.
- The ICED conference in which I participated offered me inspiration to change the emphasis of my tool from databases and storage of information into support for reflection.
- Changes in the concepts of the method and tool delayed the implementation of the prototype.

2.8.5 Fourth year

At the beginning of the fourth year, I wrote a paper about my design philosophy and design method, together with Dieter Hammer. This offered a basis for two chapters of my Ph.D. thesis and was the start for writing the core of the thesis. In a new version of the introduction, the main goal of the research was described as decreasing the gap between design research and design practice by generating knowledge about designing that is based on the literature and on the design practice and that is developed for the design practice. The first sub-goal was described as developing domain-independent knowledge about designing and making this knowledge useful for the design practice of different disciplines. The second sub-goal was described as developing support for aiding designers with regular reflection on design situations.

During the fourth year, some important decisions about the user interface of the prototype were made and a representation for the checklist was chosen. The confrontation of junior designers with my method and prototype was planned and performed. Influenced by the development of the prototype, the different types of design sessions in my design method disappeared (sessions at the beginning and end of a design process were no longer distinguished). Together with the programmer, I finished the development of the prototype.

During the writing process, the formulation of my goals and results changed several times, based on the comments I got from my supervisors. Also during the writing process, I decided to concentrate on reflection, because reflection on design processes became an increasingly important concept in my thesis.

The main results in the fourth year were the following:

- a paper about my design philosophy and design method [Reymen et al., 2000],
- a working prototype including user and implementation documentation,
- results of the confrontation of my results with design practice,
- a concept version of my Ph.D. thesis.

Important factors that influenced the research process and the results in the fourth year were the following:

- A presentation about my design method in Delft offered me a lot of feedback. Based on the comments I got, I emphasised in the design method reflection on design processes (by means of special question lists).
- My supervisors gave comments on several versions of this thesis. Peter Kroes asked mainly questions about my terminology; Kees Dorst became a member of the reading committee of my thesis, which also influenced the form and contents of my Ph.D. thesis.
− My participation in workshops of the university with the design practice in the Eindhoven Region (about a new Master’s program Industrial Design) offered me insight into the problems and needs in practice.
− Discussions with Otmar Donnenberg and Claudius Drewes increased my insight into reflection processes. They also offered me important literature about reflection.

2.9 Overview of the thesis

The thesis starts with an exploration of the world of designing, which gives background information useful for reading this thesis and which is used to position my research. Chapter 2 (this chapter) describes the research project. Note that this chapter describes the results of my research project (in Section 2.7), the research process (in Section 2.8), and the research context (in Section 2.1), similar to the three parts of a design situation. My results are described in more detail in the following three chapters: The design philosophy is given in Chapter 3; the design frame is presented in Chapter 4; the design method is explained in Chapter 5. Finally, in Chapter 6, I start from the answers to the research questions of Section 2.5 and from my research process and put my results into a broader perspective in conclusions and recommendations for further research. (In the three chapters about my results, only conclusions regarding the goals of the individual chapters are drawn.) Appendix A gives an example of the design of a new type of garden houses to illustrate the use of my design method. Appendix B describes a prototype software implementation supporting the use of my design method. Appendix C describes the approach and results of my case studies. Finally, Appendix D describes the approach and results of the confrontation of my results with design practice. The thesis also includes a glossary with definitions of the most important concepts in my thesis.

The main activities performed in my research process and the main results of my research project are positioned in the overview of my thesis in Table 2.6. In this table, the research activities and results are described in a chronological sequence, as described in my research process (see Section 2.8); the chapters of the thesis are ordered rationally. Results of the literature studies performed at the beginning and at the end of my research process can be found in the introduction to this thesis, in the chapters presenting my results, and in the conclusions. A summary of the approach to and results of the case studies can be found in Appendix C. The descriptive knowledge is described in Chapters 3 and 4; the prescriptive knowledge is described in Chapter 5 and Appendices A and B. A summary of the approach and results of the feedback can be found in Appendix D; conclusions about the feedback can be found in Section 6.2.
Table 2.6: Research activities and results positioned in the overview of this thesis.
3 Design Philosophy

3.1 Introduction

The goal in this thesis is to develop domain-independent design knowledge to support designers in several design disciplines with structured reflection on design processes. As mentioned in Section 2.6, I have chosen to first develop domain-independent descriptive knowledge that can be used for the development of prescriptive knowledge. Necessary descriptive knowledge for supporting designers in several design disciplines are general concepts and terms to describe design processes in a domain-independent way. Besides being useful for developing domain-independent support, these domain-independent concepts and terms can be useful for design practice, as described in Section 2.3.

The goal of the design philosophy, described in this chapter, is to offer concepts and terms that are useful for describing design processes in a domain-independent way. The design philosophy is based on the case studies I performed in several design disciplines in practice (see Section 2.8 and Appendix C) and on a literature study. Important concepts of design processes I recognised in several design disciplines are design situation and design activities. These concepts are very much related to a general mathematical concept, namely that of state-transition systems. In the latter concept, a state is defined at a certain moment in time; a state is changed by transitions; states and transitions can be considered during a certain period of time. A design situation corresponds to a state; a design activity may correspond to a transition; the period of time can be the duration of a design process or a shorter period of time. These periods can be any period of time within a design process, but in practice, not all possible cuts in a design process are meaningful. In Sections 3.5.1 and 5.5, a design session is introduced as a meaningful period of time (i.e., for supporting regular reflection on design processes).

The concept of state-transition systems is successfully used in computer science and control theory. Many processes can be described as state-transition systems: for example, workflow processes, logistics processes, and assembly processes. The general terminology of state-transition systems is defined independent of a certain domain. General literature about state-transition systems can, for example, be found in [Lewis et al., 1998] and [Linz, 1996]. The design philosophy presented here uses the concept of state-transition systems to describe design processes. Only the externally observable behaviour of designers is described, omitting, for example, the cognitive aspects of designing. Also, only the basic concepts of state-transition systems are used and translated to design processes. The mathematical notation and definitions of state-transition systems are not used. An attempt is made to establish a consistent set of definitions. The basic terminology of state-transition systems (state, transition, state space) is extended with terminology commonly used in technical sciences (like entity, property, factor, representation, relation, and process). The definitions of state transition and state space are identical to the original definitions. The original definition of a state is a possible set of values for all attributes concerned. This definition is adjusted to the other general definitions used.

My design philosophy is a set of domain-independent concepts and terms for describing a design process from the viewpoint of state-transition systems. As shown in Section 1.3.1, design processes can be described from many different points of view. My design philosophy offers a general descriptive model of a design process and can still be interpreted in several ways. The model does not exclude viewpoints like designing as a social, a creative, or an iterative process. To describe a design

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16 Literature about state-transition systems in general (not applied to a specific domain) can be found in books and articles about ‘finite automata’. The definition of finite automata includes all important concepts about state-transition systems. Literature about state-transition systems in the context of designing is mentioned in Section 6.1.1.
process from one of these viewpoints, the model must be extended with specific concepts. My design philosophy can thus still be extended with more concepts about how design is, might be, or should be done: It is only a partial design philosophy. A first publication of the design philosophy can be found in [Reymen et al., 2000].

In the next sections, general concepts concerning state-transition systems are given and explained using general examples (a football and a cooking process). Every concept is then adapted to modelling the design process and is illustrated with the example of designing a garden house. In Section 3.1, the concept of a state is used to define a design situation. In Section 3.2, the concept of state transitions is translated into design activities and transitions in the design context. The concept of a design activity is used, in Section 3.4, to define a design process. Section 3.5 introduces the concepts design task, which is used to define a design session, and design context. In Section 3.6, a definition of designing is derived. Finally, in Section 3.7, all concepts are combined into a design model, representing the design philosophy. The concepts and terms described in this chapter are used consistently throughout the whole thesis. General conclusions about the design philosophy can be found in Chapter 6.

3.2 A design situation as a state

The next subsection defines the general concepts entity, representation of an entity, state of an entity, and description of an entity. These concepts are used to define, in Section 3.2.2, a product, a design process, their representation, a design situation (one of the main concepts used in this thesis to describe design processes), and a description of a design situation (used in my design method to support making a description of a design situation as a basis for reflection).

3.2.1 Definition of a state

An entity is an object or a process; it exists in reality. An entity is for example a football or a cooking process. People make representations of entities, for themselves or for others. To define a representation of an entity and to define the state of an entity, the following definitions are needed. A property describes a characteristic of an entity. An entity can have a set of properties. A property can have a set of values. A property describes, for example, the colour of the football or its position. The values of these properties can be ‘white’ or ‘yellow’ and ‘on the ground’ or ‘in the air’. A factor describes an external influence on the characteristics of an entity. An entity can have a set of factors influencing it. A factor can have a set of values. A factor influencing the football describes, for example, a football player. The values of this factor are ‘head the ball’ or ‘shoot the ball’. A factor has the ‘potential’ to influence the entity in the present or in the future.

A relation between two properties and/or factors describes the way in which one property or factor influences another property or factor. Possible relations are, for example, hierarchical, causal, and dependency relations. An example of a relation is the relation between a football player and the position of the football: the first ‘can change’ the latter. A property or factor can have relations with many other properties and/or factors. Relations determine possible consequences of changes of properties and factors for other properties and factors. When a property or factor is changed, this can have consequences for all properties and factors having a relation with this property or factor. A consequence can, for example, be a new transition.

A representation of an entity is a reproduction of a relevant subset of the properties and factors of this entity in a mental image, a picture, a textual description, a drawing, a model, a graph, a computer visualisation, a prototype, or in some other way. For example, a representation of the football is a textual description or a drawing of the football. A representation can be mental or physical, formal or concrete, and permanent or volatile. Many different representations can be made of one entity because different subsets can be represented (different abstractions) and even the same subset can be represented in different ways (different media). Making a representation implies modelling the reality from a particular point of view, i.e., neglecting certain (irrelevant) characteristics and influences.

17 These characteristics and influences may be called ‘hidden’ properties and factors.
Different persons can focus on different properties and factors. Using different media and choosing different options in those media can also result in different representations of the same entity. Examples of options in media are for example the choice of fonts in a text editor or the choice between wire frames and solid models in a drawing tool. Different representations of the same entity are not always consistent with each other; for example, a mental representation can be different from the existing physical representations.

A state of an entity is the set of values for all properties and factors describing and influencing this entity at a certain moment in time. The state of an entity at a given moment is thus described by the values of all properties and factors at this moment; for example, for the football: ‘white’, ‘on the ground’, and ‘shoot the ball’. The state of an entity can be seen as a special property of an entity; it also describes a characteristic of the entity; its value is a set of values.

A description of the state of an entity is a description of a relevant subset of the state, using the general terminology of state-transition systems. For example, consider the following description: “The set of properties of a football is its colour and its position; the set of values for these properties is ‘white’ and ‘on the ground’”. A description of the state of an entity may include a description of the relations between the properties and factors of the state. A description of the state of an entity is a specific kind of representation of the entity. To make a description, concepts are needed; a state description can thus be seen as a conceptualised representation of the entity. An example of a representation that is not a description is, for example, a photograph.

![Figure 3.1: The concept of a state of an entity.](image-url)

The difference between an entity, its representation, the state of an entity, and a state description can also be explained as follows (and is also illustrated in Figure 3.1 and summarised in Table 3.9). An entity exists in reality. I have chosen to model (an entity in) reality by the concept of a state, including values for properties and factors. An entity has only one state at a certain moment; a state includes values for all properties and factors; a state is ‘objective’. An entity can be represented in many different representations. A representation of an entity consists of a limited set of properties and factors and is made by someone or something. Which properties and factors are included and made
Definition of a design situation

An entity is a product or a design process. The definition of a design process is given in Section 3.4.2. A product is an artefact (that must be designed) satisfying a human need. This artefact can be an object or a process. Examples of objects are a production machine, a building, or a software program. Examples of processes are a social process, a design process, a production process, or a logistics process. The life of a product is represented by its product lifecycle. This is a representation of the product evolution, starting from a statement about the need of the product, continuing with its design, production, use, and reuse, and ending with its decommissioning. In the remainder of this thesis, the concept of a product being designed is used to indicate the product during the design process, because the product itself does not yet exist during this process. The product being designed can be a new product or a redesign of an existing product, a mass product or a unique product, and a material or immaterial product. In any case, it must be a new creation (not-yet-existing in a specific context).

A design property describes a characteristic of the product being designed or of the design process. A design factor describes an external influence on the characteristics of the product being designed or of the design process. A designer cannot determine a design factor. In the remainder, design properties and design factors are just called properties and factors. The distinction between properties and factors is based on who ‘determines’ the property or factor and who can ‘influence’ the property or factor. A designer cannot determine factors, but a designer might be able to influence some design factors by interaction with the design context. A definition of the design context is given in Section 3.5.2. The distinction between properties and factors is explained in more detail in Sections 3.3.2 and 3.5.2.

Properties of a product being designed describe, for example, the dimensions and the kind of coating of a garden house. Values for these properties are ‘2.5m high’, ‘1.8m wide’, ‘1.8m long’; ‘coating with ingredient ‘X’’. Some of these values can be expected values (they are not yet fixed and are only preliminary). Properties of a design process describe, for example, members and characteristics of a design team, characteristics of a designer (related to the design process: skills, knowledge, attitude, experience; other: character, health, salary, power), design aids (methods, computer support), and characteristics of the environment (workplace, presence of a coffee machine). For example, values for the properties duration, cost, mood of the designer, and his experience with the design of this kind of product are ‘halfway estimated duration’, ‘$15000 spent already’, ‘optimistic’, and ‘much experience’. Possible factors in the design context describe dimensions of production machines and environmental laws; values for these factors are ‘maximal dimensions of one plank’, ‘only coatings allowed without ingredient ‘Y’’. More examples of factors describing the design context can be found in Section 3.5.2. Appendix C Section C.4 describes important properties and factors in two of the case studies I performed. In the literature, a survey of factors is given in [Hubka et al., 1996], [Wallace, 1991], and [Günther et al., 1996]. However, slightly different definitions are used there. In [Hubka et al., 1996], the survey offers ‘factors influencing the design situation’, [Wallace, 1991] lists ‘influences and their contributing factors’. [Günther et al., 1996] describes ‘factors determining the design process and its result’.

For properties, a distinction can be made between current and desired properties. This distinction is summarised in Table 3.2. Current properties are properties of the product being designed or the design process at a given moment; desired properties are related to the design goal, as defined in Section 3.3.2; Current properties are determined by a designer and can be influenced by a designer. Desired properties can be determined by a designer or by the design context. A designer can influence some of the desired properties; the other desired properties can only be influenced via interaction between a designer and the design context. Desired properties and factors correspond to the concepts constraint, requirement, and specification that are often used in design literature and practice.
Table 3.2: A distinction between properties and factors.

In design processes, the concept of ‘a proposal’ or ‘an alternative’ is very important. This concept is modelled as shown in Figure 3.3. Values of different properties can, together, describe an alternative or a proposal for the product being designed or the design process. For each alternative, different properties of the entity can be important. Proposals or sets of alternatives can occur for current as well as for desired properties.

A design relation is a relation between (design) properties and/or (design) factors. Relations exist between properties of the product being designed, of the design process, and/or factors in the design context. An example of a design relation is the relation between a description of the dimensions of the production machines and the dimensions of one plank: the first ‘limits’ the latter. In the remainder, a design relation is just called a relation. Because often in the design process, many properties and factors of the product being designed and of the design process are related, changing or adding properties and values can have consequences for many other properties and values: Related properties of the product being designed can be taken into account for integration; relations between properties of the design process can be taken into account by iterating in the design process.

Designers make representations of the product being designed, the design process, and the design context. A representation of the product being designed is a reproduction of a relevant subset of the properties describing the product being designed in a mental image, a picture, a textual description, or in some other way. A representation of the product being designed is also called a design. A representation of the garden house is, for example, a 3D model or a drawing. A representation of a product being designed can include instructions about how to produce the product, how to use the product, or how to re-use the product. It can also include rationales for the choices made. Similar definitions can be given for a design-process representation and a representation of the design context. A representation of the design process is, for example, a planning or an organisation scheme. An example of a representation of the design context is a list of the properties of the production
machines and laws. A representation of the product being designed or of the design process for a specific stakeholder is called *documentation*. In spite of the fact that the design context is not an entity, see the definition in Section 3.5.2, the definition for a representation of the design context is based on the definition of a representation of an entity. In practice, the different representations are not strictly separated: A representation of the product being designed includes, for example, also a reproduction of part of the design context. The representations help designers to communicate with themselves and with others. For the product being designed, representations are necessary because the product itself does not yet exist.

The *state of a product being designed* is the set of values for all properties describing the product at a certain moment in time. The *state of a design process* is the set of values for all properties describing the design process at a certain moment. Finally, the *state of the design context* is the set of values for all factors influencing the product being designed and the design process at a certain moment. A *current state* of a product being designed or design process is a set of values for all current properties. A *desired state* of a product being designed or design process is a set of values for all desired properties.

A *design situation* at a certain moment is defined as the combination of the state of the product being designed, the state of the design process, and the state of the design context at that moment. This means that it is

- the set of values of all properties describing the product being designed,
- the set of values of all properties describing the design process, and
- the set of values of all factors influencing the product being designed and its design process.

This is illustrated in Figure 3.4. For example, a design situation is the following set of values:

- ‘2.5m high’, ‘1.8m wide’, ‘1.8m long’; ‘coating with ingredient ‘X’’ for the product being designed;
- ‘halfway estimated duration’ ‘$15000 spent already’, ‘optimistic’, and ‘much experience’ for the process;
- ‘maximal dimensions of one plank’, ‘only coatings allowed without ingredient ‘Y’’ for the design context.

![Figure 3.4: A design situation as a state.](image)

A *description of the state of a product being designed* is a specific representation of a relevant subset of the set of values of all properties describing the product being designed. The description is made using the terminology of state-transition systems applied to the context of designing. An example is the following description: “Values for the property dimensions and kind of coating are: h 2.5m, w 1.8m, l 1.8m and coating with ingredient ‘X’”. Similar definitions can be given for the description of the state of a design process and for a description of the state of the design context. The following description, for example, describes the state of a design process: “Values for the properties duration and cost are ‘halfway estimated duration’ and ‘$15000 spent already’”. The state of the design context
is, for example, described as follows: “The value for the factor dimensions of production machines is ‘the maximal dimensions of one plank’”.

A description of a design situation is a specific representation of a relevant subset of the set of values of all properties describing the product being designed and the design process, and of the set of values of all factors influencing the product being designed and its design process. The description is made using the terminology of state-transition systems applied to the context of designing. The description may include a description of the design relations between the properties and factors of the design situation.

3.3 Design activities causing state transitions

The next subsection introduces the concept of a state transition. This concept is translated, in Section 3.3.2, to important actions in the world of designing, namely design activities and transitions in the design context.

3.3.1 Definition of a state transition

A change from one state to another is called a state transition. A transition is caused by one or more actions. An actor executes an action. For example, the state of a football at a certain moment is the set of values ‘white’, ‘on the ground’, and ‘shoot the ball’. After the action of kicking the ball, executed by a football player, the values are ‘white’, ‘in the air’, and ‘head the ball’. A goal-oriented action is called a transformation; an action without a goal is called a mutation. A mutation occurs spontaneously. A goal is the end state towards which an effort or ambition is directed. For example, when the goal is ‘to make a goal’, a transformation can be heading or shooting the ball. An example of a mutation is a change in the position of the ball caused by the wind. Changing the set of properties, factors, or values in the current state changes the current state of an entity to the next state. Changes may include additions and deletions of properties and factors. A state is changed when at least one property, factor, or value is changed.

Actors can change the state of an entity by changing the entity itself or by changing a representation of the entity. To explain the latter in more detail, a distinction must be made between existing and not-yet-existing entities. For an existing entity, only changing the properties of the entity itself and/or changing the factors influencing it can change the state. A state change can, for example, be caused by processing, painting, welding, assembling, folding, or compiling the entity. For a not-yet-existing entity, making a transition from one representation to another and from a representation to an entity and/or changing factors influencing the entity may result in a state change. A transition from a representation to an entity occurs, for example, when manufacturing an entity. Note that changing the representation of an entity does not necessarily result in a changed state. For example, the state of a not-yet-existing garden house is not changed when changing the colour of the text of the representation.

3.3.2 Definition of a design activity and of a transition in the design context

A change from one design situation to another is caused by one or more actions. Changing the state of the product being designed, the design process, and/or the design context changes the design situation. Actions changing the state of the product being designed are producing a representation of the product being designed with changed properties and/or changing factors influencing the product being designed. Actions changing the design process are producing a representation of the design process with changed properties, changing factors influencing the design process, and/or executing changes in the design process itself. Producing a representation means creating a new representation or modifying an existing representation; it is a transition from one representation to another. For example, it is making a complete drawing of a garden house, drawing just one additional line, or changing the organisation scheme of the design team. An example of changing the design process is the recruitment of a new team member.
Designers can change the properties of the product being designed and of the design process. Current as well as desired properties can be changed and proposals and alternatives can be formulated. The latter two may be ‘experiments’ to see if the idea will work and will meet the design goal; these experiments sometimes include calculating risks. Designers can determine all current and some desired properties. New properties can arise by new insights of the designer or existing properties can be combined or split in several properties. A new current property can be based on an existing desired property. Or, a new desired property can be based on an existing factor. For example, a factor can describe ‘only coatings allowed without ingredient ‘Y’’. A desired property can describe ‘the coating should have ingredient ‘Y’’. The current property can describe ‘the coating has no ingredient ‘Y’, but the positive characteristics of ingredient ‘Y’ are obtained by using ingredient ‘Z’ and painting the wood twice with the latter ingredient’. The desired property and factor remain part of the design situation.

Designers can change the state of the product being designed and of the design process, but, by definition, designers cannot determine factors and they can only influence some of them via interacting with the design context, as explained in Section 3.2.2. Designers can only change factors describing the design context in representations of the design context\(^{18}\) (these factors are thus not changed in reality). Stakeholders can change the state of the design context. Note that producing a representation of the design context and interacting with other designers and stakeholders are actions that not directly result in a changed state, but which are necessary to prepare such a change. The interaction between designers and stakeholders is explained in more detail in Section 3.5. Designers are actors executing design activities. Stakeholders are actors in the design context. The possible actions causing a state transition, namely design activities of designers and transitions in the design context, are explained in more detail.

A design activity is a transformation towards the design goal at that moment, carried out by a designer, causing a transition of the state of the product being designed or of the design process. The definition is illustrated in Figure 3.5. A design activity can result in a changed product being designed as well as in a changed design process. The concept of a design activity is well known in the literature. In my design philosophy, the actions of designers are interpreted as activities causing a state transition. This is, however, only one way of describing design activities. More about the concept of design activities in the literature can be found in Section 1.3.3.

Figure 3.5: Design activities causing a state transition.

A design goal is the goal of a design activity or a design process. The goal of a design process is defined in Section 3.4.2. The goal of a design activity is to create a desired representation of the product being designed having a desired state; the representation must thus fulfil the desired properties for a representation and the product being designed must fulfil the desired properties for the product being designed. The desired state can be specified in terms of desired properties of the product being designed in Section 3.4.2.

\(^{18}\) Note that a representation of the design context does not necessarily conform to the current state of the design context: Factors describing the context may already have changed in reality, but this change has not yet been recognised by the designer.
designed. Because a designer only works with representations, he must create a representation that is desired, i.e., that fulfils some demands about medium of representation (for example, mock-up or 3D presentation) and about usefulness for stakeholders. The goal of a design activity is usually not explicitly defined. An example of the goal of a design activity is determining the kind of coating of the garden house. In the desired state, a value for the property ‘kind of coating’ must be defined. The desired representation can be a textual description.

*Transitions in the design context* can be described by transformations or mutations. A transformation can have a goal that may or may not coincide with the design goal. A stakeholder can change the state of the context; he can influence factors and can interact with the designers. Stakeholders have an interest in the product being designed and/or the design process and can be part of the company or of society. Examples of stakeholders that are part of the society are customers and users. Examples of company-internal stakeholders are the production manager that can buy a new production machine or the logistics manager that can change the concept of distributing the garden house. A mutation is an action in the design context with a goal that is independent of the design goal. Mutations take place independently of the lifecycle of a specific product, but can influence this product and its design process. Examples of such mutations are those of a competitor and the introduction of a new law.

### 3.4 A design process as a sequence of state transitions

Based on the definitions of state transition and design activity, definitions of process and design process are given in the next two subsections. Also, an important concept in the theory of state-transition systems, namely the concept of a state space, is introduced. This concept corresponds to the important concept of design space in design theory.

#### 3.4.1 Definition of a process

A *process* is a sequence of state transitions. A *transformation process* is a sequence of transformations of an entity with the same goal. One or more actors can execute the transformations, in sequence or in parallel, using one or more aids. The goal of each transformation in a transformation process is a sub-goal of the goal of the process. For example, a cooking process consists of a sequence of actions (weighing ingredients, preparing food, boiling or baking, and presenting) with the goal of making dinner. A sub-goal of the goal of making dinner is the goal of having all food prepared. A cook executes the transformation process, using the necessary ingredients and tools. In the remainder of this thesis, the term process is used to determine a transformation process, because only processes with a goal are considered.

The sequence of transformations can be limited in time, starting from an initial state and ending in some (desired) final state. Although the states are ordered in time, nothing is said about the length of the time interval between the different states. The set of all possible states of an entity is called a *state space*. Examples of possible states of a football are:

- ‘white, on the ground (in the centre of the football field), and shoot the ball’;
- ‘white, in the air (in front of the goal), and head the ball’; and
- ‘white, on the ground (at the corner flag), and shoot the ball’.

#### 3.4.2 Definition of a design process

A *design process* is a finite sequence of design activities, necessary to obtain the design goal. Note that the design goal may change during a design process. One or more designers can execute the design activities, in sequence or in parallel, using one or more design aids. Examples of design aids are theories, methods, tools, time, space, money, skills, and knowledge. For the products envisaged in this thesis, the design process takes a finite time; this does not necessarily hold for, for example, the design of an artwork. The design process is one process (phase) in the lifecycle of the product. A design process includes, in this thesis, the design activities, but also the people performing these activities and the means for performing these activities (including the direct environment of the designer). An
alternative formulation of the definition of a design process is a sequence of evolving design situations that finally results in a design.

Characteristics of a design process are the following. The design process is, at the same time, subject to changes (properties of the design process can be changed by designers) and the cause of these changes (as the sequence of design activities). During a design process, designers can concentrate alternately on the product being designed, the design process, and the design context and on current and desired properties. Sets of properties and values (alternatives) can be added, deleted, or changed, based on new experiences. Developing and evaluating proposals and alternatives are ways of experiential learning in a design process. To proceed, designers can also look back at changes made earlier in the design process. As stated in [Gero et al., 1993], creative design involves exploration (i.e., finding new goals, new states, and new state-transition processes). More characteristics of a design process are given in Section 1.3.3. Some of these characteristics can be described in the design philosophy as follows: an iterative process (described for example in [Evbuomwan et al., 1996]) can be described as changing and refining properties; a dynamic process ([Evbuomwan et al., 1996]) as changing states and representations; and a dialectical process ([Bax, 1989]) as changing between product being designed and design process.

The goal of a design process is to create one or more desired representations of the product being designed having a desired state; the representation must thus fulfil the desired properties for a representation and the product being designed must fulfil the desired properties for the product being designed. Compared to the goal of a design activity, the goal of a design process can consist of the creation of more than one representation. Multiple representations must, for example, be made for communication with different stakeholders. Important representations are representations for the realisation of the product being designed. The desired state of the product being designed can be reached after a sequence of design activities. The goal of a design activity in a design process is a sub-goal of the goal of the design process; it can be defined as decreasing the gap between the current and the desired state of the product being designed.

Characteristics of the goal of a design process are the following. The design goal is defined by stakeholders, usually, in cooperation with the designers. Both can define desired properties of the product being designed and can determine the desired representations. Notice that desired and current properties can be added and deleted during the complete design process. This means that the current as well as the desired state continuously change during a design process. In the literature, the simultaneous evolution of desired and current properties is called co-evolution (of problem and solution); see, for example, [Maher et al., 1996]. Usually, the goal of a design process also induces desired properties of the design process. These can be desired properties about the final state of the process or desired properties about the state of the process during the design process. Examples of the first type are budget and time. Examples of the latter are moments for presentation of intermediate results and guidelines for documentation. The design goal can then be formulated as creating a specified product being designed during a specified process. The design process can be specified (designed) beforehand or during the design process.

The goal of a design process is, for example, creating a garden house with a coating that guarantees a long life, but that is not too expensive. Desired representations are a textual description, drawings, and a 3D model. The desired state of the product being designed is ‘ready for production’. The desired state of the design process is ‘finished in one week’. The design process of this garden house can, for example, consist of design activities executed by the senior designer of the design department and by some experts of coatings. They can use CAD to model the garden house and use other tools to analyse its behaviour.

A design space is defined as a limited state space. A design space at a given moment is the set of all possible next states, towards the design goal, of the product being designed and of the design process. The concept of a design space is illustrated in Figure 3.6. The set of all states of the product being designed and of the design process is limited to all ‘possible next’ states ‘towards the design goal’. The latter limitation is useful because a design process is directed. Possible next states are the states of the product being designed and the design process that are derived from the current state by changing
properties and values. The states of the design context do not belong to the design space, because the designer cannot influence these. For example, the current state of the product being designed is ‘2.5m high’, ‘1.8m wide’, ‘1.8m long’ and ‘coating with ingredient ‘X’’. The current state of the design process is ‘halfway estimated duration’ and ‘$15000 spent already’. The design goal is, for example, the goal of the design process given in the example earlier in this subsection. Possible next states are the current state with the following properties added in different combinations:

- ‘only coatings allowed without ingredient ‘Y’’,
- ‘the cost of coating ‘C’ is $10/m²’,
- ‘coating ‘D’ has also ingredient ‘X’’, and
- ‘the estimated life of the garden house is limited to 15 years’.

![Diagram](image)

Figure 3.6: The concept of a design space.

## 3.5 Design task and design context

During a design process, designers change the product being designed and the design process to design a new product that satisfies a human need (that is defined in the design context). The result of a design process, i.e., multiple representations of the product being designed, is then used to realise this product being designed. The task that for that purpose must be performed by designers is called in this thesis a design task. In Section 3.5.1, a precise definition of a design task is given. Also in Section 3.5.1, the concept of a design session, based on the concept of a design task, is introduced; the concept of a design session is an important concept for supporting regular reflection on design processes in my design method. In Section 3.5.2, the concept of a design context is investigated in some more detail.

### 3.5.1 Design task

A *design task* at a certain moment is a task to meet the design goal at that moment, starting from the current design situation. One or more designers perform a design task by executing design activities. Figure 3.7 illustrates the definition of a design task. An alternative formulation of a design task is a task to transform the current state of the product being designed and/or the design process into a desired state, taking into account the design context. The concept of a design task is similar to the concept of a design task in [Dorst, 1997]. Dorst suggests a shift in focus from design problem to design task; a designer is not only faced with a design problem, but also with a design task. Dorst defines a design task as a combination of ‘the design problem’, the design situation, and a time component. More about design problems can be found in Section 1.3.2.
At every moment during a design process, a design task can be defined by a description of the current design situation and the design goal. At the beginning of a design process, the goal of a design process is vague and ill-defined. During the design process, designers and stakeholders can refine the design goal. At the end of the design process, the state of the product being designed and its representations must conform to the design goal. In practice, a design task is not always explicitly defined. A good definition of a design task includes all product and process information that is necessary for the designers to perform their job.

A design task can be decomposed into several subtasks. A subtask at a certain moment is a task to meet a sub-goal of the design goal at that moment. A subtask can be, for example, the creation of a representation of the product being designed on a certain level of detail by concentrating on certain aspects of the product being designed and by concentrating on a certain process in the product lifecycle. Different subtasks can be executed in parallel or in sequence; iteration between subtasks can also occur. Various subtasks can be defined at the beginning of a design process or during a design process. The latter can be necessary when the complete design task reveals too many problems or is too complex, when more subtasks can be executed in parallel, when subtasks can be delegated to other, more specialised, designers, when factors describing the design context change, or when the design goal changes. Also at the end of the design process, new subtasks can be created as part of a new design process. The creation of a subtask can be an action of a project manager or of an individual designer. The execution of a subtask is influenced by its duration in time, the composition of the design team, the available aids, and the responsibilities. The general division of subtasks over a design process and the sequence of subtasks in a design process are defined in a design strategy.

A design task is being executed during a series of design sessions. A design session is defined in Section 5.5, as a period of time (for example, two or three hours) during which one or more designers are working on a subtask of a certain design task. It is a period of time between two periods during which the designers are not executing that subtask. During a design session, designers execute design activities, which result in changed design situations. The beginning and end of a design session are good moments for reflection on a design process, as proposed in Section 5.5.

### 3.5.2 Design context

A design task is performed by design activities of designers. Stakeholders can perform transitions in the design context. The design context is defined in this thesis as follows. A design context is described by the set of factors influencing the product being designed and the design process at a certain moment. Examples of factors are other processes than the design process in the product lifecycle of the product being designed (for example, the production process, the use process), stakeholders (users, suppliers, etc.), the project to which the design task belongs, a company quality
handbook, the company culture (image, vision, brand), competitors, laws, patents, new technology, discipline-specific knowledge, and the situation of the market (politics, economy, environment, culture). Note that a design context is treated as an entity, although it is not one object or process. A design context is defined relative to a design task; each design task has a specific design context. Design contexts of related design tasks at a certain moment might differ slightly. The contexts have many factors in common but differ because other factors are important for the specific product being designed and the specific design process. A design context is part of a larger context. This larger context has no direct influence on the design task and can certainly not be influenced by the designers. Notice that the direct environment of the designer, namely the design aids, the room, and the team members are all classified in this design philosophy as properties of the design process.

As defined in Section 3.2.2, a designer cannot determine a factor; a designer can only influence some of the factors. A factor must be distinguished from a current and a desired property. A factor can be something that is not explicitly desired but that influences the properties of the product being designed and/or the design process. A factor can also be an undesired side effect. The distinction between properties and factors also depends on the person describing something. Some designers in a design team can define something as a factor, whereas others call it a desired property. Factors in the design context can also become (desired) properties.

As explained in Section 3.3.2, the design context can change during a design process. However, the change rate in the design context is usually lower than in the design process: fewer new factors appear than new properties. Many factors describing the design context exist before the design task is defined and still exist after the task is finished. The factors can also change independently of the design task. For a certain design task, the choice can be made to see the design context as a static environment, instead of a dynamic one. Factors of the design context can then be ‘frozen’. When finished, the design must be validated and verified in the real context. Designers performing a design task can also interact with stakeholders in the design context to exchange information about the design situation, i.e., to get to know desired properties of the product being designed and possibly also of the design process, to refine and validate the desired properties, to get to know the important factors, and to influence factors by discussion and negotiation. My design method, described in Chapter 5, is intended to help designers to take into account all relevant factors describing the design context (by means of checklists).

### 3.6 Definition of designing

As already stated in the introduction to this thesis, it is very difficult to give one general definition of designing. Depending on the importance of certain activities or aspects in the design process, different aspects are emphasised in a definition of designing. For example, based on Section 3.5, designing could be seen as the activity of negotiating with the design context. In my design philosophy based on state-transition systems, designing can be defined as follows. (The definition is derived from the definition of a design activity.) Designing is the activity of transforming the state of the product being designed or of the design process into another state towards the design goal. A designer can perform this activity by producing a representation of the product being designed or of the design process or by changing the design process itself (see Section 3.3.2).

Note that in my philosophy, designing is the activity of transforming the state of the product being designed as well as the state of the design process. In almost all definitions of designing, the transformation or creation of the product being designed is included in one way or another. In my definition, however, also the transformation of the design process is included. My definition makes explicit that designers also change properties of the design process.

My definition of designing also includes the concept of producing representations. The same idea can be found in [Per Galle, 1999]. Per Galle describes designing as the production of design representations. ‘Design’ in his definition refers to the product; for me, representations can be made of the product (being designed) and of the design process. Note that in my philosophy, I have chosen to refer to the product during the design process as ‘product being designed’ and to define a
‘representation of the product being designed’. These choices avoid the difficulty of defining a representation of something (a product) without implying the existence of such a non-existent thing (a product does not yet exist during a design process). Per Galle offers a good discussion on the above mentioned problem and makes an attempt to solve it, but in a different way as I do, namely by defining a design representation in terms of human agents, their actions, and their ideas. The latter definition has the advantage of being more concrete than my definition, but my definition is more domain-independent and is less indirect. More about representations of designed artefacts and of design processes can, for example, be found in [Dym, 1994].

3.7 Design model

A design model representing the design philosophy is given in Figure 3.8. The purpose of this model is the same as the purpose of the design philosophy, namely offering concepts and a terminology for describing design processes in a domain-independent way. In my design model, based on a model of state-transition systems, a design process is modelled as a finite sequence of state transitions. Design situations can be changed by design activities and by transformations or mutations in the design context. To execute a design task, designers may interact with stakeholders in the design context. The goal of possible transformations in the design context does not necessarily conform to the design goal (illustrated in Figure 3.8 with different ‘stars’). The design goal can change during a design process. My model of the design process is not encountered in the literature. Related descriptive models of the design process are mentioned in Section 1.4.1. My model is unique in the sense that it is domain independent and that it combines the concepts design situation, design activity, design task, and design context in one model.

![Figure 3.8: Design model.](image)

The different concepts and terms defined in the design philosophy (both general concepts and terms and those for the context of designing) are positioned in Table 3.9. A distinction is made between reality and representations of reality. The distinction between reality and representations of reality is a difficult problem, which is closely related to our use of language for speaking about reality. I have chosen to categorise commonly used words in the daily practice of designers (like product being designed, design process, and design context) in reality. Terms like property, factor, and state are less commonly used and are in a sense more abstract; they are classified in the design model, which is seen as a representation of reality. Another possibility would have been to classify the more abstract terms also as part of reality; only representations of an entity and descriptions of the state of an entity would then be seen as ‘representations of reality’. Note that during design processes, interaction between reality and representations occur: for example, designers and stakeholders make representations of reality, designers determine properties and create design tasks, and stakeholders influence factors.
Different types of representations are distinguished, depending on their level of abstraction. The first type of representation is my design model: It is an abstract model of design processes in reality; to define this model, I introduced several concepts and terms. The second types of representations are the representations of entities that designers make during design processes. (My design model represents the process of making representations.) For making the third type of representations, namely descriptions of the state of an entity, the concepts of my design model must be used. This type, however, is less abstract than the abstract model because it is defined in terms of concrete values for the different properties and factors.

In Section 3.2.1, the differences between the general concepts entity, representation of an entity, state of an entity, and state description are already explained and can easily be recognised in Table 3.9. The other general concepts defined in this chapter (state transition, goal, relation, and state space) are abstractions of reality and can be positioned in the abstract model. The positioning of concepts about the design process is similar to the general concepts. The product being designed, the design process, the design context, the designers, and the stakeholders exist in reality. The reality is described in a design model, using, amongst others, the concepts design property, design factor, design situation, design activity, and design task. Designers make representations of reality and can describe the reality using the concepts of the design model.

<table>
<thead>
<tr>
<th>Representations of reality</th>
<th>GENERAL</th>
<th>FOR DESIGNING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reality</td>
<td>Entity, object, process, actor</td>
<td>Product being designed, design process, design context designer, stakeholder</td>
</tr>
<tr>
<td>Abstract model</td>
<td>Property, factor, State</td>
<td>Abstract model : design property, design factor, state of product being designed, state of design process, state of design context, design situation, design activity, design goal, design relation, design space, design task, design session</td>
</tr>
<tr>
<td>State transition, goal, relation, state space</td>
<td>Representation of an entity</td>
<td>Representation of product being designed, representation of design process, representation of design context</td>
</tr>
<tr>
<td>Representation of an entity</td>
<td>Description of the state of an entity</td>
<td>Description of state of product being designed, description of state of design process, description of state of design context, description of design situation</td>
</tr>
</tbody>
</table>

Table 3.9: Positioning the concepts and terms of the design philosophy.

### 3.8 Conclusions

The design philosophy described in this chapter consists of a set of domain-independent concepts and terms, useful for describing a design process from the viewpoint of state-transition systems. The mathematical concept of state-transition systems is adapted to the context of designing. The concepts design situation, design activity, design process, design task, design session, and design context are defined and a definition of designing is given. The design philosophy is represented in a design model.

This chapter gives an answer to my first research question, namely “How to describe design processes in a domain-independent way?”. This answer is used to describe the other results of my research, namely the design frame and the design method. The answer is refined in the next chapter describing my design frame: The design frame offers an answer to the question “How to structure the description of a design process in a domain-independent way?”. Together, the design philosophy and the design
frame are the basis to answer the second research question, namely “How to support structured reflection on design processes in a domain-independent way?”.
4 Design Frame

4.1 Introduction

The goal in this thesis is to develop support for structured reflection on design processes. The design method described in the next chapter offers this kind of support by helping designers to describe and analyse design situations and design activities regularly during a design process. The goal of the design frame, described in this chapter, is to support the domain-independent description and analysis of design situations and design activities by offering a structure for positioning properties, factors, design tasks, and representations. Such a structure can contribute to the intended support for designers as follows. To describe and analyse design situations and design activities, among others, properties, factors, design tasks, and representations must be described: In my design philosophy, a design situation is defined in terms of properties and factors; a design situation at a certain moment in time includes values of many different properties and factors. During a design process, one or more design tasks are performed and design activities include making representations. Complex design projects consist of multiple design tasks in which many representations of the product being designed, the design process, and the design context are made by many different disciplines. A structure for positioning these different properties, factors, design tasks, and representations can be very helpful for making descriptions and for analysing these descriptions. The structure may also give designers, while reflecting, insights into how to improve the co-ordination and integration of the different properties, factors, design tasks, and representations. To be useful in several disciplines, a domain-independent structure is necessary. The design frame offers such a structure.

The design frame is a domain-independent aid for positioning properties, factors, design tasks, and representations. The main concepts of the design frame are dimensions and subjects. The concept of a dimension is defined in Section 4.2; three dimensions are elaborated in the design frame. The three parts of a design situation, namely the product being designed, the design process, and the design context are considered in the remainder of this thesis as subjects. The design frame is the structure formed by the combination of the three dimensions for each subject. Following the different levels of theory distinguished in [Wester, 1991, p. 134], the design frame is a kind of ‘taxonomy’. The design frame can also be seen as a combination of a frame of reference and a framework for design. It is a frame of reference in the sense that it consists of a set of axes; the position of properties, factors, design tasks, and representations can be described with reference to these axes. The design frame is a framework because it offers a basic structure for positioning design-related concepts.

The theory of the design frame is mainly inspired by the design theory of Bax and Trum, described in, for example, [Bax, 1986] and [Bax, 1989]. The latter theory is based on general systems theory, which is applied to architecture; in the design theory, some aspects of general systems theory are extended. Early publications of my design frame can be found in [Reymen, 1998] and [Reymen, 1999a]. The development of the design frame is described in Section 2.8. The domain-independent concepts and terms, defined in the previous chapter, are used to describe the design frame. In the next four sections, a definition of a dimension is given and the three chosen dimensions are explained. In Section 4.6, the combination of the three dimensions and their combination with the concept of a subject are discussed. The section describes how properties, factors, design tasks, and representations can be positioned in the design frame. The section also illustrates how the structure is useful for description and analysis purposes. General conclusions about the design frame can be found in Chapter 6.
4.2 Definition of a dimension

In this thesis, a *dimension* is one ordinate of a set of ordinates of a three-dimensional space in which properties, factors, design tasks, and representations can be positioned. The three-dimensional space is called a *positioning space*. The dimensions characterise this space. Notice the difference between a positioning space and a design space, defined in Section 3.4.2. The former structures properties and factors of the current state (and design tasks and representations). The latter consists of a set of all possible next states; ordinates are not defined for a design space.

The three dimensions I choose are ‘level’, ‘perspective’, and ‘time’. These three dimensions, combined with the concept of a subject, are sufficient to reach the goal of the design frame, namely offering a structure for positioning properties, factors, design tasks, and representations, as illustrated in Section 4.6. A three-dimensional space has also the advantage of being easy to represent by a human. A positioning space formed by the three dimensions is represented in Figure 4.1. The three dimensions are defined in a domain-independent way and are described in more detail in the next sections.

![Level Perspective Time](image)

Figure 4.1: A positioning space formed by three dimensions.

Articulations on the ordinates of a positioning space are called *values*. A dimension can have a set of values. Value sets for the dimensions specify the dimensions and the positioning space. Value sets for the dimensions differ for the subject considered; this means that, for each subject, a specific positioning space must be defined. Value sets for the dimensions can be obtained by projecting a product being designed, a design process, or a design context - the subjects - onto a level, a perspective, and a time axis. These projections result in - for each subject different - value sets for the various dimensions: levels for the level dimension, perspectives for the perspective dimension, and processes\(^{19}\) for the time dimension. Values of the level dimension are ordered and discrete. Values of the perspective dimension are unordered and discrete. Values of the time dimension are ordered in time and discrete or continuous.

<table>
<thead>
<tr>
<th>Values</th>
<th>LEVEL</th>
<th>PERSPECTIVE</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRODUCT BEING DESIGNED</td>
<td>Garden house</td>
<td>Usage</td>
<td>Design process</td>
</tr>
<tr>
<td></td>
<td>Components of garden house</td>
<td>Production</td>
<td>Production process</td>
</tr>
<tr>
<td></td>
<td>Details of components</td>
<td>Performance</td>
<td>Use process</td>
</tr>
<tr>
<td>DESIGN PROCESS</td>
<td>Design process</td>
<td>Means</td>
<td>Conceptual design</td>
</tr>
<tr>
<td></td>
<td>Design activities</td>
<td>People</td>
<td>Embodiment design</td>
</tr>
<tr>
<td></td>
<td>Mental processes</td>
<td>Activity</td>
<td>Detail design</td>
</tr>
<tr>
<td>DESIGN CONTEXT</td>
<td>Branch</td>
<td>Juridical</td>
<td>Design process</td>
</tr>
<tr>
<td></td>
<td>Company</td>
<td>Economical</td>
<td>Production process</td>
</tr>
<tr>
<td></td>
<td>Product-development department</td>
<td>Social</td>
<td>Use process</td>
</tr>
</tbody>
</table>

Table 4.2: Specific positioning spaces for the case of a garden house.

\(^{19}\) I have chosen the term ‘processes’ instead of ‘times’. In the context of designing, processes are more appropriate to determine important periods of time.
In Table 4.2, three positioning spaces are specified for the case of a garden house, namely one for the product being designed, one for the design process, and one for the design context. Each table entry contains examples of values for the corresponding dimension, for the corresponding subject, of the corresponding positioning space. More examples of values for the three dimensions can be found in the next sections.

Each positioning space consists of the same dimensions (namely level, perspective, and time), but each dimension has different value sets. For any given design task, specific positioning spaces for each subject must be made because value sets are usually specific for a specific design task. However, value sets for the three dimensions can be similar for certain types of products, design processes, design contexts, design tasks, and/or design disciplines.

Each property and factor of a design situation can, at every moment during a design process, be positioned by giving values for the three dimensions: Each property or factor can be considered on a certain level, from a certain perspective, and in a process in which it is important. For example, the property ‘coating with ingredient ‘X’’ (property of the product being designed) can be positioned in the positioning space defined by the values given in Table 4.2, on the level ‘details of components’, on the perspective ‘performance’, and in the ‘use process’ in time.

![Figure 4.3: Specific positioning space for the case a garden house](image)

Every point in the positioning space can be a property or a factor on a certain level, viewed from a certain perspective, and at a certain moment in time. A property or factor can be positioned on more than one value for each dimension simultaneously. This is illustrated in Figure 4.3. For example, the property ‘dimensions of the garden house’ can be situated in the interval [design process, production process, use process] for the time dimension, because this property is important in those three processes. Note that Figure 4.3 and Table 4.2 are two different ways to represent a positioning space, namely as a vector space and as a matrix respectively.

### 4.3 Level

Values for the level dimension are called levels; they are represented in the positioning space as planes, as illustrated in Figure 4.4. These levels are a projection of a product being designed, a design process, or a design context onto the level dimension. The resulting levels can be seen as levels of specification, levels of resolution, or levels of scale. The different levels are abstractions from speciality to generality. Levels for a *product being designed*, for example a garden house, are, for example, the following:

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20 In the remainder of the thesis, a distinction is made between tables that are a matrix and tables that are not a matrix. The former are represented as in Table 4.2, the latter are represented as in Table 4.17.

21 In the remainder of this section and in the description of the three dimensions in the next sections, the theory of the design frame is explained by examples of properties and factors. However, the theory also holds for design tasks and representations. The latter is illustrated in Section 4.6.
— Level of garden house: On a high level of abstraction (for example, scale 1/100), the garden house can be described as a kind of building; many details are neglected.
— Level of components: On a lower level of abstraction (for example, scale 1/50), the different materials of the garden house, like wood, glass, and concrete can be described.
— Level of details: On yet a lower level (for example, scale 1/1), the joints between the materials can be described.

Levels for a design process can be the design process on a high level of abstraction, the level of design activities, and the level of mental processes. For the design context, levels can be defined as, for example, the branch, the company, and the product-development department (including processes like marketing, management, design, and production).

Figure 4.4: Levels in a positioning space.

To be operational, levels must be defined such that elements on each level have similar complexity. I also postulate that only those values for a dimension that are important for the other dimensions must be defined\(^\text{22}\). This means that it must be possible to make a potential link between values for one

\(^{22}\) The reason for this postulate is given in Section 4.6.
dimension and values for the other dimensions. For the level dimension, this means that levels must have relevance for perspectives and processes in time. For example, in the case of the garden house, the value sets for the level dimension must be relevant for the time dimension; the level of a garden house, of its components, and of the details of the garden house are relevant for the processes design, production, and use respectively. Similar links can be made for the perspective dimension.

Every property and factor can be situated on one or more levels. For example, the properties ‘coating with ingredient ‘X’, ‘need new software to simulate ‘Y’’, and factor ‘product planning’ can be positioned on the levels ‘details of components’, ‘design activity’, and ‘product-development department’ respectively. The positioning of properties and factors of a design situation on levels is illustrated in Figure 4.5.

Between levels, some kind of structure can be recognised: each element (property or factor) on a certain level can be seen as a system that can consist of elements on a lower level. This is illustrated in general in Figure 4.6a and for the example of the garden house in Figure 4.6b. The boxes in Figure 4.6b are filled with properties of the product being designed (the garden house).

![Figure 4.6a: Structured decomposition of a property/factor.](image)

Between levels, some kind of structure can be recognised: each element (property or factor) on a certain level can be seen as a system that can consist of elements on a lower level. This is illustrated in general in Figure 4.6a and for the example of the garden house in Figure 4.6b. The boxes in Figure 4.6b are filled with properties of the product being designed (the garden house).

![Figure 4.6b: Specific decomposition for the case of the dimensions of a garden house.](image)

### 4.4 Perspective

Values for the perspective dimension are called perspectives; they are illustrated in the positioning space in Figure 4.7. These perspectives are a projection of a product being designed, a design process, or a design context onto the perspective dimension. Perspectives are possible ways of looking at something, as illustrated in Figure 4.8. When looking from a certain perspective, certain aspects of an entity are highlighted. For each perspective, a different representation of the entity can be made. A product being designed, its design process, and its design context can be viewed from different perspectives; for example, from the perspective of the user, the technology, or the organisation. Perspectives are related to the role(s) of the designers and stakeholders during a design process.
Figure 4.7: Perspectives in a positioning space.  Figure 4.8: Perspectives on an entity.

Also for the perspective dimension, it holds that only those perspectives that are important for the other dimensions must be defined. This means that perspectives must have relevance for levels and for processes in time. Perspectives for the garden house are, for example, use, production, and performance. These are relevant for the use process, the production process, and the use process respectively.

Examples of perspectives for each subject are the following. Perspectives for the product being designed can be aesthetics, behaviour, construction, durability, function, logistics, maintenance, operation, performance, production, quality, safety, or use. Perspectives for the design process can be means (of the complete design process or of one activity), people (who has which responsibility), and activity (who does what in the design process; its efficiency and effectiveness). Perspectives for the design context can be ecological, economical (micro/macro), educational, ethical, juridical, political, scientific, social, strategic, or technological.

Figure 4.9: Positioning of properties and factors on perspectives.
Every property and factor can be situated on one or more perspectives. For example, the properties and factor ‘coating with ingredient ‘X’’, ‘need new software to simulate ‘Y’’, and ‘product planning’ can be positioned on the perspectives ‘performance’, ‘means’, and ‘economical’ respectively. The positioning of properties and factors of a design situation on perspectives is illustrated in Figure 4.9.

4.5 Time

Values for the time dimension are processes; Figure 4.10 shows planes in the positioning space representing processes. These processes are a projection of a product being designed, a design process, or a design context onto the time dimension. I have chosen to use a product lifecycle as the referential system for the time dimension. A product lifecycle consists of processes associated with the design process. Such processes are, for example, processes related to the history of the product being designed, sub-processes of the design process (for example, sketch design, preliminary design, and final design or concept, layout, and detail), the marketing process, the management process, production preparation (engineering), production, assembly, test, package, sales, distribution, installation, use, service, redesign (re-destination), re-use, recycle, and scrapping processes (see also [Buijs et al., 2000] and [Roozenburg et al., 1994])). Processes of a possible product lifecycle, ordered in time, are depicted in Figure 4.11. The choice for a product lifecycle is a meaningful one because a product lifecycle includes the design process and processes in the design context (associated processes of the design process). Together, the processes of a product lifecycle are projections of the product being designed, the design process, and the design context onto the time dimension.

![Figure 4.10: Processes in a positioning space.](image)

![Figure 4.11: Processes of a product lifecycle.](image)

For the time dimension, it also holds that only those processes that are important for the other dimensions must be defined. This means that processes must have relevance for levels and for perspectives. Processes for the garden house are, for example, the design process, the production process, and the use process. These processes are relevant for the following levels of the garden house, namely the level of the garden house, of the components, and of the details.

Because a process takes an interval in time, properties and factors can be positioned in time by positioning them in a process, namely a process in which they are important. Such a process can be part of the past, present, or future. Every process can be situated in one process or in a number of processes of the product lifecycle. A property or factor can also be positioned in a certain phase of a process. For example, the properties ‘coating with ingredient “X”’, ‘need new software to simulate ‘Y”’, and the factor ‘product planning’ can be positioned in the processes ‘use process’, ‘detail design’, ‘production process’ respectively. The positioning of properties and factors in processes in the product lifecycle is shown in Figure 4.12. Note that all properties and factors are part of a design situation at moment t(i) during a design process, but can be positioned in processes in the past, present, or future.
4.6 Combining dimensions

The previous sections illustrate that properties and factors can be positioned on the dimensions level, perspective, and time. However, the three dimensions are meant to be used together as they are in a positioning space and to be combined for each subject. The structure defining the design frame is also not only meant to position properties and factors, but also to position design tasks and representations. In this section, first, it is shown how properties, factors, design tasks, and representations can be positioned in the design frame. Then, the use of the design frame for describing and analysing design processes is illustrated.

To position a property or factor in a positioning space, the next two steps can be followed. First, defining positioning spaces for each subject, using templates; second, choosing, for each property or factor, values for each dimension. Each step is explained in more detail.

Step 1: The positioning spaces for the specific product being designed, the design process, and the design context must be defined: Value sets for the three dimensions must be defined for each subject. Values must be defined such that each value for one dimension has relevance for values for the other dimensions, as postulated in the previous sections. This restriction is necessary because the dimensions are related to each other in a positioning space. Values in the positioning spaces for one subject must also be relevant for the other subjects. For example, values of the three dimensions for a product being designed must be relevant for values of the three dimensions for the corresponding design process and design context. This is necessary because the product being designed, design process, and design context are interdependent (as explained in Section 6.1.1).

Values can be defined in a ‘template’. Such a template may have one of the following three appearances:

- a matrix, as represented in general in Table 4.13, and for the design of a garden house in Table 4.223. This type of matrix gives an overview of all values of the three dimensions for each subject.
  
  This matrix is ideal to check the relevance of values of each dimension for each subject; for

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23 To facilitate the comparison between Tables 4.13 and 4.14, numbers are given to the values of each dimension for the product being designed.
example, to check the relevance of values of the level dimension for the product being designed for the values of the level dimensions for the design process and the design context.

<table>
<thead>
<tr>
<th>Values</th>
<th>LEVEL</th>
<th>PERSPECTIVE</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRODUCT BEING DESIGNED</td>
<td>Level 1</td>
<td>Perspective 1</td>
<td>Process 1</td>
</tr>
<tr>
<td></td>
<td>Level 2</td>
<td>Perspective 2</td>
<td>Process 2</td>
</tr>
<tr>
<td></td>
<td>Level 3</td>
<td>Perspective 3</td>
<td>Process 3</td>
</tr>
<tr>
<td>DESIGN PROCESS</td>
<td>Level 1</td>
<td>Perspective 1</td>
<td>Process</td>
</tr>
<tr>
<td></td>
<td>Level 2</td>
<td>Perspective 2</td>
<td>Process</td>
</tr>
<tr>
<td></td>
<td>Level 3</td>
<td>Perspective 3</td>
<td>Process</td>
</tr>
<tr>
<td>DESIGN CONTEXT</td>
<td>Level 1</td>
<td>Perspective 1</td>
<td>Process</td>
</tr>
<tr>
<td></td>
<td>Level 2</td>
<td>Perspective 2</td>
<td>Process</td>
</tr>
<tr>
<td></td>
<td>Level 3</td>
<td>Perspective 3</td>
<td>Process</td>
</tr>
</tbody>
</table>

Table 4.13: A matrix with values for the dimensions for each subject.

− a matrix, as represented in general in Table 4.14, and for the example of the garden house in Table 4.15. This kind of template must be made for each subject. Compared to the matrices in Tables 4.2 and 4.13, these matrices offer a possibility for defining in detail the relevancy of values of one dimension for other dimensions for the same subject. With the matrices in Tables 4.14 and 4.15, different perspectives for each level and for each process can be defined for, for example, the product being designed. In Table 4.13, value sets for the three dimensions for the product being designed are defined; for each dimension, only a list of possible values is given. In Table 4.14, relations between the values of the perspective dimension and the other two dimensions can be made clear: For example, perspective 3 is only relevant for the combination level 1 and process 2, level 1 and process 3, level 2 and process 2, level 2 and process 3, level 3 and process 1, and level 3 and process 3.

<table>
<thead>
<tr>
<th>Perspectives</th>
<th>PROCESS 1</th>
<th>PROCESS 2</th>
<th>PROCESS 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEVEL 1</td>
<td>Perspective 1</td>
<td>Perspective 1</td>
<td>Perspective 1</td>
</tr>
<tr>
<td></td>
<td>Perspective 2</td>
<td>Perspective 2</td>
<td>Perspective 1</td>
</tr>
<tr>
<td></td>
<td>Perspective 3</td>
<td>Perspective 3</td>
<td>Perspective 3</td>
</tr>
<tr>
<td>LEVEL 2</td>
<td>Perspective 1</td>
<td>Perspective 1</td>
<td>Perspective 1</td>
</tr>
<tr>
<td></td>
<td>Perspective 2</td>
<td>Perspective 2</td>
<td>Perspective 2</td>
</tr>
<tr>
<td></td>
<td>Perspective 3</td>
<td>Perspective 3</td>
<td>Perspective 3</td>
</tr>
<tr>
<td>LEVEL 3</td>
<td>Perspective 1</td>
<td>Perspective 1</td>
<td>Perspective 2</td>
</tr>
<tr>
<td></td>
<td>Perspective 2</td>
<td>Perspective 2</td>
<td>Perspective 3</td>
</tr>
<tr>
<td></td>
<td>Perspective 3</td>
<td>Perspective 3</td>
<td>Perspective 3</td>
</tr>
</tbody>
</table>

Table 4.14: A detailed matrix with values for the dimensions.

<table>
<thead>
<tr>
<th>Perspectives</th>
<th>DESIGN PROCESS</th>
<th>PRODUCTION PROCESS</th>
<th>USE PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEVEL OF GARDEN HOUSE</td>
<td>Quality</td>
<td>Function Behaviour</td>
<td>Use</td>
</tr>
<tr>
<td>LEVEL OF COMPONENTS</td>
<td>Analysis</td>
<td>Logistics Performance</td>
<td>Safety Maintenance</td>
</tr>
<tr>
<td>LEVEL OF DETAILS</td>
<td>Precision</td>
<td>Tolerance</td>
<td>Aesthetics</td>
</tr>
</tbody>
</table>

Table 4.15: An example of a detailed matrix for the product being designed (garden house).

− a vector space, as depicted in Figure 4.3 or, with a different representation, shown in Figure 4.16 (using planes for values in the positioning space). This type of appearance for a template provides a visual representation for all values and illustrates the relation between the three dimensions. This kind of template must also be made for each subject.
The choice for a specific appearance of a template depends on the desired level of detail for values (Table 4.14 offers more detail) and on the preference of the user. The goal of making one or more specific templates is to create an overview of all possible values for the dimensions for the specific product that is being designed in the specific design process and design context.

Step 2: When the specific templates have been defined, values for the three dimensions must be chosen for the specific property or factor. An example of some properties and factors in the case of the garden house, positioned in the positioning spaces defined in Table 4.2, is given in Table 4.17.

<table>
<thead>
<tr>
<th>PROPERTY or FACTOR</th>
<th>SUBJECT</th>
<th>LEVEL</th>
<th>PERSPECTIVE</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating with ingredient ‘X’</td>
<td>Product being designed</td>
<td>Details of components</td>
<td>Performance</td>
<td>Use process</td>
</tr>
<tr>
<td>Need new software to simulate ‘Y’</td>
<td>Design process</td>
<td>Design activity</td>
<td>Means</td>
<td>Detail design</td>
</tr>
<tr>
<td>Product planning</td>
<td>Design context</td>
<td>Product-development department</td>
<td>Economical</td>
<td>Production process</td>
</tr>
</tbody>
</table>

Table 4.17: Properties and factors of the design of a garden house, positioned in the design frame.

Design tasks and representations can be positioned in the design frame as follows. A design task or a subtask of a design task can be defined on different levels, can focus on certain perspectives, and can concentrate on certain processes in the product lifecycle. Similar steps as described for properties and factors can be used to position a design task. For example, for the design of a new type of garden house, the following design tasks related to the product being designed can be defined: the design of the foundation and construction and the design of the materials of the skin. These can be positioned in the design frame as illustrated in Table 4.18. Of course, for reasons of integration, the focus of a designer must be broader than concentrating only on the specified level(s), perspective(s), and process(es); the subtask must be performed from an awareness of related levels, perspective, and processes. For reasons of co-ordination, each subtask must also be performed in close contact with designers performing other subtasks.

<table>
<thead>
<tr>
<th>DESIGN TASK</th>
<th>SUBJECT</th>
<th>LEVEL</th>
<th>PERSPECTIVE</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design of the foundation and construction</td>
<td>Product being designed</td>
<td>Garden house Components of garden house</td>
<td>Construction</td>
<td>Production process</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Details of components</td>
<td></td>
<td>Use</td>
</tr>
<tr>
<td>Materials of the skin</td>
<td>Product being designed</td>
<td>Components of garden house</td>
<td>Durability</td>
<td>Use</td>
</tr>
</tbody>
</table>

Figure 4.16: A spatial representation of a positioning space, using planes, for a product being designed (garden house).
Table 4.18: Subtasks of the design task of a garden house positioned in the design frame.

A representation of a product being designed, a design process, or a design context can concentrate on one or more values for the dimensions of the specific positioning spaces. For example, a representation of a product being designed (a 3D model of a garden house) can be made for the conceptual phase in the design process and may concentrate on the level of components of the garden house and on the construction perspective. To position a representation, the same two steps as described for properties and factors must be followed. Table 4.19 offers an example of representations of the product being designed, the design process, and the design context for the design of the garden house positioned in the design frame.

<table>
<thead>
<tr>
<th>REPRESENTATION</th>
<th>SUBJECT</th>
<th>LEVEL</th>
<th>PERSPECTIVE</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D model of garden house</td>
<td>Product being designed</td>
<td>Components of garden house</td>
<td>Construction</td>
<td>Design process</td>
</tr>
<tr>
<td>Organisation scheme</td>
<td>Design process</td>
<td>Design process</td>
<td>People</td>
<td>Conceptual design</td>
</tr>
<tr>
<td>List of properties of production machines</td>
<td>Design context</td>
<td>Product-development department</td>
<td>Production</td>
<td>Production process</td>
</tr>
</tbody>
</table>

Table 4.19: Representations of the design of a garden house positioned in the design frame.

Summarising, the design frame is the structure formed by the combination of the three dimensions for each subject. The examples in Tables 4.17, 4.18, and 4.19 show that the three dimensions are useful for a product being designed, a design process, and a design context and that the structure is sufficient for positioning properties, factors, design tasks, and representations of a garden house.

The positioning structure can be used for describing and analysing design processes. Designers can describe design situations and design activities using the structure of the design frame. Researchers might analyse the distribution of properties, factors, design tasks, and representations over the different values for the three dimensions. For analysis purposes, the positioning of properties can be represented in a different way, for example, as shown in Table 4.20. Note that such a table must be made for each subject, because only values of one positioning space are included.

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>PERSPECTIVE</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>L2</td>
<td>L3</td>
</tr>
<tr>
<td>P1</td>
<td>P2</td>
<td>P3</td>
</tr>
<tr>
<td>P4</td>
<td>T1</td>
<td>T2</td>
</tr>
<tr>
<td>T3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.20: Table for the analysis of the positioning of properties in the design frame.

In my design method, described in the next chapter, the design frame is used for positioning, describing, and analysing. The structure of the forms, proposed in Section 5.3.1, in which properties and factors can be described, is based on the combination of dimensions for each subject, i.e., on the design frame. Designers are supported to define and position subtasks of design sessions in the design frame using the template of FORM Design Frame, described in Section 5.7, which is based on the structure of Table 4.13. Different kind of representations developed by designers can be positioned in the design frame to give a structured answer to the questions about representations in the checklists of Section 5.3.

Besides being useful for describing and analysing design processes, the design frame might also be the basis of a method that supports the creation of new ideas. Varying the level, the perspective, or the important process a property or factor is concentrating on, to another level, perspective, or process can offer a designer new ideas. For example, changing the perspective of a property from efficiency to cost can be a source of inspiration. As a result, the designer can think of new properties or factors or change the existing property or factor. Based on the overview offered by a set of properties and factors
positioned in the design frame, a designer might also find missing properties or factors (on a certain level, from a certain perspective, or in a certain process) or integrate several properties. This means that the design frame, in some sense, can be used to explore the design space.

4.7 Conclusions

The design frame is a domain-independent aid for positioning properties, factors, design tasks, and representations. These can be positioned in a three-dimensional space, called a positioning space, which is defined by the dimensions level, perspective, and time. Value sets for the dimensions are different levels, perspectives, and processes in the product lifecycle. A positioning space must be defined for each subject, namely for the product being designed, the design process, and the design context. The concepts of the design frame are domain independent. However, the use of the design frame can be tailored to the needs of a specific discipline, because values for the dimensions can be defined in a domain-specific way.

The contribution of the design frame to this thesis lies in the structure it offers for describing and analysing design processes. The description and analysis of design processes is an important concept of my design method supporting reflection on design processes. The structure may give designers insights, while reflecting, into how to improve the co-ordination and integration of properties, factors, design tasks, and representations. The design frame might also be the basis for other applications, like a method for exploring the design space.
5 Design Method

5.1 Introduction

The overall goal of my research is to decrease the gap between design research and design practice in order to improve design processes. Reflection on a design process may help to improve the effectiveness and efficiency of a design process (see also Sections 1.5.3 and 2.3). The goal of reflection on a design process is to generate suitable next design activities in the design process. After these activities have been performed, reflection can again take place: Evaluation of the activities in the light of the current design situation and the goal of the design process can be the basis for defining a new set of design activities. Through this cycle, designers can learn from their experiences and improve the current design process and future design processes. In order to perform reflection on a design process seriously, a good overview of the design situation and design activities is necessary. For creating these overviews, implicit choices must be made explicit. Making these choices explicit can improve communication between designers and stakeholders; if the overviews are also written down (in a specific format), it can help to remember important experiences and it can even stimulate the re-use of design knowledge. The description of the design situation and design activities may be analysed to judge the progress in the design process, to compare the current state of the product being designed with the desired state, to get insight into the relations between properties and factors, and to evaluate the interactions with the design context, in order to generate ideas for possible next design activities.

The specific goal in this thesis is to develop support for structured reflection on design processes; structured in the sense of systematic and regular:
- Reflection on design situations and design activities implies paying attention to the product being designed, the design process, and the design context. Describing and analysing design situations and design activities can best be performed in a systematic way; this decreases the chance to overlook important aspects. The goal in this thesis is to develop some aids that can help designers to describe and analyse a design process in a systematic way.
- To perform explicit reflection on design situations and design activities on a regular basis, regularly during a design process (at uniform intervals), some time must be reserved for reflection. However, because reflection interrupts a design process, certain moments are more appropriate for reflection than others. The goal in this thesis is to propose good moments for regular reflection on a design process, such that the efficiency and effectiveness of the design process can increase.

My design method is a domain-independent aid that offers designers support for reflecting on design processes in a structured way. The design method supports when to reflect and partly how to reflect, namely how to describe the design situation and design activities and how to analyse these descriptions. It does not support how to generate ideas for next design activities. My design method is not a design method in a classical way: It does not explicitly guide a complete design process. An early publication of my design method can be found in [Reymen et al., 2000]. The domain-independent terminology of the design philosophy is used for describing the design method. The concepts of the design frame are included in the design method, as discussed in Section 4.6.

5.2 Concepts of the design method

The design method stimulates designers to reflect on the current design situation and on past design activities, with the goal to derive possible design activities for the future. In the terminology of the design philosophy, the design method helps designers to reflect on the current state and on the
sequence of state transitions in a design process. Figure 5.1 illustrates the kind of reflection my design method supports.

![Diagram of state transitions in the past, current state, and state transitions in the future with reflection on the past and future](image)

**Figure 5.1: Reflection on states and state transitions.**

*Reflection on a design process* is defined, in Section 1.5.3, as an introspective contemplation on the designer’s perception of the design situation and on the remembered design activities. I describe a reflection process as a process that consists of three main activities that are called preparation, image forming, and conclusion drawing (see Section 1.5.1). For reflection on a design process (see also Section 1.5.3), the facts in the preparation step are the properties, factors, and relations in the design situation and the design activities performed during the design process. During the preparation step, these facts are collected and analysed critically, using the criteria mentioned in Section 1.5.1. The goal of the image-forming step is to get an image of the design process as a whole. During the conclusion-drawing step, the image of the design process and the goal of the design process are taken into account to determine the next design activities in the design process.

My design method only supports the preparation step of a reflection process. Developing support for the image-forming and conclusion-drawing steps of a reflection process has been outside the scope of this thesis, but must be part of further research (see also Section 6.4). The latter kind of support is more difficult because it requires knowledge of cognitive and social sciences; the support will probably be of a different kind, namely less rationally and analytically, but more intuitively and synthetically.

As a first concept of my design method, the *description and analysis of design situations and design activities* is supported. The descriptions are aimed to give an overview of the important facts: the analysis of these descriptions is the basis for reflection on the design process. Three checklists and three forms are developed to help designers with performing the preparation step in a systematic way. The concepts of the design frame are used to support the description and analysis of design situations and design activities.

The second concept of my design method, namely the idea of *design sessions*, aims to support regular reflection. A design session is defined as a period of time during which one or more designers are working on a subtask of a certain design task. It is a period of time between two periods during which the designer(s) are not executing that subtask. A design session can take a period of time like one afternoon, a whole day, some days, or a week. Designers can themselves determine the duration of a design session. A design process can be seen as a sequence of design sessions. In my design method, I
propose reflection to take place at the beginning and end of a design session. By planning a design session, designers do thus automatically also plan moments for reflection. During a design session, designers can follow various other design methods.

Based on these two concepts, the design method proposes the following steps, which are refined in Section 5.7:
- Plan the next design session(s);
- start each design session with reflection on the design situation and design activities, using the checklists and forms proposed in Sections 5.3 and 5.4;
- end each design session with reflection on the design situation and design activities, again using the checklists and forms of Sections 5.3 and 5.4.

In the next sections, the main concepts of the design method are described in more detail. The two forms and checklists developed for systematic reflection on a design situation are presented in Section 5.3 and the form and checklist developed for systematic reflection on design activities are presented in Section 5.4. The concept of design sessions is explained in Section 5.5. The integration of both concepts for the purpose of structured reflection is described in Section 5.6. An overview of the design method is given in Section 5.7. In Section 5.8, the use of the design method is described. In Appendix A, a description of a complete reflection process, using the concepts of my design method for the preparation step is given for an example of the design of a new type of garden houses. General conclusions about the design method and a summary of the feedback that I got on the design method can be found in Chapter 6.

5.3 Reflection on a design situation

My design method supports the reflection on a design situation by supporting the description of a design situation and the analysis of this description. In Section 5.3.1, support for describing a design situation is given. Section 5.3.2 describes support for analysing a design situation.

5.3.1 Description of a design situation

As already defined in Section 3.2.2, a description of a design situation is a specific representation of a relevant subset of the set of values of all properties describing the product being designed and the design process, and of the set of values of all factors influencing the product being designed and its design process. Making a description implies modelling the reality from a particular point of view, i.e., neglecting certain irrelevant characteristics. To make a description, the questions “What to describe?” and “How to describe it?” must be answered. The design method helps designers to answer these questions, by means of checklists and forms, described in this subsection. The answer to the question “When to describe what?” is given in Section 5.6.

What to describe? Making a description of a design situation is similar to explaining the state of a design task to an outsider to the project: The problem, the requirements, the alternatives, and the obtained solutions are explained; the state of the design process and other related processes are given; and factors in the context that influence the design task are mentioned. To make a description of a design situation, the state of the product being designed, the design process, and the design context must be described.

How to describe a design situation? I propose to make a textual description of a design situation with references to other types of representations (graphs, sketches, drawings, or prototypes). The description can be a combination of quantitative and qualitative information and can be at any level of detail. A list of properties and factors with their values and a list of important relations between these properties and factors must be made. A more precise description can be made as follows: Properties and factors can be structured by positioning them in the design frame: for each property and factor, the subject must be determined and values for the three dimensions must be given (see Section 4.6). Relations can be described more precisely by describing, for example, the kind of relation and the rationale for the relation. Forms and a checklist can help designers in making this description. To
describe properties and factors, FORM Properties&Factors and CHECKLIST Description Design Situation can be used. To describe relations, FORM Relations can be used. More information about the two forms and the checklist is given below.

FORM Properties&Factors has been developed to help designers in making a precise description of properties and factors. An example of a filled out form is given in Table 5.2. This form is a table that consists of one column for labelling the properties and factors, one for describing the values of the properties and factors, one for the subject of the properties and factors (being the product being designed, the design process, or the design context), and some other columns for describing values for different attributes (see below). Every row of the table describes one property or factor in detail. The form also includes cells for the name of the design task, the name of the designer, the date at which the description is made, and information about the design session (subtask, start time and end time of a design session; see Section 5.6). Only important properties and factors must be described; designers themselves have to decide what is relevant in a particular situation.

Instead of including cells for describing values for the three dimensions of the design frame, FORM Properties&Factors includes cells for describing values for different attributes. Because the intended users of the design method are designers, the terminology of the form must be close to the terminology used in practice. The level of abstraction of the dimensions, however, deviates from the desired concreteness of the design method. To describe properties and factors more precisely and closer to the terminology of designers, I have chosen to introduce attributes. A property or factor can have several attributes that describe it more precisely. Values can be ascribed to these attributes. For example, to describe the colour-property of a football more precisely, a ‘reference’ attribute can be useful. A value for this attribute can be ‘RAL number’ (a colour standard). To describe the property ‘coating of the garden house’ more precisely, the value ‘best material that fulfils the law’, and ‘senior designer’ can be given to the attributes ‘rationale’ and ‘sources’ respectively. Values for attributes and for dimensions are two different ways for characterising properties and factors, using a different terminology. From a theoretical point of view, the definition of attributes is not necessary because I require that the dimensions can cover all attributes. For the same set of dimensions, many different sets of attributes can be defined.

The following attributes for properties and factors are important concepts that I encountered in the language of designers: stadium, rationale, sources, reference, and fixation. These attributes describe properties and factors more precisely and are generic in the sense that they hold for each subject. They are covered by the dimensions as follows: the attributes rationale, sources, and reference are covered by the perspective dimension and the attributes stadium and fixation by the time dimension. The attributes are only a proposal for a possible set of attributes. Further research is necessary to investigate which attributes are useful for which design discipline, kind of design task, or type of designer. Explanations of the different attributes and possible values for the attributes are given below. Examples are given for the property ‘coating of the garden house’ and the factor ‘dimensions of the production machines’.

- **Stadium**: stadium of a property or factor at a certain moment during the design process. Possible values for the stadium attribute are ‘desired property’, ‘current property’, ‘current factor’, and ‘trend factor’. A certain property can first be a desired property and later on become a current property: The stadium of the property differs. For example, for the property ‘coating of the garden house’, the stadium value is ‘current property’ because the ingredients have already been determined (the decision has been made; it is now a property of the garden house). The same holds for factors: A factor can first be a trend and later on become a current factor. Alternatives sets of values for the stadium attribute that are often used in the literature and practice, but do not use the terminology of my design philosophy, are the following:
  - problem, requirement, alternative (or variant), and solution;
  - issue, proposal, and decision;
  - idea, concept, and solution;
  - preliminary decision and decision.

Note that these values offer information about the stadium of a property or factor,
not about the stadium of the complete product being designed or the complete design process.

- **Rationale**: rationale for the introduction of a property or factor. The rationale can include advantages and disadvantages of the property. Rationale is important to make designers aware of the reasons for their choices. An example of a rationale for the factor ‘dimensions of the production machines’ is ‘fixed dimensions are cheap but not flexible in use’.

- **Sources**: designer or stakeholder (person or institute) that determined or influenced the property or factor. This information is important to evaluate the property or factor. Examples of sources are the design-team leader, the marketing manager, the production manager, the quality manager, the director of the company, the government, or a user.

- **Reference**: link to additional documentation. This link can include the medium of the documentation, the document’s name, the date of the document, and/or a specific code; for example, ‘documentation of machine layout, drawing, 24/01/1999, PD-M4’.

- **Fixation**: indicates if the property or factor is fixed or if there is a possibility to negotiate about it. Possible values for the fixation attribute are ‘negotiable’ and ‘unnegotiable’. For example, for the property ‘coating of the garden house’, the fixation is ‘negotiable’, because the designers can still negotiate about the ingredients, if necessary; the ingredients are no hard constraint, determined by law or by nature.

FORM Relations has been developed for describing relations between properties and factors. This form is a table that consists of one column for labelling the relations, one column for describing the first part of the relation (from a certain property or factor), one column to describe the second part of the relation (to a certain property or factor), and other columns for listing values for attributes of these relations (see below). Every row of the table describes one relation precisely. An example of a filled out form is given in Table 5.3.

As already mentioned earlier in this subsection, relations can be described more precisely by describing, for example, the kind of relation and the rationale for the relation. In analogy with the precise description of properties and factors, I have chosen to define ‘kind’ and ‘rationale’ as attributes. These attributes are also only a proposal for a possible set of attributes. An explanation of these attributes and their possible values is given below. An example used for this explanation is the relation between the factor ‘dimensions of the production machines’ and the property ‘dimensions of one plank’.

- **Kind**: kind of relation. Possible values for the kind attribute are ‘is part of’, ‘is caused by’, ‘depends on’, ‘is a variant of’, ‘is an answer to’, ‘is a consequence of’, ‘is important because of’, ‘is output (or input) for’, ‘is a refinement of’, ‘is a’, ‘has a’, ‘transforms’, ‘fulfils’, ‘is influenced by’, and ‘limits’; for example, the from-factor factor ‘dimensions of the production machines’ ‘limits’ the to-property ‘dimensions of one plank’. The values for this attribute can differ for a specific discipline, project, or user.

- **Rationale**: rationale for the relation between two properties or factors; for example, ‘the production machines limit the dimensions of the planks’.

CHECKLIST Description Design Situation has been developed to help designers with inventorying important properties and factors. The structure of the checklist consists of two main parts, namely one part for the design task and one part for the design context. This distinction separates questions about properties and questions about factors. Questions about the design task are subdivided into questions about the product being designed and questions about the design process. Together, these parts cover the three parts of a design situation, namely the product being designed, the design process, and the design context. For the product being designed and for the design process, basic questions about the current and the desired state are being asked. The distinction between current and desired state is important because future design activities must be determined based on differences between the current and the desired state. For the design context, only questions about the current state and possible trends can be asked. Because the checklist is meant to support only the preparation step of a reflection process, mainly ‘what’ questions are being asked (see Section 1.5.2). (The same holds for
the checklists described in the next (sub)sections.) Together, the structure and the basic questions form a basic checklist, as shown in Table 5.4.

The basic checklist is domain independent, but can be tailored to the needs of a specific design discipline, design task, or user by adding questions about specific topics. An example of a checklist including questions about specific topics is shown in Table 5.5. These specific topics are based on an inventory of important aspects of design processes in practice (see, in Section 2.8 and Appendix C, the case studies I performed) and on a literature study. Among others, the following literature has been consulted: [Badke et al., 1997], [Hubka et al., 1996], and [Hales, 1987] mentioned in [Wallace, 1991]. These authors describe factors influencing the design process and/or the product being designed. For an overview of important types of properties and factors, see also Section 3.2.2. Further research is necessary to define a good set of topics.

5.3.2 Analysis of a design situation

The goal of analysing a design situation is to look critically at the current state. A critical analysis can be executed by asking and answering a number of questions. My design method supports a designer in asking relevant questions about individual properties, factors, and relations and about a set of properties, factors, and relations.

Questions about individual properties and factors are already answered when filling out FORM Properties&Factors and FORM Relations. Adding values for the different attributes means answering the following questions: for properties or factors, “What is the stadium of the property or factor?” (“Why?”), “Why is this property or factor chosen?” , “Who defined this item?” (“Why?”), “What are references for this property or factor?” , “Which properties or factors are negotiable?” (“Why or why not?”); for relations, “Which kind of relation is described?” and “What is the rationale for this relation?”.

To support the analysis of sets of properties, factors, and relations, CHECKLIST Analysis Design Situation has been developed. CHECKLIST Analysis Design Situation consists of questions about specific topics ordered in some kind of structure. The structure of the checklist consists of four parts, namely an analysis of the state of the product being designed, of the design process, of the design context, and of the complete design situation. An example of CHECKLIST Analysis Design Situation, including questions about specific topics, is presented in Table 5.6. More empirical research is necessary to improve the list of questions. The checklist should also be tailored to the needs of specific design disciplines, design tasks, or users. The questions mentioned in Table 5.6 are based on the evaluation criteria mentioned in Section 1.5.3; these criteria are defined to perform a critical analysis. Questions about completeness and consistency can be answered by comparing the current and the desired state. Validity of the desired properties can take place together with the stakeholders. In the checklist, also questions about the feeling of the designer are incorporated. These questions are important because they offer the designer a possibility to complete the description of the design situation with his emotions, intuition, and perhaps also with a holistic picture of the design situation; these aspects are also important in designing. I am aware that using the term feeling is dangerous: The danger is that a designer can base decisions on this feeling, which can be based on prejudices or depend on the context. But, when a designer is well prepared (based on all other questions in my checklist), the danger of making mistakes is reduced. No special form for registering the answers to the questions of the analysis has been developed, because answers to these questions are supposed to be used for the completion of FORMS Properties&Factors and Relations.

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24 Because CHECKLIST 2 does not include basic questions, no basic checklist (describing the structure and basic questions of the checklist) is developed.
## FORM Properties & Factors: Description of a design situation: properties and factors

<table>
<thead>
<tr>
<th>Properties and factors</th>
<th>VALUE</th>
<th>SUBJECT</th>
<th>STADIUM</th>
<th>RATIONALE</th>
<th>SOURCES</th>
<th>REFERENCE</th>
<th>FIXATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>2.5m high, 1.8m wide, 1.8m long</td>
<td>Product being designed</td>
<td>Desired property</td>
<td>Functionality</td>
<td>Design-team leader</td>
<td>2D drawing</td>
<td>Negotiable</td>
</tr>
<tr>
<td>Kind of coating</td>
<td>Ingredient ‘X’</td>
<td>Product being designed</td>
<td>Desired property</td>
<td>Fulfils law</td>
<td>Senior designer</td>
<td>Specification document</td>
<td>Unnegotiable</td>
</tr>
<tr>
<td>Current layout</td>
<td>2.5m high, 1.8m wide, 1.8m long</td>
<td>Product being designed</td>
<td>Current property</td>
<td>Desired</td>
<td>Design team</td>
<td>Drawing 2D</td>
<td>Negotiable</td>
</tr>
<tr>
<td>Max. duration</td>
<td>3 months</td>
<td>Design process</td>
<td>Desired property</td>
<td>Budget</td>
<td>Project manager</td>
<td>Project proposal</td>
<td>Negotiable</td>
</tr>
<tr>
<td>Budget</td>
<td>$30 000</td>
<td>Design process</td>
<td>Desired property</td>
<td>Given by manager</td>
<td>Project manager</td>
<td>Project proposal</td>
<td>Negotiable</td>
</tr>
<tr>
<td>Budget</td>
<td>$15 000 spent</td>
<td>Design process</td>
<td>Current property</td>
<td>/ (irrelevant to this property)</td>
<td>Design-team leader</td>
<td>None</td>
<td>/ (irrelevant to this property)</td>
</tr>
<tr>
<td>Support</td>
<td>CAD, method</td>
<td>Design process</td>
<td>Current property</td>
<td>Useful</td>
<td>Design-team leader</td>
<td>Manuals</td>
<td>Negotiable</td>
</tr>
<tr>
<td>Stakeholders</td>
<td>Project leader, garden shops</td>
<td>Design context</td>
<td>Current factor</td>
<td>Important</td>
<td>Design-team leader</td>
<td>None</td>
<td>Negotiable</td>
</tr>
</tbody>
</table>

Table 5.2: An example of a filled out FORM Properties & Factors.
FORM Relations: Description of a design situation: relations

Design task: design of a new coating for garden houses
Date: 27/01/2000
Designer: Isabelle

Subtask: definition of alternative coatings
Start time session: 14:00h
End time session: 17:00h

<table>
<thead>
<tr>
<th>Relations</th>
<th>FROM</th>
<th>TO</th>
<th>KIND</th>
<th>RATIONALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Produceability</td>
<td>Dimensions of production machines</td>
<td>Dimensions of garden house</td>
<td>Limits</td>
<td>The production machines limit the dimensions of the planks.</td>
</tr>
<tr>
<td>Capacity</td>
<td>Staff</td>
<td>Duration</td>
<td>Influences</td>
<td>With more support, the duration of the design process can be shorter.</td>
</tr>
<tr>
<td>Environmental relation</td>
<td>Environmental law</td>
<td>Kind of coating</td>
<td>Is determined by</td>
<td>The environmental law limits the use of certain ingredients for coatings.</td>
</tr>
<tr>
<td>Dimensional relation</td>
<td>Related task</td>
<td>Dimensions of garden house</td>
<td>Influences</td>
<td>The dimensions of the garden house are determined in a related task.</td>
</tr>
</tbody>
</table>

Table 5.3: An example of a filled out FORM Relations.

CHECKLIST FOR INVENTORYING PROPERTIES AND FACTORS

Design task (properties)
- Product being designed
  - What is the desired state of the product being designed?
  - What is the current state of the product being designed?
- Design process
  - What is the desired state of the design process?
  - What is the current state of the design process?

Context of the design task (factors)
- What is the current state of the design context?
- What are possible trends in the design context?

Table 5.4: Basic CHECKLIST Description Design Situation.
**CHECKLIST FOR INVENTORYING PROPERTIES AND FACTORS**

### Design task (properties)

- **Product being designed**
  - What is the desired state of the product being designed?
  - Which main problem must be solved?
  - Which representation of the product being designed is desired? (medium, level of detail)
  - What are desired properties of the product?
  - Which representations of the desired state of the product being designed have been made?
  - What is the current state of the product being designed?
  - What are properties of the product being designed at this moment?
  - What are the important problems to be solved at this moment?
  - Which representations of the current state of the product being designed have been made?

- **Design process**
  - What is the desired state of the design process?
  - What is the deadline of the design process?
  - What is the budget for the design process?
  - What is the capacity of the design team?
  - Which other properties of the design process are desired?
  - Which representations of the desired state of the design process have been made?
  - What is the current state of the design process?
  - Can the deadline of the design process be met?
  - Who are the members of the design team?
  - Which part of the budget has already been used?
  - How is the design process supported (machines, software, tools, secretary, room, methods, procedures, environment, etc.)?
  - What are problems in the design process at this moment?
  - Which representations of the current state of the design process have been made?

### Context of the design task (factors)

- **What is the current state of the design context?**
  - Which related design tasks have been defined?
  - What are important factors in those related design tasks?
  - What are the current and the desired state of the overall design task?
  - What are the important stakeholders and their concerns?
  - What are important processes in the product lifecycle?
  - What are important factors in these processes?
  - What is the company strategy regarding product planning?
  - How does the companies vision influence the design task?
  - What are important competitors?
  - Which norms and laws are related to the design task?
  - What is state-of-the-art knowledge related to the design task?
  - Which representations of the current state of the design context have been made?

### Table 5.5: An example of CHECKLIST Description Design Situation.
CHECKLIST FOR ANALYSING DESIGN SITUATIONS

**Analysis of the state of the product being designed**
- Is the list of desired properties about the product being designed complete?
- Is the list of desired properties about the product being designed consistent?
- What is the core problem to be solved? Is this the real problem to be solved? Do I know similar problems?
- Is the list of current properties about the product being designed complete?
- Is the list of current properties about the product being designed consistent?
- Which desired properties are met up to now?
- Are all factors taken into account in the design of the product being designed?
- Which representations of the product being designed might be missing?
- What are consequences of the current state of the product being designed for processes in the product lifecycle?
- What are alternative properties and values? Why?
- How do I feel about the current state of the product being designed? (Does the product being designed fits its purpose? To what degree is the design challenge met and are the design conflicts resolved? What are the chances on the market? Is the product being designed future oriented with respect to the future development of the market and the technology? What is its aesthetic value?)
- Which current properties can be improved? Why?
- Which concepts of the product being designed can be re-used?

**Analysis of the state of the design process**
- Is the list of desired properties about the design process complete?
- Is the list of desired properties about the design process consistent?
- Which desired properties are not met?
- Are all important factors taken into account in the design of the design process?
- Which representations of the design process might be missing?
- What are consequences of the current state of the design process (duration, budget, capacity, etc.) for other processes in the product lifecycle?
- What are alternative possibilities for the design process?
- How do I feel about the current state of the design process? (How did the management support me? How was the collaboration with the design team?)
- How can the current state of the design process be improved?
- Which concepts of the design process can be re-used?

**Analysis of the state of the design context**
- Is the list of relevant factors complete?
- Are other representations of the design context desirable?

**Analysis of the complete design situation**
- What is the challenge of the design task?
- Is the list of relations complete?
- Are all relations consistent?
- Are properties about the product being designed and properties about the design process mutually consistent?

Table 5.6: An example of CHECKLIST Analysis Design Situation.
5.4 Reflection on design activities

In the previous section, support for the preparation step of reflection on a design situation is described. The current state of the product being designed, the design process, and the design context can be described and analysed with FORM Properties&Factors, FORM Relations, CHECKLIST Description Design Situation, and CHECKLIST Analysis Design Situation. In this section, support for the preparation step of reflection on a sequence of design activities, or in other words, reflection on the flow of the design process, is investigated. To have a good overview of the design activities in the design process, also an overview of interactions with the design context and of important transitions in the design context is needed. In Section 5.4.1, support for describing design activities and transitions in the design context is discussed. Section 5.4.2 describes support for analysing these activities and transitions.

5.4.1 Description of design activities and transitions in the design context

To reflect on design activities, I propose to make a textual description of design activities and of transitions in the design context. The level of detail of this description must depend on the design task and the preferences of a specific user. The following types of design activities can be distinguished:

- activities that change properties of the product being designed; for example, solving conflicts, looking up production techniques, trying out alternative solutions, and testing results;
- activities that change properties of the design process; for example, contacting a new design-team member, discussing support for the design process, and arranging a meeting with stakeholders for getting acquainted;
- activities that consist of interactions with the design context; for example, asking and receiving information from stakeholders, and giving information to stakeholders.

Also, at a certain moment during the design process, certain activities have already been executed, while others will be executed in the future.

FORM Design Activities&Transitions supports the description of design activities and transitions in the design context. This form consists of four main parts defined by two main columns and two main rows. The two columns are labelled ‘design task’ and ‘design context’. The two rows are labelled ‘past’ and ‘future’. The two columns distinguish important design activities executed in the design task and transitions in the design context. The rows distinguish design activities and transitions in the past and in the future. The first column is subdivided into three other columns: one column for describing activities about the product being designed, one column for describing activities about the design process, and one column for describing interactions with the design context. The activities, interactions, and transitions and their rationale can be given in the cells. An example of a filled out form can be found in Table 5.7.

---

25 Theoretically, every time when one attribute, value, property or factor changes, a transition occurs or a design activity is executed.
### Table 5.7: An example of a filled out FORM Design Activities & Transitions.

<table>
<thead>
<tr>
<th>Design Task</th>
<th>Important design activities</th>
<th>Design Context Transitions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Past</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ACTIVITIES</td>
<td>ABOUT THE PRODUCT BEING</td>
<td></td>
</tr>
<tr>
<td></td>
<td>DESIGNED</td>
<td></td>
</tr>
<tr>
<td>ACTIVITIES</td>
<td>ABOUT THE DESIGN PROCESS</td>
<td></td>
</tr>
<tr>
<td>INTERACTIONS</td>
<td>WITH THE DESIGN CONTEXT</td>
<td></td>
</tr>
<tr>
<td>TRANSITIONS</td>
<td>RELATED TO THE DESIGN TASK</td>
<td></td>
</tr>
<tr>
<td>Determine desired properties</td>
<td>Compose design team</td>
<td>Speak with director about product planning (rationale: to check rumours)</td>
</tr>
<tr>
<td>Analyse problem</td>
<td>Determine subtasks</td>
<td>Receive information about dimensions of the garden house from related design task</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ask information about dimensions of production machines</td>
</tr>
<tr>
<td><strong>Future</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Analyse how to link low cost with good quality</td>
<td>Solve software problem</td>
<td>Talk with supplier ingredients</td>
</tr>
<tr>
<td>Define all ingredients coating</td>
<td>Check rumours about changes in planning design task</td>
<td>Analyse patents of competitors (rationale: to find which ingredients cannot be used without permission)</td>
</tr>
<tr>
<td>Estimate cost of new coating</td>
<td>Hire other expert on coatings?</td>
<td></td>
</tr>
</tbody>
</table>

### 5.4.2 Analysis of design activities and transitions in the design context

To support the analysis of past and future design activities and transitions in the design context, CHECKLIST Analysis Design Activities & Transitions has been developed. The structure of the checklist consists of five main parts, namely an analysis of the activities about the product being designed, of the activities about the design process, of the interactions with the design context, of the complete design process, and of transitions in the design context. An example of CHECKLIST Analysis Design Activities & Transitions, including a first proposal of questions that can be asked, is presented in Table 5.8. Again, more empirical research is necessary to improve this list of questions.
CHECKLIST FOR ANALYSING DESIGN ACTIVITIES AND TRANSITIONS IN THE DESIGN CONTEXT

### Analysis of activities about the product being designed
- How did the desired state of the product evolve?
- How did the current state of the product evolve?
- How do I feel about the activities about the product being designed?
- What were problems in executing these activities?
- How can these activities be improved?

### Analysis of activities about the design process
- How did the desired state of the design process evolve?
- How did the current state of the design process evolve?
- How do I feel about the activities about the design process?
- What were problems in executing these activities?
- How can these activities be improved?

### Analysis of interactions with the design context
- How do I feel about the interactions with the design context?
- What were problems in executing these interactions?
- How can the interactions with the design context be improved?

### Analysis of the complete design process
- How do I feel about the design process? (with respect to the sequence of design activities, efficiency, effectiveness, problems, co-ordination, etc.) Why?
- What is the cause of problems in the design process? Could these problems be solved in a different way? What can be learned from these problems for future processes?
- Which design activities did not result in a change towards the design goal? Why?
- Which mistakes were made in the design process? Had it been possible to anticipate these mistakes?
- Is enough progress made in the design process?
- Which design activities can be executed more efficiently? How?
- Which concepts of the design process can be re-used for a similar design task?
- What were critical situations?
- What can be learned from the evolution of the different states?
- Which design activities must be executed in future subtasks?

### Analysis of transitions in the design context
- How did the design context evolve?
- How can transitions and future transitions in the design context better be taken into account?
- How can laws be influenced?

Table 5.8: An example of CHECKLIST Analysis Design Activities & Transitions.

### 5.5 Design sessions

The second concept of the design method, namely the concept of design sessions, is introduced to help designers with regular reflection on a design process. In [Dorst, 1997], it is described that a designer, when designing, is inside a design process (thrown into a situation) and not always in the position to consider the process critically and rationally. A designer that wants to be in control of the design process [by means of regular reflection on the design process] must step out of the ‘designerly way of thinking’ [Cross, 1994] every now and then. Based on these observations, it seems important to reserve certain moments during the design process for reflection. Reflection only at the beginning and
end of a whole design process is often too superficial; reflection must take place at many more moments during a design process. Currently, a design process is usually structured as a series of design phases (defined by milestones). See for possible design phases, for example, [Pahl et al., 1988]. Depending on the project, these phases take weeks or even several months. In my opinion, the period of a design phase is too long to support designers accurately in their daily activities\textsuperscript{26}, i.e., to support regular reflection. On the other hand, the period between two reflections may not be too short, because then, the reflections interrupt the creative process and are not efficient. The period of time of a design session is a compromise.

A design session is defined as a period of time during which one or more designers are working on a subtask of a certain design task; for example, two or three hours, a whole day, or a week. It is a period of time between two periods during which the designer(s) are not executing that subtask. In some sense, a design session is an existing (inherent) structuring principle in a design process; design sessions correspond to the daily-life rhythm of designers. Designers are not working continuously on a project; they take several breaks. Breaks can be coffee or lunch, interactions with stakeholders in the design context, other meetings, periods spent working on other projects, weekends, holidays, or others. These breaks might be considered as breaks between design sessions. Design sessions can thus have different lengths. A design phase usually includes a number of design sessions. A design process can be structured as a series of design sessions; design sessions split a design process into several parts. The concept of a design session is illustrated in Figure 5.9.

During a design session, a designer is working on a subtask of a design task. To define such a subtask, the concepts of the design frame can be used. A subtask can concentrate on (a) specific level(s), on (a) specific perspective(s), and on (a) specific process(es) in the product lifecycle (see also Section 5.7). For example, a subtask of the design task ‘design a new coating for garden houses’ is a subtask that concentrates on the level of details of the garden house, on the perspective durability, and on the use process. The kind of subtask defines the length of a design session: When the subtask includes routine design and when not many important design decisions are taken, the design session can take a long period of time (for example, one week). For non-routine subtasks, design sessions are preferably shorter.

In my opinion, the period of a design session is appropriate for regular reflection; reflection can take place at the beginning and end of such a design session. I propose the following structure for a design session: first, a period for reflection, then, a period during which a series of design activities (state transitions) can be performed, and, finally, another period for reflection. This structure is illustrated in Figure 5.10. As explained in Section 5.2, the goal of reflection is to generate possible design activities for the future; these activities must, of course, be generated with the goal of the design process in mind. Reflection at the beginning of a design session can generate ideas for possible design activities to be executed during the design session; reflection at the end of a design session can already generate ideas for possible design activities for the next design sessions.

\textsuperscript{26} This is one of the conclusions I have been drawing from the case studies I performed in practice (see Section C.4 in Appendix C).
I have chosen to support reflection on different kind of topics at the *beginning* and at the *end* of a design session. At the beginning of a design session, attention can typically be paid to the changes that occurred since the last design session (and in previous sessions). These changes are, for example, changes resulting from discussions, for example, at the coffee machine or in other meetings, changes in related design tasks, and changes in norms or laws. At the end of a design session, reflection can focus on changes in the design task, performed during the design session. The different emphasis of reflection at the beginning and end of a design session is illustrated in Figure 5.11. During the *core of a design session*, designers can transform the state of the product being designed and the state of the design process towards the design goal at that moment. For this purpose, different kind of design activities can be performed. During the core of a design session, designers have freedom to follow their own design method.
5.6 Structured reflection on design situations and design activities

The concepts defined in the previous sections can be combined to offer designers help for structured reflection: support for systematic reflection regularly during a design process. However, as discussed in Section 5.2, only support for the preparation step of a reflection process is developed. As proposed in Section 5.5, at the beginning of a design session, reflection should concentrate on changes that occurred between two design sessions; at the end of a design session, reflection should concentrate on changes in the design task, executed during the design session. In Sections 5.3 and 5.4, some help for reflection on design situations and on design activities is described. The distinction between reflection at the beginning and at the end of a design session has the following consequences for reflection on a design situation and on design activities.

Reflection on a design situation is divided into two parts. Reflection on the state of the design context is mainly done at the beginning of a design session; reflection on the state of the product being designed and the state of the design process is mainly done at the end of a design session. Of course, at the beginning of a design session, designers should also concentrate on the product being designed and the design process to know where the previous design session stopped. This can be done based on documents made at the end of the previous session. Reflection on a sequence of design activities is also split into two parts. Reflection on interactions with the design context and on transitions in the design context is mainly done at the beginning of a design session. Reflection on design activities about the product being designed and design activities about the design process is mainly done at the end of a design session.

In other words, at the beginning of a design session, a description and analysis of important factors, of interactions with the design context, and of transitions in the design context must be made. At the end of a design session, a description and analysis of important properties and design activities must be made. This answers the question, announced in Section 5.3.1, “When to describe what?” The distribution of topics for reflection over a design session is illustrated in Table 5.12.

<table>
<thead>
<tr>
<th>TOPICS FOR REFLECTION</th>
<th>BEGIN OF SESSION</th>
<th>END OF SESSION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reflection on a design situation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– State of the design context</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>– State of the product being designed</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>– State of the design process</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td><strong>Reflection on design activities</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Interactions with the design context</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>– Transitions in the design context</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>– Design activities about the product being designed</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>– Design activities about the design process</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.12: Distribution of topics for reflection over a design session.

The difference in emphasis of reflection at the beginning and end of a design session is a first proposal; the usefulness of this proposal must still be tested in design practice. The proposal is made for a design session of half a day. Because the period between two design sessions can be very short, for example, a lunch break, reflection at the beginning of a design session can be very short or not take place at all because no change could occur during the two sessions. When the period of time of a design session is, for example, one week, I suggest concentrating at the beginning and at the end of a design session on the complete design situation. This is necessary because changes in the design context can then also take place during a design session and not only between two sessions. The distribution of topics proposed in Table 5.12 is also not strict: New properties can also be described at the beginning of a design session; at the end, factors might be added; also during a design session, properties, factors, and relations can be added or an analysis can be performed. Instead of starting
from scratch in every design session, designers can also only update the previous description by adding properties and factors that are new or that have changed since the previous description.

The three checklists and forms described in the previous sections can be used for reflection on design situations and design activities, at the beginning and end of a design session. Refinements of the checklists and forms for reflection in design sessions are the following. In addition to the data that can be filled out in the FORMS Properties&Factors, Relations, and Design Activities&Transitions, also the start and end time of a session and the name of the session, i.e., the subtask, can be mentioned. Describing a design situation can best be done by filling out three separate FORMS Properties&Factors: one for all properties about the product being designed, one for all properties about the design process, and one for all factors describing the design context. The latter has the advantage that other forms are used at the beginning and end of a design session and that the three forms can evolve separately. During a design process, the number of changes for each subject differs (see also Section 3.2.2): The design context does often not change very much during a design process; the product being designed, however, changes very often during the design process. This means that in some forms changes occur more often than on other. CHECKLIST Analysis Design Situation can include the following additional questions when it is used for updating a previous description: “What is the reason for the change of state that occurred?” and “Does this change influence other properties, factors, and/or relations?”. CHECKLIST Analysis Design Activities&Transitions can be used to analyse transitions within a design session and between design sessions. Questions about the complete design process can be reformulated for a design session and for a series of design sessions (for example, for reflection at the end of a design phase). Of course, only questions that are relevant at that moment must be answered; the designer must determine the relevance of each question, based on his perception of the current design situation.

5.7 Overview of the design method

The design method can be started and used at every moment during a design process. The following five steps of the design method can be repeated for each design session:

The first step is planning a design session. The duration of a design session and the planning of a sequence of design sessions may depend on the planning of the overall design task and on the agenda of the designers and other persons involved in the design process. When planning a design session, a designer automatically plans moments for reflection, namely at the beginning and end of each session.

The second step is defining the subtask of the design session. When using the concepts of the design frame, the level(s), the perspective(s), and the process(es) the subtask should concentrate on must be defined. These levels, perspectives, and processes are values for the dimensions of the design frame and define a positioning space for a subtask. I propose to fill out a new form, FORM Design Frame, once at the beginning of a design process (at the beginning of the first subtask) and refine and extend it during the design process. FORM Design Frame is a template that can be filled with possible values for the three dimensions for each subject. This template is based on the general table represented in Table 4.13. An example of a filled out FORM Design Frame for the design task of a garden house is given in Table 5.13. The advantage of the form is that it enforces a consistent vocabulary during a design process and between a number of designers executing different subtasks. A design-team leader can, for example, also prescribe values for the template that can then be shared among several designers. After the form has been filled out, values for the three dimensions that correspond to the current subtask must be chosen to define the subtask. Of course, for reasons of integration, the focus of a designer executing a subtask must be broader than concentrating only on the specified level(s), perspective(s), and process(es); the subtask must be performed from an awareness of related levels, perspectives, and processes. For reasons of co-ordination, each subtask must also be performed in

27 The argument given in Section 5.3.1 that the terminology of the dimensions of the design frame is too abstract for designers also holds in this case; however, I believe that it is much easier to think about the possible values for dimensions of the product being designed, the design process, and the design context in general, than for each property and factor individually.
close contact with designers performing other subtasks (see also Section 4.6). The planning of a design session and the definition of its subtask can be based on a strategy for the complete design process, covering many design sessions.

<table>
<thead>
<tr>
<th>FORM Design Frame: Template with values for the dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design task:</strong> design of a new type of garden houses</td>
</tr>
<tr>
<td><strong>Designer:</strong> Isabelle</td>
</tr>
<tr>
<td><strong>Date:</strong> 24/01/2000</td>
</tr>
<tr>
<td><strong>Values</strong></td>
</tr>
<tr>
<td><strong>PRODUCT BEING DESIGNED</strong></td>
</tr>
<tr>
<td>Garden house</td>
</tr>
<tr>
<td>Components of garden house</td>
</tr>
<tr>
<td>Details of components</td>
</tr>
<tr>
<td><strong>LEVEL</strong></td>
</tr>
<tr>
<td>Usage</td>
</tr>
<tr>
<td>Production</td>
</tr>
<tr>
<td>Cost</td>
</tr>
<tr>
<td><strong>PERSPECTIVE</strong></td>
</tr>
<tr>
<td>Design process</td>
</tr>
<tr>
<td>Production process</td>
</tr>
<tr>
<td>Use process</td>
</tr>
<tr>
<td><strong>TIME</strong></td>
</tr>
<tr>
<td><strong>DESIGN PROCESS</strong></td>
</tr>
<tr>
<td>Design process</td>
</tr>
<tr>
<td>Design activities</td>
</tr>
<tr>
<td>Mental processes</td>
</tr>
<tr>
<td><strong>Means</strong></td>
</tr>
<tr>
<td><strong>People</strong></td>
</tr>
<tr>
<td><strong>Activity</strong></td>
</tr>
<tr>
<td><strong>Conceptual design</strong></td>
</tr>
<tr>
<td><strong>Embody design</strong></td>
</tr>
<tr>
<td><strong>Detail design</strong></td>
</tr>
<tr>
<td><strong>DESIGN CONTEXT</strong></td>
</tr>
<tr>
<td>Branch</td>
</tr>
<tr>
<td>Company</td>
</tr>
<tr>
<td>Product-development department</td>
</tr>
<tr>
<td><strong>Juridical</strong></td>
</tr>
<tr>
<td><strong>Economical</strong></td>
</tr>
<tr>
<td><strong>Social</strong></td>
</tr>
<tr>
<td><strong>Use process</strong></td>
</tr>
<tr>
<td><strong>Date:</strong> 24/01/2000</td>
</tr>
</tbody>
</table>

Table 5.13: An example of a filled out FORM Design Frame.

The third step is starting the design session with reflection. Only analytical activities useful for reflection (the preparation step of a reflection process) are supported in my design method. After these activities have been performed, the image-forming and conclusion-drawing step of the reflection process must still take place. Designers can start the reflection process at the beginning of a design session with the following two main activities: First, describing the important factors and important relations between these factors, using FORM Properties&Factors, FORM Relations, and CHECKLIST Description Design Situation; analysing the design context, using CHECKLIST Analysis Design Situation; and completing FORMS Properties&Factors and Relations, based on the analysis. Second, describing the interactions with and transitions in the design context, using FORM Design Activities&Transitions; analysing these interactions and transitions, using CHECKLIST Analysis Design Activities&Transitions; and completing FORM Design Activities&Transitions, based on the analysis. The activities performed during the preparation step stimulate designers to look at the current design situation and the performed design activities from different perspectives. All information collected during the preparation step can help designers to perform the image-forming and conclusion-drawing steps from a broad perspective.

The fourth step is designing during the core of the design session. Because the goal in this thesis is only to help designers with structured reflection, no specific support for performing design activities during a design session (what to do in a particular design situation) has been developed. Designers can start from representations made in earlier sessions or from the descriptions made during the reflection periods. During the core of a design session, designers also have to realise that they will need some time for reflection at the end of the design session. For example, when they go to lunch at twelve o’clock, they have to stop their design activities ten minutes before, to have some time for reflection.

The last step is ending the design session with reflection. Again, only analytical activities are supported. The image-forming and conclusion-drawing steps must follow these analytical activities and take advantage of the information collected during the preparation step. Designers can start the reflection process at the end of a design session with the following two main activities: First, describing properties of the product being designed, properties of the design process, and relations, using FORMS Properties&Factors, Relations, and CHECKLIST Description Design Situation (use separate forms for the properties of the product being designed and the design process); analysing these properties and relations, using CHECKLIST Analysis Design Situation; and completing FORMS Properties&Factors and Relations, based on the analysis. Second, describing the most important design activities, using FORM Design Activities&Transitions; analysing these design activities, using CHECKLIST Analysis Design Activities&Transitions; and completing FORM Design Activities&Transitions, based on the analysis.
When the filled out forms are kept for the next design session(s), these can be used as some kind of documentation of the previous design situations, of design activities performed in the previous design session(s), and of possible design activities for the next design session(s).

### 5.8 Using the design method

The design method has been developed to help designers with structured reflection on design processes. The design method is intended for every type of design project. Because the design method is domain independent, it may be useful in different disciplines and in multidisciplinary projects. The use of the design method can be tailored to the needs of a specific discipline and designer: The checklists and forms can be made domain specific by defining domain-specific attributes and questions; design sessions can be planned by designers. In Appendix A, the use of the design method is illustrated for the design of a new type of garden house.

Individual designers and design teams can use the design method. An individual designer can perform the five steps of the design method described in the previous section. The design method may be used in design teams as follows: the first, second, and fourth step can be performed by all team members together. Steps three and five (reflection) must start with a description and analysis by each individual team member (preparation step). The results of these description and analysis activities of all team members can then be compared and discussed within the team. The complete team can also perform the image-forming and conclusion-drawing steps. Discussions are necessary to come to a shared understanding within the design team. Because each member can use the same structure and terminology of the forms and checklists, communication problems may be reduced. More about improving team design by reflection and the importance of shared understanding within teams can be found in [Valkenburg, 2000].

The concrete use of the design method can be realised in several ways: The forms can be filled out on paper or a computer can assist the user. I developed a prototype of a software system, called Echo, to explore the benefits of using a software system to facilitate the use of the design method. In the prototype, so far, only the description and analysis of design situations is yet supported. A detailed description of the prototype, including recommendations for further research, can be found in Appendix B. Main components of the prototype are summarised below.

Echo consists of a database for storing properties, factors, and relations, a database-management system, and a user interface. In the prototype, the topics of the questions of CHECKLIST Description Design Situation and a possibility to enter properties and factors (part of FORM Properties&Factors) are combined in the concept of a 'tree'. Electronic forms have been developed to make a precise description of properties, factors, and relations; they replace FORMS Properties&Factors and Relations. Several queries and some checks support the analysis of design situations (part of CHECKLIST Analysis Design Situation). The concept of templates is added to the prototype to make it easy for a user to change the attributes in the forms and (the topics of) the questions in CHECKLIST Description Design Situation.

Echo is domain independent, but the concept of templates makes it possible to tailor the use of the design method to the terminology and concepts of a specific discipline. The prototype can be used during the third and fifth step of the design method for describing and analysing a design situation. To describe a design situation, a user can add properties and factors in the tree, describe properties, factors, and relations more precisely by using the electronic forms, and change values for the different attributes in the electronic forms. To analyse a design situation, a designer can query information and check design relations.

Using Echo for describing and analysing design situations has the following advantages compared to using pencil and paper (see also Section B.8 in Appendix B):

- The administration of properties, factors, and relations is more flexible;
- electronic information can be edited more easily;
relations between properties and factors can be visualised graphically (although not yet graphically in the current prototype);

- searching for information and comparing specific overviews of the information is easy;

- some simple consistency checking are possible;

- the prototype can easily be tailored to the needs of a specific discipline, project, or user because the attributes in the forms and the structure and questions of the checklist can be changed easily in the template.

5.9 Conclusions

My design method is a domain-independent aid that offers designers help for reflecting on design processes in a structured way. The design method introduces two main concepts, namely the systematic description and analysis of design situations and design activities (by means of forms and checklists) and the concept of a design session to support regular reflection on the design process. At the beginning and end of design sessions, reflection can be performed. Only support for the preparation step of a reflection process has been developed. A software tool facilitating the use of the design method has also been developed. In the design method and software tool, similarities between the three investigated disciplines are taken into account; room is left for their differences.

The contribution of the design method to this thesis lies in the concepts it offers to reach the goal in this thesis, namely offering support for structured reflection on design processes in several disciplines. For this purpose, the domain-independent terminology of the design philosophy is used and the concepts of the design frame for structuring descriptions and for analysis of design processes are incorporated. The goal in this thesis is only partly met because not a complete reflection process is supported. Conclusions concerning the design method and recommendations for further research are described in the next chapter.
6 Conclusions

The research project described in this thesis can be positioned in the world of designing, and more specific in the field of design research. Starting points for supporting structured reflection on design situations and design activities have been developed to improve design processes in practice. Three design disciplines, namely software engineering, mechanical engineering, and architecture, have been studied to develop domain-independent design knowledge. In the thesis, attention is paid to the results of my research, my research process, and my research context. These correspond to the three parts of a design situation, namely the product being designed, the design process, and the design context respectively.

The results of my project are a design philosophy, based on the general theory of state-transition systems, a design frame, and a design method, including a prototype software tool facilitating the use of the design method. These results offer descriptive and prescriptive design knowledge. The main activities during my research process were performing qualitative empirical research in the form of cases studies, doing a literature study, developing the design philosophy and the design frame, designing the design method, developing a prototype software tool, and performing again qualitative empirical research for a first confrontation of my results with design practice. The research was set up as an explorative study. Important factors in my research context were my supervisors, the conferences I attended, the presentations I gave, and other meetings with designers and researchers.

In the next two sections, conclusions about the results and the process of my research are given. In Section 6.3, more general conclusions for the world of designing are presented. Recommendations for further research are given in Section 6.4.

6.1 Conclusions about the results of the research project

My results are descriptive and prescriptive design knowledge, developed to answer the following research questions: “How to describe design processes in a domain-independent way?” and “How to support structured reflection on design processes in a domain-independent way?” Answers to the research questions are developed to reach the overall goal of my research and the specific goal in this thesis (see Section 2.3). Section 6.1.1 discusses the descriptive results, namely the design philosophy and the design frame. Section 6.1.2 discusses the prescriptive results, namely the design method and a prototype software tool. Finally, Section 6.1.3 discusses the results in the light of the goal of my research and the goal in this thesis. Given the explorative nature of the research project, the results can be considered as a starting point for theory forming and testing.

6.1.1 Descriptive results

My design philosophy and design frame are answers to the first research question. The goal of the descriptive knowledge is to offer concepts, terms, and structures that are useful to describe design processes in a domain-independent way.

My design philosophy is a set of domain-independent concepts and terms for describing a design process from the viewpoint of state-transition systems. State-transition systems are a special form of transformation systems: the latter transform something in something else; state-transition systems transform a state into another state. In the design literature, the notion of transformation is widely used: In [Hubka et al., 1996], a design process is modelled as a process of transforming design information. In [Yoshikawa, 1981], [Tomiyama et al., 1986], and [Takeda et al., 1990], a

28 During my research project, I observed that designing is part of the activity of doing research. I did research about designing, but this research also included the design of support for designers in practice, namely a design method and a prototype software tool.
transformation from a functional specification to an artefact specification is suggested. More transformation models in the design literature are summarised in [McMahon et al., 1995].

I have chosen to describe design processes in a domain-independent way using the theory of state-transition systems, because it is a very general theory (which was necessary because similarities between design processes in several disciplines could only be found on a very high level of abstraction) and because this theory was most appropriate to describe all the important aspects of a design process I recognised in the case studies I performed in several disciplines (see Section 3.1 and Appendix C). The cases revealed many differences, like kinds of products, terminology, and kind of representations. Similarities that I recognised in the various disciplines, like the importance of properties of the product being designed, the design process, and the design context at a certain moment and the concept of a design task can be described using the theory of state-transition systems.

Some information about state-transition systems in general can be found in Section 3.1. The concept of state-transition systems is also already used in the field of design. In [Salustri et al., 1991] and [van der Net, 1998], a design process is defined as a series of time-dependent actions that transform the information through a series of states. A similar definition is given in Section 3.4.2. The theory of Salustri et al. was, however, not taken as a basis for my design philosophy because it formalises ‘design information’ rather than concentrating on the description of the ‘design process’; I preferred concentrating on the description of the design process. State-transition systems can be represented in several ways. In [Knoop, 1999], state-transition systems are represented by Petri-Nets in order to describe bottlenecks in design processes. Petri-Nets offer a more detailed representation (and offer thus more detailed information) than my kind of representation and might be used to refine my domain-independent description of design processes. Other design philosophies and models related to my design philosophy are mentioned in Section 1.4.1 under descriptive theories within the paradigm of positivism.

In my design philosophy, a tension between the general concepts of state-transition systems and the specific aspects of design processes in practice can be recognised. I made the general theory of state-transition systems suitable for describing design processes by adding important characteristics of design processes in practice (as discussed in Section 1.3): the concept of a design situation, a distinction between current and desired properties and between properties and factors, the concept of alternatives, the concept of co-evolution of desired and current properties, the concept of a design goal at a certain moment (not ‘the’ design goal fixed during the whole process), the concept of a design task, and a specific definition of designing. Many aspects of design processes, however, are still not explicitly modelled in my design philosophy (like a designer, design skills, creativity and intuition, design decisions, and design phases). The concepts design decision and design phase can easily be modelled using the theory of state-transition systems: A design decision can be modelled as an elementary transition, taking a short period of time; a design phase can be modelled as a transition taking a long period of time. The theory of state-transition systems is not appropriate to model a designer and his characteristics; theories based on the social sciences are more appropriate to do so.

Another tension that can be recognised in the design philosophy is the tension between the description of design processes in a domain-independent terminology and the specific terminology used in design disciplines. The terminology used in different disciplines varies very much. To provide multidisciplinary design teams with a common language, the terminology must be based on similarities in the terminology of different disciplines; these similarities can only be found on a very high level of abstraction. As a consequence, it is more difficult for designers in the disciplines to understand the concepts of the design philosophy. Feedback on the design philosophy confirmed this tension. Feedback on the design philosophy indicated that designers (always having a background in a certain discipline) have difficulties with the domain-independent terminology. The concepts of the design philosophy, however, are understood in each discipline I investigated. Feedback on the prescriptive results of my research project, which are based on the concepts and terminology of the design philosophy, also revealed that the terminology of the design philosophy is very abstract. My domain-independent concepts and terminology are, however, compatible with the concepts in the general design theories, mentioned before and in Section 1.4.1; these theories, for example, also
describe the design process as a transformation system and also use concepts like properties and factors.

As a result, I can assume that the goal of the design philosophy, namely offering concepts and terms that are useful for describing design processes in a domain-independent way, is met. Below, the two main concepts of the design philosophy, namely design situation and design activity, are discussed and compared to the literature. A design activity is described in my design philosophy as an activity causing a state transition. This is, however, only one way of describing design activities. In the literature, the concept of a design activity is well known; more about the concept of design activities in the literature can be found in Section 1.3.3.

The concept of a design situation is already used in the literature about designing, but I did not find an explicit definition of it. I picked up the term design situation in [Dorst, 1997]. Dorst points out that a designer is ‘thrown’ into a design situation. He is inside a design process and is not always in the position to consider it critically and rationally. In the paradigm of positivism, [Hubka et al., 1996, p. 141] and [Badke et al., 1997] use the term (design) situation in combination with factors influencing the design process. In my definition, factors influencing the design process and the product being designed are part of a design situation. The classification of important factors made by [Hubka et al., 1996] and [Badke et al., 1997] also corresponds to the three parts in my definition of a design situation, namely the product being designed, the design process, and the design context. Also in the paradigm of constructivism, a design situation is an important concept. For example, in [Schön, 1983] and [Valkenburg et al., 1998], the term is used with a similar meaning as in my philosophy. In [McDonnell, 1997], general descriptions of design situations are generated, based on a systematic grammar network. This kind of description differs from my definition of a description of a design situation, due to the author’s specific perspective on the study of designing, namely an interpretivistic. This perspective is a complementary way of looking at designing. In contrast to my analytical perspective, which focuses on analysis of action as manifested behaviour, the interpretivist perspective focuses on understanding action as purposeful, meaningful interaction in a social setting.

My concept of a design situation is a model of reality; this means that it abstracts from certain aspects in reality. At least the following two aspects of reality are not explicitly modelled: It is a snapshot at a certain moment in time and it omits in some sense timing relations; only properties and values that exist at that moment belong to the design situation. In my concept of a design situation, a distinction is made between a product being designed, a design process, and a design context. These three parts of a design situation are of a different kind, but are treated in a similar way. The three parts influence each other in the sense that changes of one part can have consequences for the others; the three parts are interdependent. There is a difference in frequency of change between the three parts: During a design process, the product being designed changes most often, the design process changes sometimes, and the design context does not change very much or maybe change not at all.

The design frame offers a domain-independent structure for positioning properties, factors, design tasks, and representations. The design frame is described using the domain-independent concepts and terms of the design philosophy. Feedback on the design frame indicates that the dimensions and the concept of a subject appear to be domain independent, because the terminology and concepts were recognised by expert designers in the three disciplines. Feedback on the design frame and design method indicates that the design frame offers a useful structure. Junior designers using the design method, which includes the concepts of the design frame, however, had difficulties with the abstract terminology of the design frame. Nevertheless, I assume that the dimensions level, perspective, and time, combined with the concept of a subject, are sufficient to reach the goal of the design frame, namely supporting the domain-independent description and analysis of design situations and design activities. Theoretically, the three dimensions of the design frame are very much related to the three dimensions defined in the design theory described in, for example, [Bax, 1986] and [Bax, 1989]. This theory is based on general systems theory and also aims to offer a structure to position important

29 Subject as defined in Chapter 4: The three parts of a design situation, namely product being designed, design process, and design context are considered as subjects.
concepts and aspects of designing. The proposed structure of the design frame is not the only one possible; testing several alternatives for this structure may result in a better structure.

Together, the design philosophy and the design frame offer concepts, a vocabulary, and a structure to describe design processes in a domain-independent way. At least the design processes in the three disciplines I studied can be described fruitfully in a domain-independent way with these concepts, vocabulary, and structure. But, I assume that it is also possible to describe design processes in other disciplines with the same knowledge; my concepts correspond, for example, to general concepts used in the domain of electrical engineering, for example, described in [Voeten et al., 1998] and [Van der Putten et al., 1998].

6.1.2 Prescriptive results

My design method is a first step towards an answer to the second research question. It is a domain-independent aid that supports designers to reflect on design processes in a structured way. Systematic reflection is supported by means of checklists and forms, but only for the preparation step of a reflection process\(^\text{30}\) (which is the reason that the design method is only part of an answer); the concept of design sessions is used to support regular reflection. The domain-independent terminology of the design philosophy is used for describing the design method; the concepts of the design frame are incorporated in the design method. A prototype software tool has been developed as a first attempt to support the design method. The prototype is one of many possible implementations of a software system facilitating the use of the design method; it was useful to explore the advantages and disadvantages of using a software system to facilitate the use of the design method. In this subsection, first, my design method is positioned in the literature. Then, my viewpoint on reflection is discussed. Finally, the two main concepts of my design method and the main topics of the feedback on the design method I received from practice are discussed. A more extensive description of feedback on the design method can be found in Appendix D Sections D.3.3 and D.3.4; feedback given on the prototype software tool can be found in Sections D.3.5 and D.3.6.

My design method can be positioned in the literature as follows. It can be seen as a ‘systematic’ design method. Related systematic design methods are discussed in Section 1.4.2. The following systematic methods are related to my first concept, namely supporting systematic reflection by means of checklists and forms: methods for exploring design situations and methods of evaluation, as described in [Jones, 1970]. A systematic design method that is developed to support a complete reflection process is described in [Badke et al., 1999] and [Wallmeier et al., 1999]. The authors try to provide designers with support for reflecting on adequate and inadequate design processes and to teach designers to identify critical situations\(^\text{31}\). For this purpose, a training concept that asks involvement of external observers and teachers is developed. For supporting a complete reflection process, my design method might also be extended with a training concept.

In [Dorst, 1997, Section 1.1.3], it is stated that any method for aiding design activities must contain statements about the dynamics of a design process, a model of the structure of the design task, and a model of the designer. In my design method, only part of the dynamics of a reflection process instead of the dynamics of a complete design process are supported. Structure is brought into a design task by means of design sessions and subtasks. A model of the designer is not explicitly made. However, the design method makes clear that the designer plays an important role: he is not only part of the state of the design process, but also the subject performing the reflection process; he is user of the design method.

My viewpoint on reflection can partly be compared to Schön’s ‘reflection-on-action’ (see Section 1.5.3). My design method supports reflection on the current design situation (on the current state of the

\(^{30}\) A reflection process is defined, in Section 1.5.1, as a process that consists of three main activities that are called preparation, image forming, and conclusion drawing.

\(^{31}\) Critical situations are situations that have an important influence on the further direction of the design process or the product being designed.
product being designed, the design process, and the design context) and reflection on the remembered design activities (the latter corresponding to Schon’s reflection-on-action); my combination of reflection on a design situation and reflection on design activities is probably unique. Reflection on the activities in a (design) process only is often part of management tools. By including reflection on the current product being designed (the focus designers like most), designers might be more interested in the method for reflection. In some sense, my approach can be compared to the concept of concentric development, described in [Roozenburg et al., 1994]. Concentric development essentially means taking into consideration all important aspects (of a product-development process) in ‘each round’. In practice, a round corresponds to a phase of a product-development process. In my design method, concentric development can be seen as taking into account all aspects of a design situation, namely the product being designed, the design process, and the design context, in each design session.

The first main concept of my design method, namely the description and analysis of design processes by means of forms and checklists, is developed to support systematic reflection on design processes. The forms are developed to help designers making a description of a design situation and of design activities in a systematic way. These forms are similar to worksheets, design logs, diaries, and design-history systems described in the literature. The goal of all these ‘things’ is to store information about the design process that can be looked up later on (in the design process, as some kind of documentation, or for research purposes, to analyse design processes). The worksheets described in [Hansen, 1999] are used to identify work patterns applied by designers; they can be seen as a research tool. Design logs and diaries are books in which designers can describe the activities they performed and the decisions they took; these design logs and diaries are mainly intended for the designers themselves. A design-history system enables product-development organisations to record the steps in which the product is developed, including the underlying decision rationales, and makes this information available for re-use [Wiegeraad, 1999]. Further research is necessary to find out if the forms I developed are useful for re-use and research purposes. One of the questions that must be answered is “Has the use of the forms influence on the design process?”, if this question is answered positive, then, the forms are perhaps not a good research aid to describe design processes.

One of the goals of the forms and checklists I developed is helping designers to get an overview of the design process. The current checklists and forms, however, mainly help to make complete lists (which are not yet overviews). Designers are also not very much supported in determining the relevant questions of the checklists and determining the important properties and factors that must be taken into account. The forms and checklists are thus not ideal. Supporting designers to create an overview of the design situation and design activities may help to increase the effectiveness and efficiency of the design method. An overview may be generated by using different kind of forms or by using a more interactive software system. For teams, the prototype software tool can be improved by offering insight into the overview of other team members and by indicating similarities and differences between perspectives of different team members; for example, team members mentioning a different main problem that must be solved can be alerted about this fact. When choosing the concept of forms and checklists, I assumed that designers like to work with checklists and forms and that they see their usefulness. I also assumed that designers are aided with reflection by making documents that offer overview or by creating clear orderings on the screen. However, in current practice, designers are used to reflect only on their perception of the situation and their remembered experiences, and not on overviews. The junior designers giving feedback on the design method, however, appreciated the idea of creating overviews for reflection.

My forms, filled out during a design process, fulfil in some sense a documentation function\(^\text{32}\); the information described is intended for use by the designer. Further research can investigate if it is necessary to describe all the information I suggest in the design method (designers do not like describing) and can look for possibilities to reduce the amount of information. Perhaps, the concept of forms can be changed or replaced by other kinds of documentation in order to minimise the amount of

\(^{32}\) Note that the descriptions of a design situation and design activities made for structured reflection are different from the representations of the product being designed, the design process, and the design context that are made by a designer during a design session.
information that must be written down during a design process. This is important because feedback on
the design method made clear that reflection on design processes takes some time and that time is
scarce for a designer.

The second main concept of my design method is the idea of design sessions, developed to let
designers reflect regularly during a design process. This concept is, as far as I know, not yet used for
stimulating regular reflection. Schön proposes, in [Schön et al., 1996], designers to reflect when a
‘surprise’ occurs during a design process. However, when a designer does not recognise this
‘surprise’, no explicit reflection will take place. My design method stimulates designers to reflect on
the design process at the beginning and end of a design session. This means that the creative processes
in the design process are not disturbed and that each kind of designer is stimulated to reflect many
times during each design process. Whether or not a real reflection process takes place still depends on
the designer’s perception of the design situation and the performed design activities. The development
of my design method is based on the assumption that explicit reflection can improve design processes.
In the managerial context, a similar assumption is already proved: In [Daudelin, 1996], it is stated that
providing managers with a one-hour reflection session, using structured questions and guidelines,
significantly increases the learning from their experience (see also Section 1.5.2). I also assumed that a
designer is able to reflect explicitly on a design process. Designers, however, are used to take
decisions implicitly; supporting explicit reflection may be an intervention in the designers’ natural
way of working. As a result, it may be difficult to convince designers of the advantages of the
developed support. The fact, however, that the beginning and end of design sessions are natural
moments for reflection, may help the acceptance of the design method in practice. This assumes
however, that a designer is able to define design sessions and to take some time for reflection each
session. Because the design method is only tested during two design sessions, empirical research
during a longer period of time and in many different design processes is necessary to check the latter
assumption.

In my design method, reflection during each design session takes the same form during the whole
design process; only a distinction between the beginning and end of a design session is made. The
design method may be refined by distinguishing different kinds of reflection for the first and last
reflection process of a design process and for the different phases of a design process; reflection on the
main planning of a design process should, for example, only take place at the end of a design phase.
Reflection could also happen more often for certain aspects and less often for others; a software tool
can, for example, refine automatically the list of questions when more detail is required and different
kinds of overviews could be made for each phase. Also, a distinction between general and detailed
overviews and between overviews for the designer himself and for other people could be made.

In [Daudelin, 1996], I found an affirmation of my choice for the main concepts of my design method.
Daudelin’s research focuses also on reflection, but it concentrates on reflection in the context of
learning by managers (see Section 1.5.2). Daudelin states that one of the techniques for increasing the
power of reflection is the posing and answering of questions. Questions are the main components of
my checklists. She also states that to use reflection as a tool, some time and structure must created.
This idea corresponds to my second concept: Design sessions create some structure that is useful for
reflection on the design process. I propose designers to plan some time for reflection at the beginning
and end of a design session; Daudelin, however, proposes separate reflection sessions.

My design method is aimed to be used by designers, in concrete design processes, for specific design
tasks, in certain design phases, and in specific design situations. A tension can be recognised between
the domain-independent concepts and terminology of the design method and the concreteness of the
design practice. A first version of the design method was completely based on the general concepts
and terminology of the design philosophy and design frame. Feedback given by designers on this
previous version of the design method included complaints about the abstract terminology of the
design method; the designers had difficulties with translating the general terminology to their specific
terminology. In the current version of the design method, a step towards terminology more commonly
used in practice is made (see Section 5.3.1). I believe, however, that domain-independent support will
always be abstract is some sense. As a result, I think that before applying this kind of support in a
practical situation, a translation of the general terms into terms used in the specific discipline(s) (explaining the general concepts in the terminology of the designer) must be made.

The feedback of the designers indicated also that the design method might be better useable in practice when its use does not cost too much time for designers and when designers recognise its benefits. I believe, however, that a design method supporting reflection on design processes might be saving time in the long run, but not in the short run. The effectiveness and efficiency gained by using the design method might increase when the same designers use the design method more often (after some time, the designers will be less focussed on the design method itself and more on the reflection process).

I conclude this subsection with recalling the goal of the design method. The design method has been developed to answer the second research question, namely “How to support structured reflection on design processes in a domain-independent way?”. The question is answered as far as the combination of the two main concepts helps to support structured reflection on design processes and the support is domain-independent. The design method is, however, only a first attempt towards an answer because it only supports the preparation step of a reflection process. Nevertheless, the current design method can already help designers to increase the effectiveness and efficiency of their design process, given its focus on reflection and learning. A prototype software tool is developed to facilitate the use of the design method. This prototype, however, does not yet support structured reflection; it only supports the description and analysis of design situations.

6.1.3 Comparison with the research goals

The previous two subsections describe my answers to the research questions defined in Section 2.5. These answers are developed to reach the goal of my research (which defines the problem that must be solved) and the goal in this thesis (which defines how the problem is solved in this thesis). This subsection compares my answers to these goals.

The specific goal in this thesis is to develop domain-independent design knowledge to support structured reflection on design processes. This goal has been reached in the sense that all results are domain independent and that support for structured reflection on design processes is developed, namely a design method and a prototype software tool. The design method supports structured reflection by means of checklists and forms and by means of the concept of design sessions. Again, not a complete reflection process but only the preparation step of a reflection process is supported.

The overall goal of my research is to decrease the gap between design research and design practice in order to improve design processes. This goal has been achieved in the sense that I did not only study design literature, but I also looked at design practice to see which aspects of design processes are important in various disciplines. At the end of my research project, I returned to the practice to get feedback on my results. Besides getting input from design practice, I also tried to develop knowledge that is useful for design practice: I focused on important problems in design practice, like communication and integration problems in multidisciplinary teams; solutions to these problems may improve the efficiency and effectiveness of design processes in several disciplines. I tried to solve these problems by developing domain-independent support for reflection.

6.2 Conclusions about the research process

When comparing my research process (described in Section 2.8) with the final research goals (given in Section 2.3), I can say that, although my research goals changed a number of times during the research process (see Section 2.8)\(^{33}\), the research process delivered desired results (as discussed in Section 6.1). In the remainder of this section, important activities of the performed research process are compared to the research goals.

\(^{33}\) My research goals changed mainly due to influences from the design context. Another research context would certainly have resulted in another Ph.D. thesis.
Because my research project was set up very broad and required a relatively new approach in design research, namely the development of domain-independent design knowledge based on the study of several design disciplines, I have chosen an explorative study. As described in Section 1.2.8, the main goal of this kind of research is aiming at finding relations that are considered to be relevant for a certain theoretical or practical goal; theory and/or hypotheses forming and testing must follow explorative research. For my research project, I have chosen a practical goal, namely trying to improve design processes by developing support (see Section 2.6). Because I worked towards the (fast) development of support, the choices I made during my research process are more pragmatic; the results of this thesis can thus only be considered as a starting point for further theory forming and testing. Despite of this fact, my results are consistent, they have been developed in accordance with the literature and the case studies, and they have also been tested – though in a very limited way – in a first confrontation with design practice. Given my (final) research goals, I believe that the choice for an explorative study was a good one.

I performed empirical research at the beginning and at the end of my research process. The empirical research was necessary to get input from design practice. The goal of the case studies I performed at the beginning of my research project (see Section 2.8 and Appendix C), namely exploring the design practice and inventoring the most important characteristics of design processes in several disciplines, has been met: I found many differences between the design processes in the different disciplines, but I also found common characteristics of design processes, mainly on a general level. While executing the protocol I developed for the case studies, I learned that one of the two sources for case-study information I have chosen, namely interviewing designers, has some disadvantages: An interview is too short for discussing a (complete) design project and most of the designers find it difficult to talk about designing. In spite of these disadvantages, I believe that interviews are a useful technique for design research, if they are combined with other techniques. I combined interviewing designers with analysing the documentation of their design projects.

The goal of the empirical study I performed at the end of my research project (see Section 2.8 and Appendix D), namely getting an impression of the generality of my results and getting feedback on the relevance and usefulness of my results for design practice, has also be met. The empirical research was not called ‘test’, but ‘confrontation with design practice’, because the results have not been fully tested; for example, the concept of design sessions could not be fully tested, because only one day has been planned (the planned day included only two design sessions). For a real test, the design method should be used during, at least, two weeks. Although limited, the feedback on my results learned me much about my results, as discussed in Section 6.1.

My empirical research focussed on three design disciplines, namely architecture, software engineering, and mechanical engineering, and I asked input from design practice from junior and expert designers. The choice for junior and expert designers for the case studies and for the feedback can be evaluated as follows. When comparing the input given by the junior and expert designers in the case studies, generally speaking, the following can be recognised: The junior designers used important steps in the design methods (they just learned) to talk about their design process, whereas expert designers did not use the terminology of these methods. The junior designers also talked about the difference they recognised between what they have learned about designing at the university (designing a product, using techniques) and the practice in which other designers and stakeholders in the design context are also very important. The junior designers had more problems with the general terminology than the expert designers. Comparing the feedback on the developed support given by the junior and by the expert designers, expert designers made merely proposals for their application domains, whereas junior designers tried to think together with me about the main assumptions and possible improvements of the current support. Expert designers were more experienced with different forms of reflection already used in practice. Finally, expert designers could better compare their own discipline to other disciplines. Summarising, both types of designers offered me different kinds of input; both have been of great value for my research project. In the comparison I made between the answers given by designers from the three disciplines, I recognised the following differences: all architects stressed the importance of social aspects during a design process and only software engineers had few problems with my general terminology and with my systematic design method. When positioning
architecture and software engineering as two extremes (importance of social aspects, less systematic against importance of logic, familiar with more systematic approaches) and when positioning mechanical engineering somewhere in the middle\textsuperscript{34}, I recognised that the three disciplines offered me a balanced mix of important aspects of design processes.

At the beginning and at the end of my research process, I also performed a literature study. Given the explorative nature of my research project, this study was sufficient to reach the goals of the project. The literature study concentrated on general design literature and design literature in the three disciplines; results of this study can be found throughout the whole thesis. My research process also included the development of support. When comparing the huge amount of time needed for developing support (i.e., a software tool) and the research goals, the following can be concluded: I think that a tool must only be built if it is essential for the result of the research project; the importance can thus compensate for the required effort. The same holds for doing empirical research; this research activity also takes a lot of time and must thus also only be conducted if it is essential. In my case, the development of the prototype software tool did not contribute to my results sufficiently to compensate for the effort. This was partly caused by the fact that my results are only preliminary whereas the development of a software tool needs a strong theoretical and practical basis.

The research activities performed in my research project have their origins in the constructivist paradigm (see Section 1.2.8). For my research process, no clear-cut research methodology has been followed. Despite of the fact that not yet mature research methodology for design research exists, design research, together with all other topics of research, must fulfil certain criteria, for example, mentioned in [Cross, 1998] (see also Section 1.2.8). My research project fulfils these criteria as follows: My research is purposive in the sense that it is based on the identification of problems worthy and capable of investigation, namely the gap between design research and practice and the problems in multidisciplinary teams (see Section 2.2). My research is inquisitive in the sense that is seeks to acquire new knowledge, namely domain-independent design knowledge that is useful for design practice (see Section 2.3). The research is informed because of the performed literature study. The qualitative empirical research I performed is planned and carried out in a disciplined matter, i.e., methodical (see Appendices C and D). Finally, my results can be tested and accessed by others (as also proposed in Section 6.4), which means that my research is communicable.

### 6.3 Conclusions for the world of designing

As mentioned in Section 2.2, problems in the world of designing are the gaps between the different fields. Problems in design practice are the communication in multidisciplinary teams and the integration and co-ordination of different aspects during a design process. Design processes in practice can be improved by increasing their effectiveness and efficiency. The study of similarities and differences between design processes in several design disciplines deserves more attention in design research; the same holds for the development of support for reflection on design processes.

This section discusses the contribution of each of my results to solve these problems and the contribution and usefulness of my results to each field in the world of designing. A general contribution of my thesis to the world of designing is that it pays attention to the concept of reflection, which is important in the three fields in the world of designing. The discussion on how I tried to bridge the gap between design research and design practice can be found in Section 6.1.3. Figure 6.1 gives an overview of my results, of the fields in the world of designing, and of the relations between them.

Design literature and results of my case studies are the basis of the descriptive knowledge developed in this thesis. The design philosophy and design frame can be useful for the world of designing: The contribution of my design philosophy to design research is that it offers a domain-independent description of design processes that is based on the study of design processes in several disciplines. Various important concepts about designing are described from the viewpoint of state-transition

\textsuperscript{34} This way of positioning the three investigated design disciplines is based on the case studies and the literature study I performed at the beginning of my research project.
systems. The design philosophy provides a definition of a design situation, a new definition of designing, and a new model of the design process (see Figure 3.8). The design philosophy was a basis for the description of the design frame and for the development of the design method and is a basis for the development of many other applications, based on the same concepts. For example, it can be a basis for a more extensive study of similarities and differences between several disciplines (as described in the recommendations in Section 6.4). The design philosophy is elaborated in such a way that it allows further extensions; for example, the concept of hierarchy or parallelism can be added.

![Diagram](image)

**Figure 6.1:** Basis and usefulness of my results in the world of designing.

The design philosophy can offer designers and design students a vocabulary for talking and thinking about design situations and design activities and can offer more insight into their design processes. A precise and consistent vocabulary is a necessary condition for improving communication in practice. Because the concepts of the philosophy are domain independent, designers in specific disciplines can use the terminology. They can also tailor the general concepts and terminology to their specific concepts and terminology. The vocabulary may also be used for communication between designers in multidisciplinary projects.

The contribution of the *design frame* to design research is the structure it offers for positioning important concepts that are used by designers, like properties, factors, design tasks, and representations. The structure of the design frame may help designers (and design students) to compare properties, factors, design tasks, and representations in terms of their level, their perspective, the process they focus on, and their subjects. The structure may also help the integration and coordination of important aspects; for example, aspects, positioned on several levels, can be integrated per level. The concepts of the design frame are used in the design method to support the systematic description and analysis of design processes, but they are also starting points for the development of possible new support for designers.

My descriptive knowledge forms the basis for my prescriptive knowledge. My design method can be useful for the world of designing as follows. The contribution of the *design method* to design research can be seen as a first proposal of a design method that supports (structured) reflection on design processes. The method includes concepts for the systematic support of the preparation step of a reflection process and for regular reflection during a design process. Mainly the reflection process of individual designers is supported. In contrast to many other design methods, my method pays attention to the product being designed, the design process, and the design context. The design method also introduces the idea that designers can be supported on the level of design sessions instead of only on the level of design phases (design sessions are usually shorter than design phases).

I believe that the design method is useful for design practice and design education, although the method must still be tested extensively. The design method is domain independent, which means that it may be useful in several disciplines and multidisciplinary teams. Feedback on my design method demonstrates, however, that it is important that the domain-independent terminology is tailored to the specific terminology of designers in a specific discipline. The domain-independent concepts, described in their terminology, must then only be applied to their specific design task and design situation. Because the design method stimulates reflection, which is an important activity in a learning process,
designers using the design method may learn from their design process and improve it (see also Section 2.3). I believe that structured reflection on design processes may increase the efficiency and effectiveness of design processes in practice; to obtain these results, however, the design method should be refined and extended as indicated in the next section. Also, the prototype software tool derived from the design method, as described in Appendix B, is not yet useful for design practice and design education; it must first be extended and improved.

6.4 Recommendations for further research

Given my results and their current usefulness for the world of designing, this section discusses how the results can be improved and extended. The most important recommendation for further research is to test all results extensively in design practice: in the disciplines I studied, but also in other disciplines, and with individual designers and in (multidisciplinary) teams. Further research can also investigate how to apply the results in design education (in the form of courses, guidelines, techniques, and/or tools). More specific possibilities for further research for each of my results are given below.

The design philosophy must be tested with respect to generality and usefulness for design practice and design education. These tests must, for example, answer the question “Is the division between states (design situations) and design activities useful for describing design processes?” The tests can be performed by making descriptions of design processes in several design disciplines, using the terminology and concepts of the design philosophy, in order to find out if the terminology and concepts are sufficient to describe all these different design processes. Perhaps, the terminology is also useful to describe similarities and differences between different design processes. The design philosophy can also be tested by using the concepts and vocabulary in some kind of support and by then testing the concepts and vocabulary during the use of this support.

The design philosophy can be refined with the concepts hierarchy and parallelism. Hierarchy (of properties, factors, relations, design tasks, and representations) can, for example, make explicit the relation between subtasks of design tasks and these latter tasks and make explicit the relation between representations that cover part of other representations and these latter representations. Parallelism makes it possible to describe the execution of several subtasks in parallel. The philosophy can be extended with concepts of designing that are not yet fully taken into account, such as design decisions, and perhaps also with concepts like the role of a designer and design skills. The concept of design decisions can easily be added to the design philosophy (see Section 6.1.1). To add the other two concepts, however, the concepts of the design philosophy should be extended with concepts from social sciences in which humans (designers) get a central role. For the extension of the design philosophy with more domain-independent design concepts, further research can be based on multidisciplinary teams instead of on individual design disciplines as I did.

Further research for the design frame should concentrate on a better theoretical and empirical foundation of the set of dimensions and its combination with subjects of a design situation. Empirical research can also investigate if there exist other dimensions that can help to structure and position properties, factors, design tasks, and representations (by testing alternative structures). Also, alternative terminologies can be tested. New applications can be developed for designers, based on the current design frame, as already proposed in Section 4.6; these applications should then be tested in design practice and design education.

Further research for the design method can concentrate on empirical research and on a literature study to test and improve the design method, on the extension of the concepts of the design method (and of the prototype software tool), and on a translation of the design method for use in design education. Below, each of the recommendations is explained in more detail.

Performing empirical research that concentrates on reflection on design processes in current design practice can offer insights that are useful to improve my design method. The following questions can be answered: “Do designers already reflect in practice?” “How?” “Do there exist differences in natural ability for reflection between designers?” “What are the benefits of reflection on design
processes?”, and “What are the differences between explicit (for example, following a certain method) and implicit reflection?” The research can be performed by questionnaires and by observing designers, for example, one group that is stimulated to reflect explicitly and one group that is not. Besides concentrating on the concept of reflection in design practice, empirical research can also concentrate on testing the two main concepts of my design method, namely the description and analysis of design situations and design activities and the concept of design sessions, and on testing the design method as a whole, as discussed below.

Empirical research is also necessary to answer the following questions: “Is it effective and efficient to split reflection on a design process in reflection on the current design situation and in reflection on the performed design activities?”, “What is the impact of describing and analysing design situations and design activities on the design process?”, “Do the activities ‘describing’ and ‘analysing’ support a reflection process?”, “Are forms and checklists useful means to support description and analysis of design situations and design activities?”, “Are the developed forms useful for re-use and/or research purposes?”, and “How to create overviews of the design process, in different phases of the design process?”. The answers to these questions are important for improving the first concept of my design method, namely the description and analysis of design situations and design activities. The answers can be obtained by testing several alternatives and/or by observing one group of designers that is supported by the concept and another that is not. Testing the design method can improve the structure and the questions of the checklists and the lists of attributes and possible values for properties, factors, and relations. Based on these tests, also guidelines can be developed to tailor the design method to different disciplines; for example, guidelines to translate the general terminology to the terminology in the various disciplines and guidelines to make the checklists more specific for different kind and magnitudes of design tasks in the various disciplines.

For testing and improving the second concept of my design method, namely the concept of design sessions, the following questions must be answered: “What are average duration of design sessions in practice?”, “What are good periods between two moments of reflection, or in other words, what are good duration for design sessions (assuming that reflection takes place at the beginning and end of a design session)?”, “Is it useful to reflect at the beginning and the end of a design session?”, “Is the distinction of topics for reflection between the beginning and the end of a design session useful?”, “Is a further refinement of the topics for reflection during a design process useful (different topics at the beginning and end of a design process and/or during each design phase, etc.)?”, and “Is it useful to reflect on some aspects more frequently than on other aspects?”. These questions can be answered by testing several alternatives and by observing designers during a long period of time (including several design sessions) in a number of real cases. The habits and preferences of designers concerning design sessions must then be combined with the concepts of my design method.

By letting individual designers and design teams follow the five steps of the design method (see Section 5.7), the whole design method can be empirically tested and the benefits of the use of the design method in terms of efficiency and effectiveness can be analysed. By testing the design method in several design disciplines, the domain independence can be tested.

Besides empirical research, also an extensive literature study can be performed to improve the design method. It seems important to me to look in more detail than I did at systematic design methods; these also include checklists and classification systems that can improve the structure and the questions of my checklists and my lists of attributes and possible values for properties, factors, and relations. Another source of information can be the literature about social sciences that concentrates on improving learning processes in practice (for example, the learning process of managers, as investigated in [Daudelin, 1996]); this kind of literature includes analytic as well as intuitive techniques. It also seems important to me to investigate the differences in benefit between reflection-on-action (the kind of reflection I supported) and reflection-in-action and to find out when which kind of reflection can best be supported for design processes. At this moment, an increasing amount of literature concerning reflection-in-action and related situated experiences can be found; see, for example, [Seibert, 1999] and [Suwa et al., 2000].
The design method can be extended as follows. Because my design method only concentrates on the preparation step of a reflection process, developing support for the image-forming and conclusion-drawing steps of a reflection process must extend the design method. The latter kind of support must take into account knowledge of cognitive and social sciences (see also Section 5.2). Support can, for example, consist of a training session in which designers can learn the necessary skills for the image-building and conclusion-drawing steps.

Also the prototype software tool can be extended to improve the use of the design method; possible improvements and extensions of the prototype are described in Appendix B Section B.9. It seems also useful to me to think about the possible use of the design method in design education: for example, the concept of design sessions may help students to structure their design process; supporting students with structured reflection can help them to learn from their design process.

My results can also be a starting point to study similarities and differences between design disciplines in more depth than I did. As explained in Section 2.3, such a study can be useful for improving design processes in several design disciplines and multidisciplinary design processes. I started my research project with the investigation of similarities and differences between design disciplines and I found that it is necessary to have domain-independent terminology, concepts, and structures to describe the similarities and differences. The domain-independent descriptive knowledge presented in this thesis can serve as a starting point for further research on similarities and differences. To study similarities and differences, a researcher has to look at the different disciplines in more detail than I did. Design practice, design education, and design literature in each discipline must be studied to find similarities and differences in viewpoint, aspect, terminology, approach, design situation, multidisciplinarity, etc..

Important questions that must be answered, taking for each question the specific research and design context into account, are the following: “Which aspects are absent or underexposed in a certain discipline?”, “Is there a difference between disciplines designing material and immaterial products?”, “Which aspects get less or no attention in certain disciplines?”, “Which aspects of a design situation change often in the different disciplines?”, “Are the differences between disciplines structural or only based on tradition (socially, culturally, historically determined)?”, “What are similarities and differences in terminology of designers from different cultures (different companies, application areas, and geographical areas), working in international teams?”, “How has design methodology evolved in the various disciplines?”.

Summarising, a very extended research program including a lot of empirical research is proposed. All proposed questions, however, cannot be answered in one study, because then, too many variables must be taken into account; making a meaningful choice for further research is not that easy. I propose to start with extending the design method, based on an extended literature study, with support for the image-forming and conclusion-drawings steps of a reflection process; this kind of support can be developed using my general terminology. Afterwards, individual designers from several disciplines can test the whole design method in practice; before the tests can be performed, the terminology used in the design method must be translated to the specific terminology of each discipline. After the design method is improved based on the feedback resulting from these empirical tests, I advice to make the design method useful for design teams. Finally, a new software tool facilitating the design method can be build. Notice that this proposal for further research continues my research process as an interactive process consisting of actions concentrating alternately on design research and on design practice.

6.5 Closing remarks

With this thesis, I hope to contribute to a (renewed) interest in developing domain-independent design knowledge in the field of design research, or even better, to a renewed interest in crossing the boundaries of the various disciplines. Not only designers, but also researchers should collaborate in multidisciplinary teams (teams with researchers having a background in different disciplines, both technical and non-technical). Given the gaps between the different fields in the world of designing, I believe that also a good interaction between design research, design education, and design practice is necessary.
As a final remark, I hope that this Ph.D. thesis demonstrates people outside the research community that research about designing is possible; I also hope that my work may be an impulse to continue the debate on the importance of design research for supporting design practice and for the education of designers. I believe, based on [Reymen, 1999b], that the position of current design research must be improved by stimulating the exploration of new fields of research in order to decrease the gaps between the different fields in the world of designing and to integrate the design knowledge of the various design disciplines. Domain-independent as well as domain-specific design research is important. Further research concentrating on the development and validation of methods for design research must also be stimulated.

‘Good general theory does not aim for maximum generality, but for the right generality’

Saunders MacLane (University of Chicago), mentioned in [Hillier et al., 1972]
A  Design of a New Type of Garden Houses

A.1  Introduction

This appendix describes part of a design process to design a new type of garden houses for Dutch gardens. The goal of this example is twofold: giving an example of a reflection process in the context of designing, as defined in Sections 1.5.1 and 1.5.3, and illustrating the use of my design method. (The design method is described in Chapter 5; the use of the design method is described in Section 5.8.) The example is an artificial example; it is not supposed as justification of the usefulness of the design method and it is too simple to be representative for problems in design practice.

My design method proposes designers when to reflect (at the beginning and end of a design session) and how to perform the preparation step of a reflection process. The design method consists of five steps for each design session (see Section 5.7). These steps are planning a design session, defining the subtask of that design session, reflecting at the beginning of the design session, designing during the core of the design session, and reflecting at the end of a design session. A reflection process consists in this thesis of three steps that are called preparation, image forming, and conclusion drawing. Forms and checklists support the preparation steps of the reflection processes at the beginning and end of a design session.

In the example, a designer of a company producing garden houses (Cathy) started a design process to design a new type of garden house; she used the design method to do so. I describe her first design session, which is part of the conceptual design phase of the design process. The execution of the five steps of the design method is described, including a description of the complete reflection process. A representation of the current type of garden houses is given in Figure A.1.

A.2  Step 1: planning a design session

The first session of the design process was planned on August 20, 2000 and took place on August 22, 2000, from 14 o’clock till 16 o’clock.

A.3  Step 2: defining the subtask

The subtask of the design task that was defined by Cathy for the first design session was making a conceptual design of a new type of garden houses. This subtask was positioned in the positioning...
space defined in Table 5.13 as follows: The subtask had to concentrate on the level of a garden house, had to consider the perspectives usage, cost, and (environmentally friendly) production, and had to focus on the use process.

A.4 Step 3: reflection at the beginning of a design session

A.4.1 Preparation step

My design method proposes designers to describe and analyse a design situation and design activities during the preparation step. At the beginning of a design session, a designer must concentrate on factors influencing the design process, on interactions with the design context, and on transitions in the design context.

Description and analysis of the design situation

CHECKLIST Description Design Situation helped Cathy to determine the most important factors. In the first design session of the design process, the questions about stakeholders and their concerns and the questions about important processes in the product lifecycle seemed relevant to Cathy. Important stakeholders were customers of garden houses, garden shops, and companies producing (parts of) garden houses. The resulting factors were filled in FORM Properties&Factors; the result is given in Table A.2. (For reasons of clarity, I only include the attributes stadium and rationale in the form.) Relations between these factors were described in FORM Relations, given in Table A.3.

<table>
<thead>
<tr>
<th>FORM Properties&amp;Factors: Description of a design situation: properties and factors</th>
<th>Date: 22/08/2000</th>
<th>Designer: Cathy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design task:</strong> design of a new type of garden houses</td>
<td><strong>Start time session:</strong> 14:00h</td>
<td><strong>End time session:</strong> 16:00h</td>
</tr>
<tr>
<td><strong>Subtask:</strong> conceptual design</td>
<td><strong>Factors</strong></td>
<td><strong>VALUE</strong></td>
</tr>
<tr>
<td>Size of Dutch gardens</td>
<td>Small</td>
<td>Design context</td>
</tr>
<tr>
<td>Dutch climate</td>
<td>Rains very often, not really cold</td>
<td>Design context</td>
</tr>
<tr>
<td>Importance of garden for Dutch people</td>
<td>High, gives status, often used</td>
<td>Design context</td>
</tr>
<tr>
<td>Attitude of owners garden shops concerning new products</td>
<td>Positive</td>
<td>Design context</td>
</tr>
<tr>
<td>Market for current type of garden houses</td>
<td>Saturated</td>
<td>Design context</td>
</tr>
<tr>
<td>Concern of company producing garden houses</td>
<td>Environmentally friendly production</td>
<td>Design context</td>
</tr>
</tbody>
</table>

Table A.2: FORM Properties&Factors filled out for factors.
FORM Relations: Description of a design situation: relations

| Design task: design of a new type of garden houses | Date: 22/08/2000 | Designer: Cathy |
| Subtask: conceptual design | Start time session: 14:00h | End time session: 16:00h |

<table>
<thead>
<tr>
<th>Relations</th>
<th>FROM</th>
<th>TO</th>
<th>KIND</th>
<th>RATIONALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation</td>
<td>Attitude of owners garden shops concerning new products</td>
<td>Market for current type of garden houses</td>
<td>Is a consequence of</td>
<td>Owners of garden shops recognise need for new products</td>
</tr>
<tr>
<td>Innovation</td>
<td>Market for current type of garden houses</td>
<td>Importance of garden for Dutch people</td>
<td>Is a consequence of</td>
<td>Customers want new types of garden houses (something ‘special’)</td>
</tr>
</tbody>
</table>

Table A.3: FORM Relations filled out for relations between factors.

During the analysis of the design context, using CHECKLIST Analysis Design Situation, Cathy mentioned that the list of factors describing the design context and the list of relations between these factors was far from complete and had to be completed in the next design sessions.

Description and analysis of design activities

In FORM Design Activities&Transitions, given in Table A.4, Cathy described the interactions she already had with the design context and the planned interactions. Also the transitions that happened in the design context and the transitions that might take place in the future were written down.

FORM Design Activities&Transitions: Description of design activities and transitions

| Design task: design of a new type of garden houses | Date: 22/08/2000 | Designer: Cathy |
| Subtask: conceptual design | Start time session: 14:00h | End time session: 16:00h |

<table>
<thead>
<tr>
<th>Design Task: Important design activities</th>
<th>Design Context: Transitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTERACTIONS WITH THE DESIGN CONTEXT</td>
<td>TRANSITIONS RELATED TO THE DESIGN TASK</td>
</tr>
<tr>
<td><strong>Executed</strong> Spoke with director about new product-development process</td>
<td>Competitor ‘X’ failed (reason not yet clear)</td>
</tr>
<tr>
<td><strong>Executed</strong> Asked director the degree of innovation allowed (rationale: to get to now what changes are possible)</td>
<td></td>
</tr>
<tr>
<td><strong>Planned</strong> Talk with production manager</td>
<td>The size of some gardens in The Netherlands will increase (rationale: more people will move to the countryside)</td>
</tr>
<tr>
<td><strong>Planned</strong> Talk with representative of consumers of garden houses</td>
<td></td>
</tr>
</tbody>
</table>

Table A.4: FORM Design Activities&Transitions filled out for interactions with the design context and transitions in the design context.

Because of the early stage of the design process, the analysis of the interactions with and the transitions in the design context, using CHECKLIST Analysis Design Activities&Transitions, did not result in new insights.

A.4.2 Image-forming step

During the image-forming step, Cathy tried to get a picture of what a moderate Dutch man/woman wants to have in his/her garden. She did not get a good impression.

A.4.3 Conclusion-drawing step

During the conclusion-drawing step, Cathy defined design activities that had to be performed during the design session, based on her image of the design context, the first interactions with the design context, and the goal of the design process. Because she only had some vague ideas of desired
properties, she decided that it was best just to start the development of some alternatives of possible types of garden houses and verify these against the important factors (by looking for advantages and disadvantages).

**A.5 Step 4: designing**

After the first reflection period, the design method proposes designers to perform design activities. Recall that the design method does not prescribe design activities in any way. The designers can choose their favourite methods. In the example, the result of these activities were the following three variants of a possible type of garden houses:

- The first variant is a cave in the ground that can be reached by a stair (see Figure A.5a).
- The second variant is a garden house 2.5-meter above ground level (see Figure A.5b). This garden house can be reached by a spiral stairs and is covered with a new type of coating to make it gleam;
- The third variant is an open construction, consisting of four wooden beams and a canvas (sail) tight between these beams. Inside this construction, a box is placed in which material can be stored (see Figure A.5c).

**A.6 Step 5: reflection at the end of a design session**

**A.6.1 Preparation step**

At the end of a design session, the design method proposes a designer to concentrate on properties of the product being designed and the design process and on design activities performed or to be performed in the design task.

*Description and analysis of the design situation*

The most important properties of the product being designed and of the design process were described using FORM Properties&Factors; the results are given in Table A.6 and Table A.7, respectively. The description in Table A.6 includes for each variant values of the properties of the product being designed (for a definition of variants in the design philosophy, see Section 3.2.2). The rationale for the different values was not written down by Cathy, but can easily be derived from the pictures. Relations between properties and factors were described in FORM Relations, presented in Table A.8.
### Table A.6: FORM Properties&Factors filled out for properties of the product being designed (garden house).

<table>
<thead>
<tr>
<th>Properties of the product being designed</th>
<th>VALUE</th>
<th>SUBJECT</th>
<th>STADIUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perception of space</td>
<td>Moderate</td>
<td>Good</td>
<td>Very good</td>
</tr>
<tr>
<td>Perception of environment</td>
<td>Bad (No relation)</td>
<td>Good</td>
<td>Very good (In close relation)</td>
</tr>
<tr>
<td>View on garden</td>
<td>Bad (No view)</td>
<td>Very good</td>
<td>Good</td>
</tr>
<tr>
<td>Protection (of people and equipment)</td>
<td>Very good</td>
<td>Good</td>
<td>Moderate</td>
</tr>
<tr>
<td>Storage of equipment</td>
<td>Good</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Multifunctionality</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Occupation of space</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
</tbody>
</table>

Table A.7: FORM Properties&Factors filled out for properties of the design process.

<table>
<thead>
<tr>
<th>Properties of the design process</th>
<th>VALUE</th>
<th>SUBJECT</th>
<th>STADIUM</th>
<th>RATIONALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximal duration of design process</td>
<td>Two months</td>
<td>Design process</td>
<td>Desired property</td>
<td>Overcapacity of production machines in two months</td>
</tr>
</tbody>
</table>
FORM Relations: Description of a design situation: relations

<table>
<thead>
<tr>
<th>Relations</th>
<th>FROM</th>
<th>TO</th>
<th>KIND</th>
<th>RATIONALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental relation</td>
<td>Perception of environment</td>
<td>Size of Dutch gardens</td>
<td>Is determined by</td>
<td>The perception of the environment depends on the position of the garden house in the garden.</td>
</tr>
<tr>
<td>Openness</td>
<td>View on garden</td>
<td>Size of Dutch gardens</td>
<td>Is determined by</td>
<td>The view on the garden depends on the position of the garden house in the garden.</td>
</tr>
<tr>
<td>Spatial relation</td>
<td>Occupation of space</td>
<td>Size of Dutch gardens</td>
<td>Is limited by</td>
<td>The space occupied by the garden house is limited by the size of the garden.</td>
</tr>
<tr>
<td>Appropriateness for Dutch climate</td>
<td>Protection (of people and equipment)</td>
<td>Dutch climate</td>
<td>Is important because of</td>
<td>The protection given by the garden house must be appropriate for the Dutch climate.</td>
</tr>
<tr>
<td>Usefulness</td>
<td>Multifunctionality</td>
<td>Importance of garden for Dutch people</td>
<td>Is important because of</td>
<td>When the garden house is multifunctional, it can be used often.</td>
</tr>
</tbody>
</table>

Table A.8: FORM Relations filled out for relations between properties.

The most important question of CHECKLIST Analysis Design Situation that was answered during the analysis of the state of the product being designed and the state of the design process was “Are all factors taken into account?”. Only the concern of the company about environmentally friendly production was not yet taken into account; this factor would become important during the next sessions.

Description and analysis of design activities

The important design activities that were already performed and those needed to be executed in the future were written down in FORM Design Activities&Transitions, described in Table A.9.

FORM Design Activities&Transitions: Description of design activities and transitions

<table>
<thead>
<tr>
<th>Design Task: Important design activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACTIVITIES ABOUT THE DESIGN PROCESS</strong></td>
</tr>
<tr>
<td>Executed</td>
</tr>
<tr>
<td>Planned</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Table A.9: FORM Design Activities&Transitions filled out for design activities.

The analysis of design activities and design processes, using CHECKLIST Analysis Design Activities&Transitions, resulted in the following recommendation. Cathy proposed to involve the production manager already early in the design process because she expected communication problems about the production of the probably unusual concept that would come out of the design process.
A.6.2 Image-forming step

During the image-forming step, Cathy tried to get a good impression of the current garden houses and of each of the variants, by looking at the values for all properties. She described the positive aspects of each of the types as follows:

− Current garden houses offer good protection and good storage functionality.
− Variant 1 offers very good protection and storage possibilities and occupies almost no place on the ground level.
− Variant 2 offers a very good overview on the garden, a good perception of space and environment, and a good protection.
− Variant 3 offers a very good perception of space, a very good relation with the environment, and a good view on the garden, and is multifunctional.

General negative aspects of each variant were the following:

− Variant 1 is not human friendly.
− Variant 2 is unrealistic because of neighbours all around.
− Variant 3 is the complement of current garden houses: It is not good in protection and storage, whereas the current garden houses are good for these functions (both occupy a lot of space).

A.6.3 Conclusion-drawing step

During the last step in the reflection process, Cathy noticed that she really did not know which functions Dutch consumers appreciate most of a garden house. Because the three variants have good and bad characteristics, Cathy proposed the following design activities for the next design sessions: analyse which functions of a garden house are desired and think of combinations of variants. (At that moment, Cathy thought of the combination illustrated in Figure A.10: A wooden frame, following the contours of the current garden houses, forms the main construction; the walls can be removed easily; storage of small material can take place in a box in the ground. This variant combines the current type of garden houses with variants 1 and 3. Properties of this type are the following: The perception of space and environment, and the view on the garden is very good when the walls are removed; protection is very good when the walls are left in the garden house. Because of the concept of flexible walls, the garden house is multifunctional. The only disadvantage of the combination is that it still occupies a lot of space.) At 16 o’clock, Cathy had a meeting for another project.

![Figure A.10: Combination 1.](image-url)
B Prototype Software Tool

B.1 Introduction

The prototype software tool described in this appendix is a first implementation of a software system facilitating the use of the design method. (The design method is described in Chapter 5; the use of the design method is explained in Section 5.8.) The prototype, called Echo, has been developed to explore the benefits of using a software system to facilitate the use of the design method. A software system can be good at storing and managing information and at offering overview on complex data; a software system might also be helpful for the preparation step of a reflection process, namely for describing and analysing design situations and design activities. In the current prototype, only the description and analysis of design situations is supported. Echo has been developed in parallel with the design method. Although the design method evolved\(^35\) after the development of the prototype stopped (the prototype is thus based on a previous version of the design method), the current concepts for reflection on a design situation can still be recognised in Echo.

General concepts of Echo are explained in the next section. In Sections B.3 through B.7, the concepts of the prototype are explained in more detail. In Section B.8, advantages and disadvantages of the prototype, when compared to the use of pencil and paper for executing the design method, are described. Section B.9 describes possible improvements and extensions of Echo, based on the feedback received from a confrontation of the prototype with junior and expert designers (see Appendix B, Sections B.3.5 and B.3.6) and based on the evolution of the design method. In Section B.10, some general conclusions are drawn. More information of the prototype and user and implementation documentation can be found in [Reymen et al., 2001] and on the CD-ROM belonging to this report. The development of the prototype software tool is described in Section 2.8.

B.2 General concepts

In the design method, the description and analysis of design situations is supported by FORMS Properties&Factors and Relations and CHECKLISTS Description Design Situation and Analysis Design Situation. FORM Properties&Factors can be used to list properties and factors and to describe them more precisely; CHECKLIST Description Design Situation can help to inventory the most important properties and factors; FORM Relations allows to describe relations; CHECKLIST Analysis Design Situation contains questions for a critical analysis of the design situation.

In Echo, (part of) FORM Properties&Factors and CHECKLIST Description Design Situation are combined in the concept of a ‘tree’, further explained in Section B.4. Electronic forms have been developed to make a precise description of properties, factors, and relations; they replace FORMS Properties&Factors and Relations and are described in Section B.5. Several queries (see Section B.6) and some checks (see Section B.7) support the analysis of design situations (part of CHECKLIST Analysis Design Situation). The concept of templates is added to the prototype to make it easy for a user to change the attributes in the forms and (the topics of) the questions in CHECKLIST Description Design Situation; the concept of templates is further explained in Section B.3. The prototype is domain independent, but the concept of a template makes it possible to tailor the use of the design method to the terminology and concepts of a specific discipline. The prototype consists of a database for storing properties, factors, and relations, a database-management system, and a user interface, as illustrated in Figure B.1.

\(^35\) Based on the results of confrontations of the design method and the prototype with junior and expert designers (see Section 2.8 and Appendix B).
Echo can be used during the third and fifth step of the design method for describing and analysing a design situation. To *describe a design situation*, a user can add properties and factors in the tree, describe properties, factors, and relations precisely via the electronic forms, and change values for the different attributes in the electronic forms. To *analyse a design situation*, a designer can query information and check design relations. The prototype is implemented in Java Swing. Because Java is platform-independent, the application can be used on PC/Windows and Sun/Unix platforms. The prototype was developed via rapid prototyping; if it is decided that a new version will be built, it is going to be implemented from scratch.

![Figure B.1: Basic structure of the prototype.](image)

### B.3 Templates

The basic Echo template is a structure that can be used to define specific attributes of properties, factors, and relations, predefined values for some of the attributes, and topics and structure of a checklist (CHECKLIST Description Design Situation). A template can be filled out for each type of design task, user, project, and/or discipline. When starting the prototype, a particular (filled out) template can be chosen to initialise the prototype. An advantage of the use of templates is that attributes, predefined values, and checklists do not have to be fixed in the prototype. This means that users can use their own terminology and structuring principles (if defined in templates). Templates can also easily be changed, which makes it (from a research point of view) easy to test different concepts.

### B.4 A tree

To understand the concept of a tree, a file system can be taken as an example. The tree concept is used in Echo to implement CHECKLIST Description Design Situation and (part of) FORM Properties&Factors. As mentioned in the previous section, topics and structure can be defined in a template. The checklist defined in the template is made visible as a tree in the basic screen of the prototype, using the style of Windows Explorer. A user can enter properties and factors at different levels in the tree; when information is entered, the tree shows (part of) the current design situation (this function corresponds to that of FORM Properties&Factors). An example of a tree is given in Figure B.2. A ‘+’ in the tree indicates that information exists at a lower level in the tree. A ‘-’ means that all information at lower levels is visible. Properties and factors are distinguished from the topics and structure of the tree by a ‘>’ sign and a different colour. In the example, three factors are visible.
Electronic forms

The design method contains forms for making a precise description of a design situation. In Echo, electronic forms replace FORMS Properties&Factors and Relations. An example of electronic FORM Relations is given in Figure B.3. The names (attributes) in the left column of the electronic form correspond to the names of the columns in FORMS Properties&Factors and Relations. In the right column, values for these attributes can be filled in or they can be chosen from a pull-down menu; the values in this menu are predefined by a user in a template or are generated by the prototype. In the example of Figure B.3, values for the attributes ‘From DF’, ‘To DF’, and ‘Type’ can be chosen in a pull-down menu; values for the first two of these three attributes are generated by the prototype (they are the properties and factors in the database); values for the type attribute are predefined by the user.

Three type of attributes are distinguished in the prototype, namely attributes that always occur in an electronic form (called basic attributes), attributes that can be defined by a user in a template (called additional attributes), and extra attributes (explained below). I defined the following basic attributes
for properties and factors: label, value, source, reference, and rationale and for relations: label, from, to, and rationale. Examples of additional attributes for properties and factors are stadium and fixation. An example of an additional attribute for relations is the attribute type. Extra attributes are defined to perform some kind of configuration and version management. These attributes do not correspond to attributes defined in the design method. The extra attributes are not visible for the user and values for these attributes are added automatically by the software. The extra attributes are the following (In the remainder, I use the term ‘item’ to refer to ‘a property, a factor, or a relation’):

- **Unique identifier**: A value for this attribute is a unique code given to each item that is added to the database.
- **Time-stamp**: The value for this attribute is the date and time when the item is added to the database.
- **Topic**: A value of this attribute gives the topic (question) under which the property or factor is added to the checklist. This attribute is only defined for properties and factors, not for relations.
- **Status**: Values for the status attribute are ‘actual’ and ‘obsolete’. When an item is added, it automatically gets the value ‘actual’. When a user changes this value, the old value becomes obsolete. Making an item obsolete replaces the action of deleting the item. An obsolete item can also be changed back again into an actual one by a user. The advantage of using a status-attribute is that no items are removed permanently (they can all be retraced) and that the data in the database is not static.
- **Version**: The value of this attribute is the version-number of an item. A new version is made of an item when any value of an attribute of the item is changed. The software detects this change automatically and increments the version-number by one. A user can look up earlier versions of an item (see also the next section).

### B.6 Queries

With the current prototype, only some simple analysis of the data entered in the database can be performed; CHECKLIST Analysis Design Situation is only partly supported. Echo includes three kinds of query mechanisms: a mechanism to look at the detailed data in the database; a mechanism to look from different points of view to the data; and a mechanism to search for specific information.

With the **first type of query**, all the details of one property, factor, or relation can be viewed. The tool works similar for properties and factors. The screen ‘detail of a design factor’ in Figure B.4 shows the result of a query of the first type applied to a selected factor. The screen shows all values of the selected factor and all properties and factors that are related to this factor. The screen consists of three columns. The middle column (B) gives the attributes of the selected factor and values for these attributes. Previous versions of the factor can be requested. The left (A) and right (C) columns represent properties and/or factors related to the factor in column B (from A to B and from B to C). By selecting a relation and subsequently select ‘Relation A->B’ from the ‘View’ menu, values for attributes of the selected relation can be viewed.

The **second type of query** offers an overview of all properties and factors that are entered in the tree under a certain topic; for example, all properties about the product being designed or all properties about the desired state of the product being designed. Also, an overview of all relations concerning a property or factor that is entered in the tree under a certain topic can be asked. As an example, the screen ‘overview design factors’ is shown in Figure B.5; in this case, all factors in the design context that have the value ‘no’ for the document attribute are shown.

The **third type of query** offers the possibility to search on specific values for specific attributes defining certain items. Examples are queries giving

- an overview of all properties of the product being designed, with the value ‘negotiable’ for the fixation attribute;
- all factors with status ‘actual’, with stadium ‘desired’, and with some value including the word ‘coating’;
all relations of a certain type.

The third type of query can be performed for properties, factors, and relations. The screen ‘Query Design Factors’ is shown in Figure B.6. In the left column, specific values for attributes can be entered; the middle column shows the number of items left in the selection (updated each time a refinement of the query is made); in the third column, a user can mark which attributes and values must be shown in the overview. The result of the specific query in Figure B.6 is the overview shown in Figure B.5.

![Figure B.4: Screen ‘Detail of a design factor’.](image1)

![Figure B.5: Screen ‘Overview design factors’.](image2)
Figure B.6: Screen ‘Query Design Factors’.

### B.7 Checks

Echo can do some very simple consistency checking on the data entered in the database and can give warnings to the user. The prototype offers the possibility to check if both properties and/or factors of a relation exist and are actual (when a new relation is entered) and if the relation between two obsolete items is also obsolete. If a relation is not consistent, then, a warning message appears on the screen.

### B.8 Advantages and disadvantages of the prototype

The prototype has been developed to explore the benefits of using a software system to facilitate the use of the design method. Using my prototype for describing and analysing design situations has the following advantages compared to using pencil and paper:

- The administration of properties, factors, and relations is more flexible;
- electronic information can be edited more easily;
- relations between properties and factors can be visualised graphically (although not yet graphically in the current prototype);
- searching for information and comparing specific overviews of the information is easy;
- some simple consistency checking are possible;
- the prototype can easily be tailored to the needs of a specific discipline, project, or user because the attributes in the forms and the structure and questions of the checklist can be changed easily in the template.

A disadvantage of the software system is that information that is possibly already stored in other databases must be entered again; this is not time efficient and it does not motivate the users. Other disadvantages are specific for the current version of the prototype and can (easily) be eliminated in next versions, as explained in the next section.
B.9 Possible improvements and extensions

The current implementation of Echo can be improved in a technical way. The prototype can also be extended to support all concepts of the design method. In addition, the prototype can be extended with useful concepts that are not (yet) included in the design method.

Echo can be improved in a technical way as follows. The general user interface can be improved in the sense that the standard machine interaction can be extended with speech technology. A user interface to easily define and edit a template, even during a design session, can be very useful. A user must also be supported to compose a new template from parts of other templates. The tree structure must be extended with more editing facilities and it must be easy to change the position of properties and factors in the tree. The user interface of the tree can be improved by using different colours for actual and obsolete items and by attaching questions to the topics in the checklist (these questions should, for example, also be refined automatically when more detail is needed). The use of the electronic forms can be made more user friendly; for example, for the ‘reference’ attribute in the electronic forms, a viewer can be included to open the documents referred to (images, drawings) in other applications. The user interface of the query output can be improved to stimulate the analysis of overviews, can be improved with a graphical user interface that shows relations between properties and factors, and can be extended with a document-generation and a printing facility.

Echo, currently only including concepts for describing and analysing a design situation, can be extended for supporting all concepts of the design method as follows. The prototype can be extended to support also the description and analysis of design activities and to include the concept of design sessions. The tool can, for example, support the comparison of planned and executed design activities; a user can then check if everything that was planned has been executed. The tool can also support the comparison of specific descriptions and analyses of different design-team members and designers in specific disciplines. Queries can, for example, support qualitative and quantitative analyses. The checking mechanism can be extended to check the consistency of the data by, for example, checking the uniqueness of items (taking into account near doubles). Other syntactic and perhaps also some semantic consistency checks can be added, depending on the need and the required implementation effort. Some simple ‘requirements tracing’ can be added (for example, a check that verifies whether all desired properties are linked to the solution). Perhaps, also some progress checking can be done. The general user interface of the tool must stimulate that reflection is performed seriously and thoroughly.

Echo can be extended with concepts beyond the design method as follows. The current concept of the database can be improved and extended in many possible ways. One possibility is to combine information from different sources (text documents, CAD) and databases (of other tools) in the database of the tool. It is also possible to develop a database (or use an existing one) that is not exclusively used by the tool, but that can be shared by many applications. Another extension of Echo is to allow sharing of (part of) the information in the database by multiple users; for example, all participants of a project can share the information of the design context and of related design tasks. Important questions are then “Which data of a common database may be received, added, and changed by the users of the tool?” and “Who determines what is important for the different users of the common database (the creator of the data or the receiver of the data)?”. To support exchange of information all over the world, collaborative-engineering and groupware systems, which manage distributed and co-operative work, can be linked to the tool. The tool may also include a configuration and version management system; these systems are especially useful when large amounts of data must be stored. (The extra attributes introduced in the prototype are already placeholders for configuration and version management.)

Because the tool will offer only support for reflection and not for specific design activities, it must be used in co-operation with domain-specific tools. Currently used tools can be linked to Echo or Echo can be linked to one or more of the currently used tools (like a module that can be added to or is embedded in a CAD-system). The tool can also be linked with other general tools that support, for example, evaluation techniques, creativity techniques, or selection techniques. The tool can also be
coupled to systems that have been developed for re-use of design information; this is especially useful for projects in almost the same design context. A design-history system stores the steps made in a design process, as well as the decisions and their rationale, and make these available for re-use. A case-based-reasoning system offers information of previous projects (cases) for use during the design process of a new product. More research is necessary to determine what kind of interaction with what kind of system is desired. It is also important to look at the latest techniques and possibilities in the field of software development. The tool must combine the benefits of the design method with the benefits of the medium (software).

For use in practice, the tool must be tailored to a specific design environment. For example, to support communication in multidisciplinary design teams, the tool can be extended with a translation function. Individual designers can perform (part) of a reflection process with the tool, using their own terminology and the general concepts of the tool. The tool can then (1) translate the specific terminology of one designer to the general terminology and (2) translate the general terminology to the specific terminology of other designers, as illustrated in Figure B.7. Comparison of the reflection processes of several designers can then be understand by each designer in his own language. For developing this translation function, specific terminology in several disciplines/domains must be studied.

![Figure B.7: Translation function of a software tool.](image)

### B.10 Conclusions

Echo is one of many possible implementations of a software system facilitating the use of the design method. The contribution of the prototype to this thesis lies in the fact that it is a first step towards concrete support for reflection on design processes in practice. The current prototype is not yet useful in the world of designing, but was useful for exploring the advantages, the disadvantages, and the possibilities of using a software system to facilitate the use of the design method (see Sections B.8 and B.9).
C Empirical Research: Case Studies

C.1 Introduction

This appendix summarises the approach to and results of the empirical study I performed to get input from the design practice at the beginning of my research project. The empirical study, including case studies, has been performed to explore the design practice and to inventory the most important characteristics of design processes in several disciplines. Design projects in the disciplines architecture, software engineering, and mechanical engineering have been studied. The results of the performed cross-case analysis have been a basis for the development of the design philosophy, described in Chapter 3, and the design frame, described in Chapter 4. First, the approach to the case studies is summarised, then, the approach to the cross-case analysis is described, and, finally, some results of the case studies are summarised. A more extensive description of this empirical study and its results can be found in [Reymen, 2001a]. The case studies are positioned in the overview of my research process in Section 2.8.1. Conclusions concerning the case studies are drawn in Section 6.2.

C.2 Approach to the case studies

The choice for a case-study approach is motivated in the next subsection. The case-study protocol I followed to perform the case studies is described in Section C.2.2. Section C.2.3 motivates the selection of the cases.

C.2.1 Motivation of the case-study approach

To find general characteristics of design processes in several design disciplines in practice, at the beginning of my project, qualitative empirical research seemed most appropriate and was chosen as a general form of research. Case-study research is a specific form of qualitative empirical research. To explain my choice, I recall two definitions from the literature. The first one is found in [Yin, 1994]. “A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident.” The second one is a translation of the definition given by [Wester, 1991]. “A case-study approach is an inquiry of one or more cases going into depth by putting central the complex relations in which the case functions.” Design processes are contemporary phenomena with complex relations between different aspects and many interactions with their context. Hence, case studies are well suited for investigating design processes in practice. The case-study approach, its characteristics, and its types are further described in [Yin, 1994], [Wester, 1991], and [Verschueren et al., 1995].

As sources of case-study information, I have chosen for interviews with designers and for analyses of design-project documentation that was made by each of these designers. With interviews performed at the end of a design project, I could get insight into a complete design process and its context: I could get an integral picture of the design project. The second source of information, namely the project documentation, was used to corroborate the information of the interviews.

I preferred the case-study approach over the widely used method of protocol studies in design research. Protocol studies are performed in laboratory conditions, cover often only part of a design project, and offer thus only information about the design activities performed in the experiment. I was interested in a complete design project and not in detailed information about design activities during short periods in time. In my interviews, I could ask designers to look back on the complete design process and on the design context. An advantage of case studies was also that less pre-structuring was
necessary than for performing an experiment using the method of protocol studies; at the beginning of
my research project, I had not yet that many ideas about important (domain-independent)
characteristics of design processes. For a description of protocol studies, see the special issue of
Design Studies [Dorst, 1995].

C.2.2 Case-study protocol

The course of one case study is described in my case-study protocol. This is a document that contains
all the procedures and general rules that are followed to execute one case. It can be seen as a script or
scenario to be followed. This instrument increased reliability and continuity between cases, and guided
me in carrying out the case studies. The importance and design of a protocol is described in [Yin,
1994]. My case-study protocol includes a description of the following main activities: preparing and
executing a first interview, processing data of the first interview (transcription), analysing the
documentation received from the designer, making a summary, preparing and executing a second
interview, processing data of the second interview and correction of the summary, and making a
summary report of the case. The protocol is first performed for junior and then for expert designers.
After the cases with junior designers, a summary of characteristics of design processes in each
discipline was made based on a brief cross-case analysis of the junior cases and on the literature I
studied. Then, the choice for the expert designers was made and these cases were performed. Finally, a
real cross-case analysis was executed (see Section C.3).

In the interviews of one hour and a half, open questions about the complete design project were asked.
The interviews were tape-recorded and, for each case, written notes were made in Dutch. The first
interview was prepared by the designer and by myself. I sent to the designer documents including a
personal introduction, a description of the research project, a description of the course of the case
study, and a description of how to prepare the interview. The designers provided some facts about
themselves by completing a special form and they gathered documentation of their chosen project. I
developed a question list to inventory the important aspects of design processes. This list was based on
a preliminary version of the design frame (see Section 2.8). Because I unavoidably made my own
interpretation of the answers to the questions of the interview and the contents of the documents, I
asked the designers to check my description of their answers and to correct my view. This was done in
a second interview or by mail (based on an extended summary of the first interview I sent them).

The raw data (the notes of the first and second interviews and the analysis of the documents) were
structured using a transcription scheme (a classification system). The use of this transcription scheme,
based on a preliminary version of my design frame (see Section 2.8), was necessary for comparing the
different cases in a cross-case analysis. The transcription scheme included the fields of attention of the
first interview. Fields of attention in the first interview with the junior designers were the product
being designed, the design process, bottlenecks in the design process, and things learned from the
project. A new question list was made for the expert designers. Fields of attention in the first interview
with the expert designers were the product being designed, the design process, management of the
design process, and things learned from the project. The expert designers were also asked to give
feedback on the summary I made about characteristics of design processes in their design disciplines
and to give their opinion on similarities between designing in their disciplines and other disciplines.
The summary report of each case included a summary of the interviews (in Dutch), a summary of the
documentation, the question lists, the transcription, and the transcription scheme.

Two pilot case studies were executed to test a preliminary version of the case-study protocol
(including the question lists for the interviews) and to make a time planning for the next cases. One
designer from the Faculty of Mathematics and Computing Science and one from the Faculty of
Mechanical Engineering of the TU/e, performing a Ph.D. on design, were interviewed, following the
preliminary protocol. Afterwards, the interviews were evaluated on contents and procedure and the
question list and protocol were improved. After that, 12 more designers were interviewed.
C.2.3 Selection of the cases

The selection of the cases for my research was inspired by replication logic [Yin, 1994]. This means that every case served a specific purpose within the overall scope of inquiry; this is called the logic of theoretical sampling. Theoretical sampling is opposed to statistical random sampling. Statistical random sampling follows sampling logic [Yin, 1994]; the cases are sample units. For statistical random sampling, a higher number of cases is necessary than for theoretical sampling. Within replication logic, two types of replications are distinguished. For literal replication, cases deviate minimally and are expected to predict similar results; for theoretical replication, cases deviate maximally and are expected to produce contrasting results, but for predictable reasons. In my research, I chose for literal replication within one discipline, whereas I chose for theoretical replication between disciplines. Table C.1 illustrates the selection of the cases.

<table>
<thead>
<tr>
<th>THEORETICAL SAMPLING</th>
<th>STATISTICAL RANDOM SAMPLING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Every case serves a specific purpose</td>
<td>Cases are sample units</td>
</tr>
<tr>
<td>Few cases</td>
<td>Many cases</td>
</tr>
<tr>
<td>Replication logic</td>
<td>Sampling logic</td>
</tr>
<tr>
<td>Literal replication</td>
<td>Theoretical replication</td>
</tr>
<tr>
<td>Within a discipline</td>
<td>Between disciplines</td>
</tr>
<tr>
<td>Minimal deviation</td>
<td>Maximal deviation</td>
</tr>
<tr>
<td>Predict similar results</td>
<td>Produce contrasting results</td>
</tr>
</tbody>
</table>

Table C.1: Selection of cases following replication logic.

I was interested in common characteristics of design processes in several design disciplines. I chose to analyse the design process of individual junior and expert designers at the end of their design project in three disciplines. The choice for individual designers was made to limit the scope of the research. Furthermore, I assumed that, at the end of a design project, designers have a good overview of the design project (but may also have already forgotten certain aspects). The combination of junior and expert designers was chosen to get a good overview of important aspects of design processes: I assumed that for expert designers, many aspects of a design process are already part of their implicit knowledge. Junior designers just learned how it is to design during a real design process. Thus, I expected that junior designers experienced certain aspects explicitly, whereas those aspects would already be implicit for expert designers and vice versa. Summarising, the cases were chosen to differ from each other with respect to the experience of the designer and the product being designed. Together, the junior and expert cases covered a wide range of design projects.

Twelve case studies were performed, four in every discipline: two junior and two expert designers. A first source of cases was found in the design projects carried out at TU/e. The interviewees were junior designers who had just finished their first large design project. This could be the final project to get their Master’s degree, the final project of one of the design programmes of the SAI, or a Ph.D. design project. Professionals in industry (in the Eindhoven Region) formed a second source of cases. The professionals were chosen for their expertise in their design discipline and their amount of design experience (between 10 and 20 years). Their design projects were more complex than those of the junior designers’ and these projects were executed by more than one person. Since most of the expert designers fulfilled the role of design-team leader, they had a good overview of all the important aspects of the project. The junior designers were Chris Arts, Janneke Bierman, Paul de Crom, Douwe de Vries, Edwin Hautus, Marcel Renkens; the expert designers were Jan Brouwer and Migiel van der Palen of XX Architecten, Astrid Dobbelaar of Philips Design, Henk Döll of Mecanoo, M. Koster of Philips CFT, Jan Kuithof of Daf, Piet Sanders of TU/e, Wim van der Sanden of Panfox, and Karel Verhulst of Philips Medical Systems.

C.3 Approach to the cross-case analysis

The case studies, summarised in a single report per case, offered me empirical material for a cross-case analysis. The cases were compared for similarities and differences within one discipline and in
different disciplines. A description of design processes in each discipline was made based on the mutual comparison of the cases per discipline. These descriptions were compared to make a general description of design processes, including domain-independent characteristics of design processes transcending disciplines. In this general description, I introduced synonyms for the different terminology used in the three disciplines. (Some terms are shared between disciplines, but these terms often have a different content or meaning in the different disciplines.) At the end of my research project, I described the results of the cross-case analysis in the current terminology of the design philosophy. (The design philosophy is based on the case studies, but evolved later on, influenced by literature and feedback from expert designers). The final result can be found in [Reymen, 2001a].

C.4 Some results of the case studies

The results of the case studies and the cross-case analysis are reports for each case, a description of design processes in each discipline, and a description of general characteristics of design processes, which formed the basis for the current design philosophy and design frame. As already mentioned, all the results are summarised in [Reymen, 2001a]. In this section, in Tables C.2 and C.3, the main characteristics of the analysed design processes of one expert designer and one junior designer are described. These two cases are chosen to illustrate the source of inspiration I used to develop the descriptive results presented in this thesis. The first case is an example of the design of utility buildings in architecture; the second case is taken from mechanical engineering. Only topics important in the light of the results described in this thesis are given.

General conclusions that resulted from the cross-case analysis and that influenced my results very much are the following three. First of all, I noticed that the combination of the product being designed, the design process, and the design context was important in all cases. Second, I learned that designers change both properties of the product being designed and of the design process. Third, I observed that design phases are the major structuring principle of design processes in practice; design phases take long periods in time (usually several months). Design methods guiding designers during a design process are all based on these phases. These phases are also often part of norms and standards (ISO norms, building norms, software standards, etc.); the standards also often justify their use. Shorter periods in time are not used for structuring a design process, although there appeared to be a need for such a short-term structuring mechanism. This last observation inspired me to introduce the idea of design sessions (see Section 5.5).

<table>
<thead>
<tr>
<th>Important properties of the product being designed:</th>
<th>The problem of waste transhipment, the logistics, the location (near water and housing), the planning of the execution in phases, the town planning, the soil, the building (protection against noise and smell, quality of the façade, large span, human scale), the re-use of materials, the energy usage, the durability, the climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Important properties of the design process:</td>
<td>The use of phases as milestones; the interaction with different stakeholders at the beginning of the design process</td>
</tr>
</tbody>
</table>
| Important factors in the design context: | Important stakeholders:  
- Architects office  
- Project-management office  
- Commissioner  
- Government (determines rules, gives permissions)  
- Contractor (must build the design) |
| Important design activities: | Drawing, estimating building cost, making details, making models, discussing, determining strategy |

Table C.2: Main characteristics of the design process of an expert designer.
| Important properties of the product being designed: | Important viewpoints: thermodynamic, optical, mechanical, architectural, production-technical, and economical. |
| Important properties of the design process: | Requirements and a planning formed the basis for a structured way of working. Time constraints and quality requirements drove the process. |
| Important factors in the design context: | Stakeholders that were directly involved: |
| | − a company of solar cells |
| | − a company of sun collectors |
| | − the Energy Centre of The Netherlands |
| | − TNO |
| | − TU/e: Department of Mechanical Engineering and the program Computational Mechanics (SAI program) |
| Other stakeholders: Architects | The stakeholders were important because: |
| | − the companies offered possibilities for realising a prototype |
| | − the Department of Mechanical Engineering influenced the viewpoints mentioned above |
| | − the SAI program demanded extensive computations to be performed (these were, however, not necessary for the project) |
| | − a technically good solution was rejected because of a low architectural (esthetic) quality |
| Important design activities: | Main activities: thinking of concepts (qualifying), modelling (quantifying), and documenting decisions. It was an iterative design process: For each concept, a model was made, experiments were performed, and the model was evaluated. Important were also the discussions with other junior designers, the contacts with the companies, and the discussions after presentations of the (preliminary) results. |

Table C.3: Main characteristics of the design process of a junior designer.
D Empirical Research: Feedback

D.1 Introduction

In this appendix, the approach to and the results of the empirical study I performed to get input from the design practice at the end of my research project are summarised. The study was performed to get an impression of the generality of my results and to get feedback on the relevance and usefulness of my results for design practice. It was only a first confrontation of my results with design practice. The study is positioned in the overview of my research process in Section 2.8.1. Conclusions drawn from the feedback and conclusions about the form of the study are given in Sections 6.1 and 6.2. A more extensive description of this empirical study and its results can be found in [Reymen, 2001b].

D.2 Approach

As for the case studies I performed at the beginning of my project (see Appendix A), a distinction was made between junior and expert designers. The expert designers were almost the same designers I interviewed for the case studies. Some of the junior designers were the same as well; others were chosen based on the same criteria as for the case studies. All designers had a background in one of the three design disciplines I studied in this research project. The junior designers were Wilbert Alberts, Sander de Jonge, Raymond Habets, Albert Hofkamp, Marcel Renkens, and Nicole Segers; the expert designers were Jan Brouwer of XX Architecten, Henk Döll of Mecanoo, M. Koster of Philips CFT, Jan Kruthof of Daf, Tinneke Reijbroek of Paper Design, Bart van den Hoge of Paper Design, and Wim van der Sanden of Panfox.

First, Section D.2.1 describes the approach I followed to get feedback from the expert designers. Then, in Section D.2.2, the approach to get feedback from the junior designers is summarised. Finally, in Section D.2.3, the procedure to analyse and synthesise the feedback is given.

D.2.1 Experts

Six expert designers gave feedback on the preliminary versions of the design philosophy, design frame, and design method and the current version of the prototype software tool. I sent the designers a short letter with an explanation of the goal of the feedback, a summary of the last interview we had, and an abstract of my Ph.D. thesis. In a discussion of one hour, I explained each result briefly, using some figures, and received feedback on the results, which I wrote down. Despite the fact that I had an idea of what comments to expect, I asked open questions. Afterwards, I translated the feedback to English and transcribed it following a transcription scheme; this scheme was structured following my four main results (a design philosophy, a design frame, a design method, and a prototype software tool) and included a section for some comments.

D.2.2 Juniors

Six junior designers were invited for a whole day to give feedback on the use of a preliminary version of the design method and the prototype software tool. In a document sent to the designers in advance, I asked them to choose one of their design tasks to work on during that day (while using the design method and tool). I also sent them an abstract of my Ph.D. thesis, a planning of the ‘design day’, and a list of participants. I did not give information about the design method and tool beforehand so that they could start open-minded.
The day started with a general introduction: Before lunch, during a first session, the design method would be used and feedback on the design method would be given; after lunch, the prototype of the software tool would be tested. I started the first session with a general presentation about the design method and used the example of the garden house (see Appendix C). After the introduction, the designers were asked to write down their expectations of the design method. (The goal was to capture the designers’ experiences with the design method; these were related to their expectations.) The designers received blank forms, various checklists (including an explanation), and an example of the use of the design method. The designers worked on their design task and used the design method. In the mean time, I observed the designers and helped them to use the method. At the end of the session, each designer was asked to write down, on an evaluation sheet, positive and negative experiences on the following topics: general impression, time spent on reflection in relation to the duration of the design session, support offered by the forms and checklists, relevance of the design method, usefulness of the design method, and suggestions for improvement. Afterwards, all designers came to the blackboard to cluster their feedback (written on yellow memos) with respect to the six topics. In front of the black board, we had a group discussion on each of the topics; I wrote down the results of the discussion.

After lunch, I presented the ideas of the prototype of the software tool and gave a demonstration of its use. The course of the second session was similar to the course of the first session. Again, the designers had to write down their expectations. They received a manual of the prototype including a general explanation of the screens and buttons and some screen dumps. During the session, the designers worked on their design tasks and used the prototype. (I arranged a laptop for each user.) Afterwards, they filled out the evaluation sheet and we had again a discussion on topics similar to those for the design method (general impression, time spent using the tool in relation to the duration of the design session, support offered for reflection, relevance of computer support for reflection, usefulness of the tool, suggestions for improvement). During the discussion, I tried to have a real discussion on the concepts of the tool; I was not that much interested in topics about the user interface. The next days, I made a summary document of all individual feedback and of the discussions (in Dutch).

D.2.3 Analysis and synthesis of the feedback

First, all feedback was translated to English. Then, the feedback of the expert designers was synthesised in several iterations. The individual feedback of the junior designers was first integrated, then, added to the group discussion (structured according to the six topics), and finally, synthesised. Suggestions for improvement of the design philosophy, the design frame, and the design method were taken into account in the further development of these results. The development of the prototype had stopped before the feedback on the prototype was given, but the feedback was taken into account for describing possible improvements and extensions of the prototype (see Appendix B).

D.3 Results

For the design philosophy and the design frame, only feedback from expert designers was received. For the design method and the prototype software tool, feedback from expert and junior designers was received. The following subsections describe the feedback I received on each result.

D.3.1 Feedback on the design philosophy

In general, all experts recognised the concepts of the design philosophy and understood its terminology; the concepts and terminology seem to be domain independent. To improve my description of design processes, they suggested adding the concepts of risks (uncertainties) and of iterations. The concept of risks can be found in Section 3.3.2; the concept of iterations is discussed in Section 3.5.1. The experts stressed that changing desired properties during a design process is common practice. The architects also stressed the importance of the design context and the interaction
of designers with the design context during a design process. The importance of changes and interactions is written down by Henk Döll [LeCuyer (ed.), 1999] as follows: “The problem is constantly revised, reshaped, and reframed through interaction with this complex entity called the client.”

**D.3.2 Feedback on the design frame**

The relevance of the three dimensions of the design frame was judged as follows: Koster sees the dimensions as abstractions that can be used in a general language; such a language is necessary to understand designers from different disciplines. Abstractions, together with representations, are very important and their importance will increase in design practice when everything must be communicated faster and more efficiently. Brouwer says that, not only designers, but also the commissioners have to see the importance of dimensions. Already at the beginning of a design project, it is important to consider different levels, different aspects, and different processes in the product lifecycle. Commissioners must give designers time to do so.

The experts also asked questions to get a better understanding of the concepts of the design frame. These questions inspired me to improve the description of the design frame.

Specific comments I received on each of the dimensions are the following:

- Brouwer mentions that levels are very important: Architects have to look at both the overall structure and the details. Döll also says that levels are substantial in architecture. Architects must be trained to think on different levels of abstraction; for example, when an architect works on a high level of abstraction (part of a city), it is also important to consider in detail the functions or the compactness of the buildings.
- For Koster, the most important perspective is that of the customer; other viewpoints must be derived from the former. Brouwer supports the importance of the perspective dimension, calling it ‘the study of aspects’. A designer should not concentrate on one aspect in isolation; in a design, always multiple aspects are important.
- Koster mentions that paying attention to other processes than the design process is very important.

**D.3.3 Feedback on the design method: expert designers**

Table D.1 shows different kinds of reflection and critical analyses already performed in the current design practice of the experts. A distinction is made with respect to different moments in time when the reflection is executed, with respect to reflection by an individual (I) and a group (G), with respect to formalised (F) and non-formalised (NF) reflection, and with respect to the fact that results of the reflection are used for documentation (D) or not (ND). For the expert designers, the term ‘session’ refers to meetings (group sessions); I could distinguish the following kinds of sessions (meetings) in the design practice of the experts:

- progress (time and money) and contents (plan, techniques) meetings (in complex projects),
- regular and incidental meetings,
- internal (in company) and external (with customers, other stakeholders) meetings.

Before using the design method in practice, it must thus first be analysed how to combine my ideas of reflection and design sessions with the current kind of reflection and sessions used in practice.

Brouwer mentions that the need for reflection on design processes is high: Certain aspects (mainly the production methods and the market) are usually only too late in a design process taken into account. This results in many problems during the implementation process: 30 to 40% of the design has to be redone. The latter consumes a lot of time and money and results in a lot of misery.
Suggestions for the possible application of the design method in design practice are the following:

- Learning sessions must not be executed too often. Non-trivial analyses consume very much time; when these analyses are executed too often, it becomes a ritual, people avoid the problems, and do not learn anything. (Van der Sanden)
- Van der Sanden sees possibilities for a briefing and de-briefing about the design situation every week. He thinks that awareness of the product being designed, the design process, and the design context becomes routine when reflection on the design situation is performed too often.
- Koster calls reflection a retrospective moment. For him, retrospective moments can best be based on the planning of a project. During certain phases, reflection is not meaningful, because only less important decisions are taken.
- Both architects (Brouwer and Döll) suggest incorporating the design method in the qualitative procedures of an architect’s office; only then, architects are forced to work methodically (make documentation and check things). In a quality handbook made by Mecanoo, it is already described what must be done in each design phase. The handbook consists of checklists that describe all documents that are needed, the parties with which a discussion is necessary, and which calculations must be made. The role of the project leader is to check these lists. To make such a quality handbook, it is necessary to keep in mind that work should be structured but not too structured. The quality handbook must be used in a flexible way: Certain aspects are not always important in a specific phase in a specific project. The starting point is that you work in a professional organisation with high-qualified persons; these persons must be able to follow certain procedures without being controlled too strongly.

Because in my design method the length of a design session is flexible and checklists and forms can be made, among others, company specific, the design method can be applied as suggested by the expert designers.

<table>
<thead>
<tr>
<th>REFLECTION</th>
<th>MOMENT IN TIME</th>
<th>I/G</th>
<th>F/NF</th>
<th>D/ND</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awareness of the mental state of the designer</td>
<td>Each hour</td>
<td>I</td>
<td>NF</td>
<td>ND</td>
</tr>
<tr>
<td>Thinking about the achievements and progress of the day (Note that people who do not do so, will likely not be triggered by a method to do so (Kruithof).)</td>
<td>Every evening</td>
<td>I</td>
<td>NF</td>
<td>ND</td>
</tr>
<tr>
<td>Thinking about what needs to be done the next day; make a to-do list (Van der Sanden, Döll)</td>
<td>Every evening</td>
<td>I</td>
<td>NF</td>
<td>ND</td>
</tr>
<tr>
<td>Status reports from employees working externally, required by a project leader</td>
<td>Every week</td>
<td>I</td>
<td>F</td>
<td>D</td>
</tr>
<tr>
<td>Evaluation of the satisfaction of a client, by employees working for that client</td>
<td>Regularly</td>
<td>I</td>
<td>F</td>
<td>D</td>
</tr>
<tr>
<td>Informal questions asked to employees working externally (Learned something interesting?)</td>
<td>Regularly</td>
<td>I</td>
<td>NF</td>
<td>ND</td>
</tr>
<tr>
<td>Reports for clients</td>
<td>Regularly</td>
<td>I</td>
<td>F</td>
<td>D</td>
</tr>
<tr>
<td>Status reports of regular meetings</td>
<td>Every two months</td>
<td>G</td>
<td>F</td>
<td>D</td>
</tr>
<tr>
<td>Reports (drawings, calculations, decisions)</td>
<td>At a milestone</td>
<td>G</td>
<td>F</td>
<td>D</td>
</tr>
<tr>
<td>Scenario-telling: telling stories about the consequences of certain decisions for the future.</td>
<td>Every three months</td>
<td>G</td>
<td>NF</td>
<td>ND</td>
</tr>
<tr>
<td>Evaluation</td>
<td>At the end of a project</td>
<td>G</td>
<td>F</td>
<td>D</td>
</tr>
</tbody>
</table>

Table D.1: Different kinds of reflection in (part of) current design practice.

D.3.4 Feedback on the design method: junior designers

The general goal of the design method was clear to the junior designers. The example of the garden house was useful to offer more insight into this goal; however, an explanation based on a real case from design practice would have been more valuable. The junior designers judged the concepts of the design method as useful. The form and elaboration of the design method (at that moment), however, were seen as not yet good enough to be useful in design practice. It would also be difficult to sell the design method to management because no visible or measurable effect on throughput time could be
shown; the designers would only use the design method when they could see the advantages. I believe that the form and elaboration of the current design method may be useful in practice. Despite the fact that I cannot yet show positive effect on throughput time or on the quality of the design, I believe that the method can increase the efficiency and effectiveness of the design process. I also believe that after using the design method during some design sessions, the designers (and their management) can see the benefits of structured reflection for improving design processes.

A negative aspect of the design method mentioned very often by the designers was that the design method was presented in a very general way and that it was not focussed to a specific discipline. Making the translation of the general terminology of the design method at that moment to the designer’s discipline-specific terminology was experienced as difficult. No domain-specific questions were included in the checklists. The design method also forced designers to write down very specific information and left them little freedom. A different structure for specific phases would be advantageous. The design method also required too much administration from the designers. The junior designers suggested that reflection might not necessary require the documentation of a lot of information; documenting has several negative aspects: The information written down is not necessarily only used by the designer whereas reflection is personal; there can be a problem of consistency and completeness; and it can be difficult to find back information. In the current version of the design method, the terminology of the design frame (which is too abstract for designers) is replaced by attributes (see Section 5.3.1). The design method now suggests making (domain) specific forms and checklists for a specific application of the design method; the forms and checklists can be tailored to a specific user, company, or discipline, but also to specific phases in the design process. Defining sessions taking a long period of time can solve the problem of too much administration. Further research is necessary to find out what amount of information is necessary for reflection.

The designers mentioned that the amount of time spent on reflection during a design session depends on the product being designed, requirements from the market, and the throughput time. An optimal proportion between reflection and design felt to be about 10% for reflection and 90% for design. The design method can be used faster when the terminology is known better; some learning time is needed to get experienced with the design method and to use it efficiently. It was also said that reflection once during a design session (instead of at the beginning and end of a session) is enough; otherwise, it consumes too much time. Others said that once a day is enough. Because the length of design sessions is flexible, designers can plan their moments for reflection according to their preferences.

Almost all participants mentioned the same advantage of my design method, namely that it offers help to get an overview (of the design situation and of the design activities). Other characteristics of the design method mentioned by the designers are the following: The design method

- can help to increase awareness about the design situation, the steps taken, and the working method;
- asks relevant questions to think about;
- can help to identify problems that might otherwise have been forgotten;
- supports learning from shortcomings;
- can help to work more in a focussed way;
- can help to bring order in a chaotic design process;
- offers opportunities to define and improve the design process;
- is directed towards a continuous improvement of the design quality and a comparison with other stadia of the process; the comparison of the present state with the past and the future is important;
- can help to make good documentation of the project state;
- offers help to describe the design process; the availability of this information later on in the design process is useful;
- can give more confidence in the completeness of the information.

Determining the possible value sets for the three dimensions once at the beginning of a project (with the current FORM Design Frame) was regarded as very useful. Also determining terminology and definitions can be very useful; it must then also be possible to structure these definitions in different
ways during the course of a design process. Documenting at the end of a session what has been done and which problem has been solved was also seen as very useful.

The designers suggested the following improvements:
- give an explanation based on an example in a specific discipline;
- make translations of the terminology to specific disciplines (domain-specific forms and checklists);
- make the checklists and forms adaptable in time and adaptable to a specific designer;
- make the design method more compact (decrease the number of forms in order to decrease administration);
- test the method in a design process taking more than one month.

As mentioned before, the design method now suggests making (domain) specific forms and checklists for a specific application of the design method. Further research is still necessary to make the design method more compact and to test the design method for a longer period of time.

### D.3.5 Feedback on the prototype software tool: expert designers

Suggestions from the expert designers to extend the prototype for use in practice are the following:
- The tool can be extended for supporting learning. Van der Sanden mentions that learning from earlier experiences is not yet supported in practice: Existing support concentrates on development (how to design), modelling (how to represent reality), and management (how to control a process). Brouwer says that the biggest problem of a tool supporting learning and reflection is how to enforce people to think about certain aspects and not only mention the aspects.
- The tool can be extended for process support. Döll qualifies process support as highly useful. For architecture, a link can be made with a quality handbook. The idea of a checklist can be elaborated; with software, a checklist can easily be made specific for a project (copy and paste of a general checklist). The checklist can show what must be done.
- The tool can be extended for concurrent engineering. Koster sees possibilities for all parties to retrieve information on the project from the database of the tool. He adds that the tool must be tested in complex projects involving multiple disciplines.
- The tool can be extended for documentation and control. Van der Sanden mentions possible things to document: important decisions, ideas, user opinions, planned actions, risks (can be part of a checklist), and links to data of the product being designed. Possible things to control with the tool are checking the factors influencing a goal and checking if no things that are asked are forgotten. He suggests starting with unstructured data in the tool; when the amount of data increases, some kind of structure can be added. He also mentions that a user must make himself familiar with the tool by means of training; once familiar, the user can give input very fast and the ideas of the user can be checked very fast. A user also needs a training to choose good terminology. Döll, however, mentions that during a design process, millions of things are important. Decisions cannot all be described and underpinned; many decisions are taken implicitly, only a few are taken explicitly. For Döll, an important requirement for the use of the tool is that information can be entered very fast. Kruithof says that designers will not be motivated to use this kind of tool in practice when it is enforced. Technicians like to make their own tool and they already think in an abstract way. The most important links between facts are already in their heads. In his perception, just entering data in a tool offers a designer not much added value; there is also a natural resistance against entering a lot of data. Only when a designer has experienced certain problems, such a tool will be appreciated; a designers sees the necessity to document relations when he realises in a practical situation that he forgot important relations.

The designers made these suggestions based on the current prototype, which only supports the description and analysis of design situations and which is not yet a tool supporting a reflection process. My suggestion is to extend and improve the prototype for reflection (and learning), as described in Section B.9. Some kind of process support can be made part of the support for reflection.
The suggestions about concurrent engineering and documentation and control seem useful to me and can also be taken into account when developing a new version of the prototype.

D.3.6 Feedback on the prototype software tool: junior designers

Implementation-oriented suggestions to improve the prototype, given by the junior designers, are described in [Reymen et al., 2001]. The junior designers judged the prototype as having potential value; however, the tool does not yet have a useful form. They mention that for the further development of the tool, the following important questions must be answered:

- How can the goal of the tool, namely support reflection on a design process, be reached without developing a management tool (a management tool aims to control and monitor the design process)?
- Will the tool become a group (reviews) or individual (reflection on own design process) tool? Will it be possible to see reflections of other designers? The answers are important because documentation made by a designer for himself and documentation made for others are fundamentally different (there is less argumentation and more detail in personal documentation).
- Is it necessary to couple administration of the design process and reflection?
- Is automating the design method a step forward? Computer support is not necessary for reflection.

Answers to these questions are (partly) given in Section B.9, which discusses possible improvements and extensions of the prototype.

About several aspects of the current prototype, there was no consensus between the designers. Some designers mention that the tool makes it possible to get an overview, others describe that the dimensions of a computer screen are too small to make it possible to get a good overview. It was also said that, on the one hand, a good insight into the relations could be obtained with the prototype, whereas on the other hand, designers mention that the prototype does not contain a specific structure for relations and does not give a good overview of relations. The proportion between the time spent using the tool in relation to the time spent designing was judged both as reasonable and as too much.

The designers did agree on the following advantages and disadvantages. Advantages of the design tool are that the prototype helps not to overlook important things and it simplifies administration; furthermore, the tree structure is useful and also the predefined values are useful. Disadvantages mentioned by the designers are that the design tool asks too much work, the user interface is not clear, and the prototype is textual, whereas a designer prefers to work graphically.

Compared to the design method, the prototype is more flexible. For some designers, the lack of overview makes the prototype less useful than the paper version (the design method). Compared to handwriting, the information is better readable on a computer, but there are limitations to the number of characters. Data can be edited more easily, but some designers judged navigating through the data as more difficult.

The designers suggested the following extensions and improvements:

- an easy-to-use user interface (including more graphical visualisation (of relations) and functionality for reflection);
- a possibility to change the template during a design process;
- import/export facilities for text documents, drawings, and animations;
- import/export facilities for existing tools;
- when using the prototype in current design practice, product and process data will be stored at least twice: in a domain-specific tool (compiler, CAD tool, etc.) and/or a project-management system and in the database of the prototype: It is desirable to separate the database from the prototype, thus allowing a common database for different tools.
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Glossary

Action/Activity/Mutation/Transformation/Transition

A state transition is a change from one state to another.  

A state transition is caused by one or more actions. An action is executed by an actor.

State $t(i)$: values ‘white’ and ‘on the ground’
Action: shooting
Actor: football player
State $t(i+1)$: values ‘white’ and ‘in the air’

A goal-oriented action is called a transformation. An action without a goal is called a mutation.

Transformation: shooting
Mutation: a change in the position of the ball, caused by the wind

A design activity is a transformation towards the design goal at that moment, carried out by a designer, causing a transition of the state of the product being designed or of the design process.

Changed product being designed: value for the property ‘kind of coating’ is ‘X’
Changed design process: new team member is recruited

Actor

An action is executed by an actor.

The actors in a design process are called designers.

Stakeholders are actors in the design context.

Attribute/Value

A property or factor can have several attributes that describe it more precisely. Values can be ascribed to these attributes.

For example, to describe the colour-property of a football more precisely, a ‘reference’ attribute can be useful. A value for this attribute is, for example, ‘RAL number’.

Values are articulations on the ordinates of a positioning space.

These values are possible levels of abstraction, perspectives, and processes in the product lifecycle. A dimension has a corresponding value set.

For example, for a product, values for the dimension level can be ‘level of components’ and ‘level of detail’.

Context

A design context is described by the set of factors influencing the properties of the product being designed and the design process at a certain moment.

The design context is treated as an entity, although, it is not one object or process.

Factors describing the design context are, for example, ‘dimensions of production machines’ and ‘environmental laws’

Description

A description of the state of an entity is a description of a relevant subset of the state, using the general terminology of state-transition systems.

A description is a specific representation.

The set of properties of a football is its ‘colour’ and its ‘position’;
the set of values for these properties is ‘white’ and ‘on the ground’.
A description of the state of a product being designed is a specific representation of a relevant subset of the set of values of all properties describing the product being designed. The description is made using the terminology of state-transition systems applied to the context of designing.

Values for the properties ‘dimensions’ and ‘kind of coating’ are ‘h 2.5m, w 1.8m, l 1.8m’ and ‘coating with ingredients ‘X’”.

A description of the state of a design process is a specific representation of a relevant subset of the set of values of all properties describing the design process. The description is made using the terminology of state-transition systems applied to the context of designing.

Values for the properties ‘duration’ and ‘budget’ are ‘halfway estimated duration’, and ‘$15000 spent already’.

A description of the state of the design context is a specific representation of a relevant subset of the set of values of all factors influencing the properties of the product being designed and the design process. The description is made using the terminology of state-transition systems applied to the context of designing.

The value for the factor ‘dimensions of production machines’ is ‘the maximal dimensions of one plank’.

A description of a design situation is a specific representation of a relevant subset of the set of values of all properties describing the product being designed and the design process, and of the set of values of all factors influencing the product being designed and its design process. The description is made using the terminology of state-transition systems applied to the context of designing.

See states of product being designed, design process, and design context.

Design/Designing

A design is a representation of the product being designed.

Designing is the activity of transforming the state of the product being designed or of the design process into another state towards the design goal. This activity is executed by producing a representation of the product being designed or of the design process, or by changing the design process itself.

Producing a representation means creating a new representation or modifying an existing representation.

Design research

Design research refers to that body of work which attempts to improve our understanding of design through ‘scientific’ (i.e., systematic, reliable) methods of investigation. (based on the definition of science of design in [Cross, 1993])

Design session

A design session is a period of time during which one or more designers are working on a subtask of a certain design task.

A design session is limited in time.

Design situation

A design situation at a certain moment is defined as the combination of the state of the product being designed, the state of the design process, and the state of the design context at that moment.

It is the set of values of all properties describing the product being designed and the design process, and the set of values of all factors influencing the product being designed and its design process.

See states of product being designed, design process, and design context.

Design task

A design task at a certain moment is a task to meet the design goal at that moment, starting from the current design situation. A design task is executed by design activities.

For example, a task to design foundations of a garden house or a task to design the materials of the skin of a garden house.
Dimension
A **dimension** is one ordinate of a set of ordinates of a three-dimensional space in which properties, factors, design tasks, and representations can be positioned.  
The dimensions characterise the space.  
The dimensions that are defined are level, perspective, and time.

Domain independent
**My domain-independent approach** is an approach based on the study of and intended to be useful for several design disciplines.

**Domain-independent design knowledge** is, in contrast to domain-specific knowledge, not specific for a certain domain (or design discipline). Domain-independent design knowledge abstracts from domain-specific aspects and contains only aspects that are also valuable for other domains (or disciplines).

Entity
An **entity** is an object or a process.
An entity exists in reality.

- **Object:** football
- **Process:** cooking process

Factor: see Property

Goal
A **goal** is the end state towards which an effort or ambition is directed.
For example, making dinner

A **design goal** is the goal of a design activity or a design process.
The **goal of a design activity** is to create a desired representation of the product being designed having a desired state.

The representation must thus fulfil the desired properties for a representation and the product being designed must fulfil the desired properties for the product being designed.

- **Design goal:** determine the kind of coating of the garden house
- **Desired representation:** textual description
- **Desired state:** value for property ‘kind of coating’ is defined

The **goal of a design process** is to create one or more desired representations of the product being designed having a desired state.

The representation must thus fulfil the desired properties for a representation and the product being designed must fulfil the desired properties for the product being designed.

- **Design goal:** creating a garden house with a coating that guarantees a long life of the garden house, but that is not too expensive.
- **Desired representations:** 3D model, textual description
- **Desired state:** ‘ready for production’

Mutation: see Action

Process
A **process** is a sequence of state transitions.

A **design process** is a process. It is a finite sequence of design activities, necessary to obtain the design goal.

A design process includes the design activities, but also the people performing these activities and the means for performing these activities. One or more designers can execute the design activities, in sequence or in parallel, using one or more design aids.
For example, the design process of new type of garden house.
A (transformation) process is a sequence of transformations of an entity with the same goal. One or more actors can execute the transformations in sequence or in parallel, using one or more aids.

Process: for example, a cooking process: weighing ingredients, preparing food, boiling or baking, and presenting with the goal of making dinner.
Actor: cook
Aids: ingredients, tools

Product

A product is an entity. It is an artefact (that must be designed) satisfying a human need. For example, a garden house

During a design process, the product is described as a product being designed. The product itself does not yet exist during a design process. For example, a garden house during the design process

The life of a product is represented in its product lifecycle. This is a representation of the product evolution, starting from a statement about the need of the product, continuing with its design, production, use, and reuse, and ending with its decommissioning. For example, the design process of a new type of garden house, the production, the use, the re-use, and the demolition process of a garden house.

Property/Factor

A property describes a characteristic of an entity. An entity can have a set of properties. A property can have a set of values.
Object: football
Property: ‘colour of the football’, ‘position of the football’
Values: ‘white’, ‘yellow’; ‘on the ground’, ‘in the air’

A factor describes an external influence on the characteristics of an entity. An entity can have a set of factors influencing it. A factor can have a set of values.
Object: football
Factor: ‘football player’
Values: ‘head the ball’ or ‘shoot the ball’

A design property is a property. It describes a characteristic of the product being designed or of the design process. A design property is just called a property.
Product being designed: garden house
Property: ‘dimensions’, ‘kind of coating of garden house’
Values: ‘h 2.5m, w 1.8m, l 1.8m’; ‘coating with ingredients ‘X’’

A design factor is a factor. It describes an external influence on the characteristics of the product being designed and/or of the design process. A designer cannot determine a factor. A design factor is just called a factor.
Product being designed: garden house
Factor: ‘the dimensions of production machines’
Values: ‘maximal dimensions of one plank’

Reflection

Reflection is seen as an introspective contemplation of the contents or qualities of one’s own thoughts or remembered experiences. (based on [Webster, 1986])

Reflection on design processes is seen as an introspective contemplation on the designer’s perception of the design situation and on the remembered design activities.

Structured reflection refers to systematic reflection that is performed on a regular basis.
Relation

A relation between two properties and/or factors describes the way in which one property or factor influences another property or factor.

- Factor: ‘football player’
- Property: ‘the position of the football’
- Relation: can change

A design relation is a relation between (design) properties and/or (design) factors.

- Factor: ‘the dimensions of the production machines’
- Property: ‘the dimension of one plank’
- Relation: limit

Representation

A representation of an entity is a reproduction of a relevant subset of the properties and factors of this entity in a mental image, a picture, a textual description, or in some other way.

Many different representations can be made of one entity.

- Object: football
- Object representation: textual description or drawing of football

A representation of the product being designed is a reproduction of a relevant subset of the properties describing the product being designed in a mental image, a picture, a textual description, or in some other way.

- A representation of the product being designed is also called a design.
- A list of dimensions of the production machines

A representation of the product being designed or of the design process for a specific stakeholder is called documentation.

A design-process representation is a reproduction of a relevant subset of the properties describing the design process in a mental image, a picture, a textual description, or in some other way.

- An organisation scheme

A design-context representation is a reproduction of a relevant subset of the factors influencing the properties of the product being designed and the design process at a certain moment in a mental image, a picture, a textual description, or in some other way.

Results of design research

A design philosophy is a school of thought expressed by designers and researchers as regards how design is, might be, or should be done. [Evbuomwan et al., 1996]

My design philosophy is a set of domain-independent concepts and terms for describing a design process from the viewpoint of state-transition systems.

A design theory is a collection of concepts, principles, and experientially verified relationships useful for explaining the design process and providing a foundation for the basic understanding required for proposing useful methods. (based on [Evbuomwan et al., 1996])

My design frame is a domain-independent aid to position properties, factors, design tasks, and representations.

A design method is a set of guidelines that can be followed during the design process in order to arrive at a realisable product. (based on [Evbuomwan et al., 1996]) Design methods are any procedures, techniques, aids, or ‘tools’ for designing. They represent a number of distinct kinds of activities that the designer might use and combine into an overall design process. (following [Cross, 1994])

My design method is a domain-independent aid that offers designers support for reflecting on design processes in a structured way.
A **design strategy** describes the general plan of action for a design project and the sequence of particular activities (i.e., the tactics or design methods) which the designer or design team expect to take to carry through the plan. [Cross, 1994] p. 19

A **design model** is a representation of a philosophy or strategy proposed to show how design is and may be done. [Evbuomwan et al., 1996] p. 19

**Space**

A **state space** is the set of all possible states of an entity. p. 59

- *Possible states of a football*: ‘white, on the ground (in the centre of the field), shoot the ball’; ‘white, in the air (in front of the goal), head the ball’; ‘white, on the ground (at the corner flag), shoot the ball’.

A **design space** is a limited state space. At a given moment, it is the set of all possible next states, towards the design goal, of the product being designed, and of the design process. p. 60

- *Current state of the product being designed*: ‘h 2.5m, w 1.8m, l 1.8m’; ‘coating with ingredients ‘X’’
  
- *Current state of the design process*: ‘halfway estimated duration’, ‘$15000 spent already’
  
*Design goal*: see goal of a design process

- *Possible next states are*: current state of the product being designed and the design process with the following properties added in different combinations: ‘only coatings allowed without ingredient ‘Y’’, ‘the cost of coating ‘C’ is $10/m²’, ‘coating ‘D’ has also ingredient ‘X’’, and ‘the estimated life of the garden house is limited to 15 years’.

A **positioning space** is a three-dimensional space in which properties, factors, design tasks, and representations can be positioned. p. 68

**State**

A **state of an entity** is the set of values for all properties and factors describing and influencing this entity at a certain moment. p. 53

- *Object: football*
  
- *State*: value white for property colour, value on the ground for property position, value head the ball for football player

The **state of a product being designed** is the set of values for all properties describing the product at a certain moment. p. 56

- ‘h 2.5m, w 1.8m, l 1.8m’ and ‘coating with ingredients ‘X’’

The **state of a design process** is the set of values for all properties describing the design process at a certain moment. p. 56

- ‘Halfway estimated duration’ and ‘$15000 spent already’

The **state of the design context** is the set of values for all factors influencing the properties of the product being designed and the design process at a certain moment. p. 56

- ‘Maximal dimensions of one plank’

A **design situation** at a certain moment is defined as the combination of the state of the product being designed, the state of the design process, and the state of the design context at that moment. p. 56

- It is the set of values of all properties describing the product being designed and the design process, and the set of values of all factors influencing the product being designed and its design process.

- See states of product being designed, design process, and design context.

A **current state** of a product being designed or design process is a set of values for all current properties. p. 56

A **desired state** of a product being designed or design process is a set of values for all desired properties. p. 56
Subject
A subject is one of the three parts of a design situation, namely the product being designed, the design process, or the design context.

Transformation/Transition: see Action

Value: see Attribute

World of designing
In the world of designing, three fields of attention can be recognised, namely design practice, design education, and design research.
Summary

In the world of designing, three fields of attention can be recognised, namely design research, design practice, and design education. Gaps exist between these three fields. In this thesis about designing, the focus is on the gap between design research and design practice. Design practice includes many design disciplines and an increasing number of multidisciplinary teams. Main problems in design practice are the communication between designers with a different background and the integration and co-ordination of important aspects during a design process. By tackling these problems, the effectiveness and efficiency of design processes in practice can be improved. The study of similarities and differences between design processes in several design disciplines and the development of support for reflection on design processes are topics that can improve design practice and that deserve more attention in design research.

The goal of my research is to decrease the gap between design research and design practice in order to improve design processes. Reflection on design processes can help designers to improve their design process, its results, and the designer’s proficiency: By reflecting explicitly on the current design situation and on the performed design activities, in a systematic way and on a regular basis, designers can plan next design activities that can be performed effectively and efficiently given the design goal at that moment. In this thesis, the combination of systematic and regular reflection is called structured reflection. To improve design processes in various design disciplines in practice, the study of similarities and differences between design processes in several disciplines can be useful. Similarities between design processes are the basis for domain-independent design knowledge (as distinguished from domain-specific design knowledge). To reach the goal of my research, I have chosen to combine, in a broad explorative study, the development of support for structured reflection on design processes and the development of domain-independent design knowledge. This thesis describes a domain-independent approach to improve design processes through structured reflection.

My research process can be summarised as follows. I studied three design disciplines, namely architecture, mechanical engineering, and software engineering. To get input from design practice, I did qualitative empirical research: I performed twelve case studies in the three disciplines to inventory characteristics of design processes and I compared the cases for similarities and differences. The similarities, together with the results of a literature study, have been the basis for the development of domain-independent descriptive design knowledge. The developed descriptive knowledge, in turn, formed the basis for developing domain-independent prescriptive design knowledge. At the end of the project, I confronted all results with design practice to get feedback on the results in another empirical study and I performed a literature study to position the results in the design literature.

My design philosophy and design frame are the descriptive results developed to answer the first research question, namely “How to describe design processes in a domain-independent way?”. My design philosophy is a set of domain-independent concepts and terms for describing a design process. The concepts and terms are based on an application of the general theory of state-transition systems to the context of designing; the concepts of state and state transition correspond to the main concepts of design situation and design activity in my design philosophy. The answer to the first research question given by the design philosophy is refined in a design frame: The design frame offers a means to structure the description of a design process in a domain-independent way. Major structuring concepts of the design frame are dimensions and subjects. I define three dimensions, namely level, perspective, and time. These dimensions define a three-dimensional space, called a positioning space, in which important aspects of design processes can be positioned. A positioning space must be defined for each subject, being the three parts of a design situation: the product being designed, the design process, and the design context. My design frame is a domain-independent structure formed by the combination of the three dimensions for each subject.
My design method is the prescriptive result developed to answer the second research question, namely “How to support structured reflection on design processes in a domain-independent way?” My design method is a domain-independent aid that offers designers support for reflecting on design processes in a structured way. Reflection on design processes is defined as an introspective contemplation on the designer’s perception of the design situation and on the remembered design activities. A reflection process is described as a process that consists of three steps that are called preparation, image forming, and conclusion drawing. The design method is based on two main concepts: The first concept is the systematic description and analysis of design situations and design activities by means of forms and checklists; only systematic support for the preparation step of a reflection process is developed. The second concept is the idea of design sessions, introduced to stimulate designers to reflect regularly during a design process. A design session is defined as a period of time during which one or more designers are working on a subtask of a certain design task, for example, one afternoon, a whole day, or a week. Both concepts are combined to support structured reflection on design processes. The complete design method consists of five steps for each design session, namely planning a design session, defining the subtask of the design session, reflecting at the beginning of a design session, designing during the core of a design session, and reflecting at the end of a design session. A prototype software tool, called ECHO, has been developed to explore the benefits of using a software system to facilitate the use of the design method.

Together, the design philosophy and the design frame offer concepts, a vocabulary, and a structure to describe design processes in a domain-independent way. The design method is a first proposal of a method that supports structured reflection on design processes. My results are thus possible answers to the mentioned research questions and are starting points to improve the effectiveness and efficiency of design processes. Based on the feedback I collected, I am optimistic about the applicability of my results in design practice. By asking input from design practice and by developing results that are useful for design practice and that contribute to design research, I contribute to decrease the gap between design research and design practice. The most important recommendations for further research are to test all results extensively in design practice and to investigate how to apply the results in design education.
Samenvatting (Dutch Summary)

In de wereld van het ontwerpen kunnen drie aandachtsgebieden worden onderscheiden, namelijk ontwerponderzoek, ontwerppraktijk en ontwerponderwijs. Tussen deze gebieden bestaan kloven. Dit proefschrift over ontwerpen concentreert zich op de kloof tussen ontwerponderzoek en ontwerppraktijk. De ontwerppraktijk bevat vele ontwerpdisciplines en een stijgend aantal multidisciplinaire teams. De belangrijkste problemen in de ontwerppraktijk zijn de communicatie tussen ontwerpers met een verschillende achtergrond en de integratie en coördinatie van belangrijke aspecten tijdens een ontwerpproces. Door deze problemen aan te pakken kan de effectiviteit en de efficiëntie van ontwerpprocessen in de praktijk worden verbeterd. De studie van overeenkomsten en verschillen tussen ontwerpprocessen in verschillende ontwerpdisciplines en de ontwikkeling van ondersteuning voor reflectie op ontwerpprocessen zijn onderwerpen die de ontwerppraktijk kunnen verbeteren en die meer aandacht verdienen in het ontwerponderzoek.

Het doel van dit onderzoek is de kloof tussen ontwerponderzoek en ontwerppraktijk verkleinen om zo ontwerpprocessen in de praktijk te verbeteren. Reflectie op ontwerpprocessen kan ontwerpers helpen deze processen, de resultaten, en de eigen vaardigheden te verbeteren: door expliciet te reflecteren op de huidige ontwerpsituatie en op de uitgevoerde ontwerparticiviteiten, systematisch en regelmatig tijdens het ontwerpproces, kunnen ontwerpers de volgende activiteiten zo plannen dat ze effectief en efficiënt uitgevoerd kunnen worden gegeven het ontwerpdoel op dat moment. In dit proefschrift wordt de combinatie van systematische reflectie die regelmatig tijdens het ontwerpproces wordt uitgevoerd gestuctureerde reflectie genoemd. Om ontwerpprocessen in verschillende ontwerpdisciplines in de praktijk te verbeteren kan een studie van overeenkomsten en verschillen tussen processen in verschillende disciplines nuttig zijn. Overeenkomsten tussen processen vormen de basis voor domein onafhankelijke ontwerpkennis (te onderscheiden van domein specifieke ontwerpkennis). Ik heb gekozen om, in een brede exploratieve studie, de ontwikkeling van ondersteuning voor gestuctureerde reflectie op ontwerpprocessen te combineren met de ontwikkeling van domein onafhankelijke ontwerpkennis om zo het doel van het onderzoek te bereiken. Dit proefschrift beschrijft een domein onafhankelijke aanpak om ontwerpprocessen te verbeteren door middel van gestuctureerde reflectie.

Mijn onderzoeksproces kan worden samengevat als volgt. Ik heb gekozen om de ontwerpdisciplines architectuur, werktuigbouwkunde en software ontwerpen te bestuderen. Om input te krijgen uit de ontwerppraktijk is kwalitatief empirisch onderzoek uitgevoerd: twaalf gevalstudies in de drie disciplines zijn uitgevoerd om eigenschappen van ontwerpprocessen te inventariseren; de gevalstudies zijn vergeleken op overeenkomsten en verschillen. De overeenkomsten, samen met de resultaten van een literatuurstudie, vormden de basis voor de ontwikkeling van domein onafhankelijke beschrijvende ontwerpkennis. De ontwikkelde beschrijvende ontwerpkennis, op zijn beurt, vormde de basis voor de ontwikkeling van domein onafhankelijke voorschrijvende ontwerpkennis. Aan het einde van het project zijn alle resultaten geconfronteerd met de ontwerppraktijk in een nieuwe empirische studie om feedback te krijgen op de resultaten. Ook werd nog een literatuurstudie uitgevoerd om de resultaten te positioneren in de ontwerpliteratuur.

Mijn ontwerfilsosofie en ontwerpraam zijn de beschrijvende resultaten ontwikkeld voor het beantwoorden van de eerste onderzoeksvraag, namelijk “Hoe ontwerpprocessen domein onafhankelijk beschrijven?”. Mijn ontwerfilsosofie is een verzameling domein onafhankelijke concepten en termen voor het beschrijven van een ontwerpproces. De concepten en termen zijn gebaseerd op een toepassing van de algemene theorie van toestand transitie systemen voor de context van het ontwerpen; de concepten toestand en toestand transitie komen overeen met de belangrijkste concepten ontwerpsituatie en ontwerparticiviteit in mijn ontwerfilsosofie. Het antwoord dat op de eerste onderzoeksvraag is gegeven door de ontwerfilsosofie is verfijnd in een ontwerpraam. Het ontwerpraam is een middel om de beschrijving van een ontwerpproces domein onafhankelijk te
structureren. De belangrijkste structurerende concepten van het ontwerpraamwerk zijn dimensies en subjecten. De dimensies niveau, perspectief, en tijd definiëren een drie dimensionale ruimte, een positioneringruimte genoemd. In deze ruimte kunnen belangrijke aspecten van ontwerpprocessen worden gepositioneerd. Een positioneringruimte moet worden gedefinieerd voor elk subject, zijnde de drie delen van een ontwerpsituatie: het te ontwerpen product, het ontwerpproces en de ontwerpcategorie. Mijn ontwerpraam is de domein onafhankelijke structuur gevormd door de combinatie van de drie dimensies voor elk subject.

Mijn ontwerpmethode is het voorschrijvend resultaat ontwikkeld om de tweede onderzoeks vraag te beantwoorden, namelijk “Hoe gestructureerde reflectie op ontwerpprocessen domein onafhankelijk ondersteunen?” Mijn ontwerpmethode is een domein onafhankelijk hulpmiddel dat ontwerpers ondersteund bij het structureerd reflecteren op ontwerpprocessen. Reflectie op ontwerpprocessen is gedefinieerd als een introspectieve contemplatie op de perceptie van de ontwerpsituatie door de ontwerper en op de herinnerde ontwerpectiviteiten. Een reflectie proces is beschreven als een proces dat bestaat uit de stappen voorbereiding, beeldvorming en conclusie trekken. De ontwerpmethode is gebaseerd op twee hoofdconcepten. Het eerste concept is de systematische beschrijving en analyse van ontwerpsituaties en ontwerpectiviteiten door middel van formulieren en checklists; alleen systematische ondersteuning voor de voorbereidingsstap van een reflectieproces is ontwikkeld. Het tweede concept is het idee van ontwerpsessies, geïntroduceerd om ontwerpers te stimuleren regelmatig te reflecteren tijdens een ontwerpproces. Een ontwerpsessie is gedefinieerd als een periode tijdens welke een of meerdere ontwerpers werken aan een deeltaak van een bepaalde ontwerptaak, bijvoorbeeld een namiddag, een hele dag, of een week. Beide concepten zijn gecombineerd om gestructureerde reflectie op ontwerpprocessen te ondersteunen. De complete ontwerpmethode bestaat uit vijf stappen voor elke sessie: plannen van een sessie, definiëren van een deeltaak voor de sessie, reflecteren aan het begin van de sessie, ontwerpen tijdens de kern van de sessie en reflecteren aan het eind van de sessie. Een prototype van een software hulpmiddel, ECHO genoemd, is ontwikkeld om de voordelen van het gebruik van een software systeem voor het vergemakkelijken van het gebruik van de ontwerpmethode te verkennen.

Samen bieden de ontwerfilsosofie en het ontwerpraam concepten, een vocabulaireum en een structuur om ontwerpprocessen domein onafhankelijk te beschrijven. De ontwerpmethode is een eerste voorstel van een methode die gestructureerde reflectie op ontwerpprocessen ondersteund. Mijn resultaten zijn dus mogelijke antwoorden op de genoemde onderzoeksvragen en zijn startpunten om de effectiviteit en de efficiëntie van ontwerpprocessen te verbeteren. Gebaseerd op de feedback die ik verzamelde ben ik optimistisch over de toepasbaarheid van mijn resultaten in de ontwerppraktijk. Door input te vragen van de ontwerppraktijk en door resultaten te ontwikkelen die bruikbaar zijn voor de ontwerppraktijk en die bijdragen aan het ontwerponderzoek, draag ik bij aan het verkleinen van de kloof tussen ontwerponderzoek en ontwerppraktijk. De belangrijkste aanbevelingen voor verder onderzoek zijn alle resultaten uitvoerig testen in de praktijk en onderzoeken hoe de resultaten toegepast kunnen worden in het ontwerponderwijs.
Isabelle Reymen was born on November 18, 1973 in Elsene (Brussels), Belgium. She grew up and went to school in Keerbergen, a small village in Belgium. In June 1991, she finished her secondary school. In October of the same year, she started the study of Architecture at the Faculty of Applied Sciences of the Katholieke Universiteit Leuven, Belgium. Her Master's thesis focussed on the possibilities of a computer-aided-design system for facility management for the Academic Hospitals in Leuven. She graduated as Burgerlijk Ingenieur Architect (Civil Engineer Architect) in June 1996. The summer months during her studies, she used to develop practical design experience in the architect's office of her father, the Multidisciplinary Studying Group USEG Ltd.. Halfway September 1996, she started as a Ph.D. student (Assistent in Opleiding) of the Stan Ackermans Institute (SAI) at the Technische Universiteit Eindhoven (TU/e), Eindhoven, The Netherlands. Because research activities at the SAI were only being set up at that time, she did her research within the Department of Computing Science of the Faculty of Mathematics and Computing Science at the TU/e, the department of her supervisor prof.dr.Dipl.Ing. Dieter K. Hammer. This thesis contains the most important results of her research. Since February 2001, she is working as a postdoc at the SAI. Supporting designers of several design disciplines in order to improve their design processes is still the main goal of her research.

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