INFORMATION PROCESSING IN DESIGN

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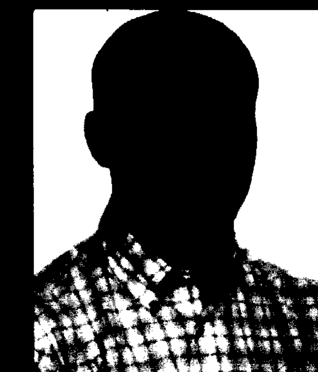

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Contents

1 Problem Structuring and Information Access in Design

Abstract *This chapter proposes design as a problem solving activity. It claims that that due to ill-definedness of the design problems, active problem structuring is required. It also proposes that problem structuring is based on three elements: One, the strategy used by the designer in structuring the problems. Two, the design requirements generated (or given). Three, the information accessed. It is claimed in this chapter that in order to study the role of information in design, we need a better understanding of these three elements.*

1.1 Introduction

Design is primarily a problem solving activity, but because of the special nature of the problems it solves, not a common one. Classical literature on cognitive science considers human problem solving as an information processing activity, and problem solvers as information processing systems. Newell and Simon (1972) proposed that an information processing system (ISP) is a relatively unconstrained physical symbol manipulator that is provided with memory (long term, short term and external), a processor, sensory receptors and motor effectors. There are, of course, more sophisticated accounts of human information processing in literature, but the premises and descriptions provided by Newell and Simon's theory suffice for the purposes of this work.

In the paradigm of design as a rational activity that follows Simon's views (Dorst, 1997), it is proposed that design is a process of searching for a solution in a certain problem space, that is, a metaphorical space in which the problem solving activities take place. According to Newell and Simon's theory, such a space should contain complete information about the initial state of the task (problem), information about the transformation function to move from the problem state to the solution, and information about the goal.

However, because of the nature of design problems, described as ill-defined or ill-structured, there is often very little information about the problem, even less information about the goal (solution) and absolutely no information about the transformation function. This means that design problems require structuring. *Problem structuring* is a process of drawing upon knowledge [or external information] to compensate for missing information and using it to construct the problem space (Simon, 1973).

This is not significantly different from what is proposed in the paradigm of design as a reflective practice. Schön proposed that a designer would frame a problematic design situation by setting its boundaries, selecting particular things and relations for attention, and imposing on the situation a coherence that guides subsequent moves. He called it *problem setting.*

This is not to say that information is taken into the process exclusively with the objective of structuring the problem. Information is also required during problem solving, but the nature and the objectives of the information required in both problem structuring and problem solving are very different. In problem solving, most of the required information refers to specific data whereas the information required for problem structuring requires more active interpretation.

Problem structuring occurs mainly in the beginning of the design process but also recurs periodically as the design activity progresses. This makes for difficulty in differentiating between problem solving and problem structuring, as it is not always clear whether designers are talking about the problem or about the solution.

This process of problem structuring is based on three elements: One, the strategy used by the designer in structuring the problems. Two, the design requirements generated (or given). Three, the information accessed. We need a better understanding of all three elements.

This chapter is structured as follows. It starts with a discussion of what a design problem is. This discussion is fundamental, as it provides the grounds to further discuss strategies in problem structuring. The next section discusses the literature on problem and solution focusing as design strategies and presents an empirical study in which these strategies are evaluated as a factor in the quality of the results of a design process. Following there is a discussion and an empirical study on the role of design requirements in the process of structuring design problems. In the section that follows, the role of information in problem structuring is discussed.

1.2 What is a Design Problem?

During the last four decades problem solving has been a field of continuous research. However, much of the research on problem solving has been carried out, for practical reasons, on well-structured, semantically impoverished tasks, having well-defined goals, initial states and transformation functions (Goel and Pirolli 1992). Examples of this research are cryptarithmetic, logic, puzzle solving and physics problems in the classroom.

Design is a unique type of problem solving. It is the maximum expression of human intelligence and the prototypical case of cognition, as it requires devising future states of the world (goals), recognizing current ones (initial states) and finding paths to bridge both (transformation functions). Moreover, it requires the generation of external representations of such states and paths (Restrepo *et al* 2000). These characteristics make design a very attractive subject of study in cognitive psychology. Alexander (1964) and Archer (1969) observed that design is an activity that requires both logic and creativity. The idea of the design methodology movement that appeared in the 60's, partially as a response to the demands of the industry and the military, and partially because of the advent of cognitive psychology, was to create systematic methods and tools better to conduct the logical analysis in order to unload the designer to engage in the creative aspects of the problem solving (Cross 1984)

Research in different design disciplines started to produce models, concentrating on different aspects of the design process (Lloyd and Scott 1994). For instance, design engineering provided models that rely upon the premise that analysis of problems precedes synthesis of solutions (Cross 1989; Jones 1963; Pahl and Beitz 1984; Roozenburg and Eekels 1995). Architectural models proposed that solution concepts precede problem structuring; and models derived from computer science showed the designer negotiating the structure of the problems (Guindon 1990).

However, as Goel and Pirolli (1992) noted, this research suffers from the difficulty that it either *"tends to concentrate on the analysis of discipline–specific design domains and shies away from cross–disciplinary generalizations, or the term design has been applied to an increasingly large set of activities that begins to drain its substance"* (p. 398). Such tasks that include learning (Perkins 1986), communication (Thomas 1978), letter writing, naming and scheduling (Thomas and Carroll 1979) have all been called design activities. Other tasks less dissimilar but still not completely comparable to design, like music composition and painting, have also been called design.

The criticisms of Goel and Pirolli are based on their view that design characterizations are not necessarily discipline-specific nor is design an ubiquitous activity. *"There is no more reason to construe every cognitive activity as a design activity than there is reason to construe every cognitive activity as a game–playing activity or a natural language–generation activity".* (p. 398)

Hence, although various design professions differ in aspects such as the nature of the artifacts designed, they certainly share common issues that identify them as design professions, and that make them different from non-design professions like medicine and law. Such common issues refer to the similarity in the structure of the problems they solve and in the process of solving them. Based on these common features, several researchers concluded that the nature of the act of designing is largely independent of the character of what is being designed. (Archer, 1969).

Design problems in general can be characterized as not being subject to systematization, incomplete, and vague. Reitman (1964) pointed out that design problems (and some other open-ended real life problems) are radically underspecified. He noted that there is a lack of information in each of the three components of design problems. The start state is incompletely specified, the goal state is specified to an even lesser extent and the transformation function from the start to the end is completely unspecified.

Simon (1973) referred to these problems as ill-defined or ill-structured , and Rittel and Webber as wicked (1973). In design, problems are wicked, in the sense that a design problem and its solution are linked in such a way that in order to think about the problem the designer needs to refer to a solution. Furthermore, there is not an absolute way to tell when the problem has been solved because the referents for such a judgment are dynamic and arbitrary. Tamed problems (like math problems), as opposed to wicked problems, have a mission that is clear, as it is also clear when the problem has been solved. However, it is important to note that the fact that design problems are radically underdetermined does not mean that they are completely undetermined. There are still some unchangeable constraints that the designer has to learn to live with.

The work of Goel and Pirolli suggests that there are many similarities across design problems that make them significantly different from non-design problems. They claim that there are structural similarities between the problems dealt with in different disciplines such as engineering, architecture and industrial design. It is these structural similarities what allows us to compare studies on design made in different disciplines. However, whenever we refer to *design* in this text, we mean *product design*. All the empirical studies presented in this work are conducted with design briefs for office furniture, gardening tools, bicycle accessories, etc. Though it might be possible to extend the results to other design disciplines, we make no such claims.

1.3 Problem Structuring and Designers' Strategies

Problem structuring begins with an interpretation of the problem situation. Darke (1979) proposed that designers interpret the design situation through images of the possible solutions and called these preconceptions *"the primary generators of design"*. She stated, *"these preconceptions seem to act as points of departure in the development of a design concept. When confronted with a new design situation, the designer imposes images of possible solutions to it. These images provide a means for the designer to analyze and structure the design situation, thus directing the actual development of the product form."* (p. 37)

Several design protocol studies have observed that designers jump to solutions or partial solutions before they have a full formulation of the problem. Cross (2001) proposes that *"this is a reflection of the fact that designers are solution-led, not problem-led; for designers, it is the evaluation of the solution what is important, not the analysis of the problem"* (p.82)

This is quite a radical view, as there are significant differences in the way designers formulate and solve their problems. In some cases, they generate conjectures about possible (partial) solutions and use these conjectures as a way of exploring and define the problem and the solution together (Kolodner and Wills, 1996; Cross 2001; Suwa *et al.*, 2000). This is what Lawson (1979) called *"analysis through synthesis"*.

Education, experience and personal preferences such as idiosyncrasy and tolerance to uncertainty have been given as explanations for the tendency to focus on problems or on solutions. Thomas and Carroll (1979), for instance, studied several problem-solving tasks, including design problems. What they observed was that designers tend to treat all problems as though they were ill-defined. They do so by changing the problems' constraints and goals. They behave in this way even in those cases in which the problems might have been treated as well-defined. The implication, conclude Thomas and Carroll, is that *"designers will be designers even if they can be problem solvers"* (p. 9).

Lawson's (1979) observations on problem-solving behavior suggested that focusing on either the problem or the solution is a learned behavior. He compared scientists with architects. Whilst the scientists were trying to discover the structure of the problem, the architects were generating solutions, until one proved satisfactory. The scientists presented a problem oriented strategy and the architects a solution-oriented one. He then compared first year students of science and architecture and did not find the same differences.

Lloyd and Scott (1994) in a protocol study of experienced engineers found that the tendency to focus on the problem or on the solution appeared to be a function of the level and type of previous experience. Designers with more experience of the type of problem studied tended to focus more on solutions (generative reasoning) and designers with less experience tended to use more problem analysis (deductive reasoning). They concluded, *"It is only when designers have specific experience of the design problem that they start to approach design tasks through solutions"* (p. 139).

The problem or solution focus of designers during problem structuring, as it has been discussed, has been recognized by many researchers. However, the difference between these strategies has been drawn mostly from retrospective accounts, and while 'solution oriented' designers have received a lot of attention, 'problem oriented' designers have not. This might be because it is thought that solution oriented strategies have a link to fixation and therefore have a negative effect on the design process, leaving the by-default assumption that a problem oriented approach would produce *better* results, or at least, that it will not have such negative effects. This, however, is purely speculative, for the effects of using either strategy on the process have not been compared empirically.

Simon (1973) argues that the ill- or well-definedness of a problem is not intrinsic to the problem; rather, these attributes can only be endowed by observing the relationship between the problem solver, his available knowledge and the problem to be solved. In the same line, one could propose that the tendency to focus on solutions or on problems is situational and idiosyncratic to the designer, but we have no evidence for this. The reasons for focusing on either problems or solutions are far from clear. There is no single cause for this behavior; instead, it seems to be caused by a combination of factors. However, the choice of either strategy has a great influence on the way the designer structures the problem, on the type of information accessed and on the requirements or design issues generated. This is the focal point of discussion in chapter 2.

1.4 Problem Structuring and the Generation of Design Requirements

Design is a discursive activity. Designers propose *design issues*, reflect upon and discuss them and for each issue propose answers (also called positions). For each position, they discuss the pros and cons and finally a decision is made about which position to accept (Rittel and Webber, 1973). This is what Schön called *"design moves"* (1983).

Issues can be requirements (new goals), specifications, ideas, etc. posed during the design process and can contribute either to further structure the problem or to solve it. However, problem structuring is not a clearly distinguishable phase of the design process, but instead an activity that reoccurs regularly. This makes the distinction between problem structuring and problem solving rather difficult to make.

The design process involves the synthesis of solutions that satisfy a set of given requirements, but designers also put significant effort in altering and negotiating given requirements and *generating* new ones. Design requirements are powerful means for the exploration of the solution. On the one hand, requirements act as anchors to the design problem, helping reduce uncertainty and on the other, they allow for a description of possible solutions. In this sense, requirements serve as a bridge between the client and the designer and between the problem and the solution.

Requirements are used to specify the design assignment (defining the problem space) and to describe and explore aspects of the desired solution (exploring the solution space) and are therefore an important aspect of problem structuring. They are either given or dynamically generated during the design process and are used by designers to express what they consider the most important aspects of the given assignment. This creation of design requirements *on the fly* seems to be triggered by prior knowledge or by knowledge acquired during the design process by interacting with the designed object (Schön 1983) or with external sources of information. This aspect will be explored in chapter 3 through an empirical study.

1.5 Problem Structuring and Information Access

As it has been stated previously in this chapter, one of the cornerstones of problem structuring is information access. Choices made by the designers depend on their understanding of the problem and its context, on their ability to structure both problem and context and consequently, on their success in obtaining proper information about the problem and about the context (Song, Dong and Agogino, 2002).

This is not to say that information access is not important during problem solving, the difference is made because the type of information and the support required for problem structuring and problem solving are different. The type of information accessed during problem solving is often more related to properties of materials, manufacturing conditions, functional characteristics, etc. During problem structuring information accessed referred more to users, the company and the environment in which the product is used. Information for problem structuring requires much more active interpretation and manipulation before it can be used by the designer than the information typically required for problem solving.

There have been some studies on the use of information for problem structuring. For instance, Cross *et al.* (1994), based on a study by Christiaans (1992) on differences between novice and intermediate design students, reported that students of both levels of experience display different behavior regarding information gathering and problem formulation strategies. The more successful students changed very rapidly from gathering information to reflecting upon it and using it to structure the problem *"building a structured representation of requirements, constraints, etc."* The less successful students asked for large amounts of information, but for them, *"gathering data was sometimes just a substitute for any design work"* (p.50). Interestingly, they found that the ability to gather information and use it to structure the problem did not depend on the level of experience or education of the designers, as some senior students also were trapped into information gathering for problem structuring. What this could mean is that the need to gather information (to structure the design problem) is related to the (in)ability of the designer to cope with uncertainty.

Eastman (2001) proposes that a designer's conception of a design and its context is built up over time, using information from the designer's already gained knowledge and experience, and from external sources of information. These external sources can be other designs (examples), the design brief, the client, or encoded sources like books, drawings, pictures, etc. But another source also applies, that is, the information generated (inferred) during the design process (Ullman *et al.*, 1988).

Designers rely heavily on prior knowledge and experience. Several empirical studies in the field of information processing in engineering reveal that one of the most prominent reasons designers have not to use other sources of information is that they are not considered accessible. This lack of awareness (Cross *et al.*, 1994; Court, 1997) produces as a result many designs being generated without the benefit of information that does exist.

Accessibility is a subjective measure of the effort that a designer needs to make in order to access such an information source. There are many factors affecting the accessibility of an information source, like familiarity to the source, quality of the results, format, right level of detail, etc. (Fidel and Green, 2003, Choi and Rasmussen, 2002).

The selection of an information source will depend on the type of activity the designer is performing. For instance, designers will consult more books and manuals when they need specific data about properties of materials, tolerances, etc. whereas when negotiating the structure of the problem humans will be the most consulted, if not the only ones (Fidel and Green 2003). The reasons for this is that humans are considered more accessible, but also because humans are able to translate their knowledge in terms that fit more closely the requirements of the person asking.

Research in the field of information access by designers and engineers has the objective of improving access to information. Access to information will be improved if the information provided is deemed by the user as relevant, for relevance is not a property of the information itself, but an attribute endowed by the user in a certain situation. Relevance is therefore a product of the interaction between the designer and the information source. A document, for instance, will be considered relevant if it closely fits the designer's expectations, that is, if the information it contains is what the designer expected it would contain. Improving the relevance of the information retrieved by a system will improve the perceived accessibility of the information system.

1.6 Overview of the Book

In order to design proper information systems for designers, it is important to understand how they enrich their knowledge base during the design process, what triggers their queries for information, what strategies they use and what factors influence their behavior in relation to information seeking. Exploring these questions requires a closer look into the design process and the factors that influence information intake. The aim of this research was to address these issues.

It starts by proposing that because of the special nature of the problems typically faced by designers, active problem structuring is required. In this interpretation of Newell and Simon's (1972) theory of human problem solving, problem structuring in understood the as the process of bringing new information to bear on the problem situation. Chapter 1 proposes that three elements provide the support for problem structuring: the strategy used, the design requirements generated (or given), and the information accessed. All three aspects are explored through a series of empirical studies.

Chapter 2 considers some of the issues regarding the structuring of design problems, and deals with the effects of different strategies and their consequences. It takes issue, via an empirical study, with the conventional credo of design educators that problem orientation is better than solution orientation. It considers the problem of fixation and suggests some inadequacies in current definitions, and proposes that the use and application of information is more important than some other, highly regarded design strategies. This chapter concludes with a discussion on the consequences of the results for design education.

The focus point of chapter three is the generation of design requirements as a means for problem structuring, and the role information access play in the process of generating new requirements. This chapter shows, using an empirical study, that the requirements generated play a crucial role in structuring design problems, and that, contrary to what literature suggests, this process of generating new requirements is neither smooth nor incremental. Instead, it involves both, incremental steps and radical re-organizations. This empirical study also showed that the information accessed in the system was used to stimulate the creative side of the process, and influenced the way designers perceived the ideal solution leading in cases to new requirements. In this studio, designers accessed more information about design precedents and considered it as more useful than the other information available in the information system. They expressed that information on unrelated products could act as powerful inspiration sources for their designs. These results were later used to design a new information system to support this creative side of the process, which is described in chapter 5.

Information access is the third element for problem structuring. It has been the guiding line for the first two empirical studies presented in chapters 2 and 3. Nonetheless, several aspects of accessing and using information such as the criteria used by the designers in judging the relevance of the information accessed and the role of information in the designers' perception of the design problem could not be researched in those chapters, but are discussed in chapter 4.

Chapter 4 studies the criteria used by the designers to assess the relevance of accessed information. It proposes that relevance judgments are cognitive, situational and dynamic: they depend on the designer's previous knowledge and understanding of the situation, on the particular information needs to perform a task and that they change as the designer progresses in the information seeking process. It shows, through an empirical study, how these relevance criteria are used in determining the usefulness of information, and discusses how this information is used in the design of a flexible workspace

Chapter 5 focuses on the use and handling of visual information during early stages of the design process, with the objective of studying how an information system to support designers in the handling of visual information could be developed. It starts from the premise that in thinking of a solution to a problem, the designer has a vague image of the form that will embody the solution, and that creating collages, sketches and other types of (external) visual representations are used to help in shaping and establishing this image among which, design precedents. This chapter shows that many of the existing computer tools to support designing with precedents suffer from a serious drawback: they rely on textual descriptions that have to be added to the collection of images prior to using the system. This approach brings along a series of difficulties: it is impractical for large collections; considers only the viewpoint of the editor; fixes descriptions in time and restricts attribution of meaning.

In chapter 5 both theoretical and technological aspects of the use and handling of design precedents are explored. On the theoretical side, it discusses questions related to how to represent design precedents in such a way that they can be effectively used in design education and in design practice. On the technological side, it shows how to implement such representations in a computer program so that it eliminates the problems associated with human mediated indexing and description. The development of the system is accompanied by a series of three empirical studies in which aspects of the usability of the interface are studied. It concludes with suggestions on how to continue the development of such type of tools.

Chapter 6 discusses the most important lessons learned during the research. It starts by presenting the aspects found to be the main impediments to information processing related to both the designer and the information system. Then, it proposes the variables that we need to study in order to make progress in understanding how designers use information and interact with information systems. Next, the research methodology, regarding the data collection and the experimental settings is presented and critically reviewed. It closes discussing the consequences of the results in design education and making suggestions for the design of information systems for designers, proposing along the way, how to proceed with future research.

2 Structuring Design Problems: Strategies, Hindrances and Consequences

Abstract *This chapter considers some of the issues regarding the structuring of design problems, and deals with the effects of different strategies and their consequences. It takes issue, via an empirical study, with the conventional credo of design educators that problem orientation is better than solution orientation. It considers the problem of fixation and suggests some inadequacies in current definitions, and proposes that the use and application of information is more important than some other, highly regarded design strategies.*

2.1 Introduction

Design is a mediator. It precipitates and facilitates change from a present state or condition to a future (more desirable?) one. It is thus frequently regarded as a problem solving activity and this is particularly so in so-called 'professional design' in which parameters are set and boundary conditions imposed. In this activity, due to the nature of design problems, active organization is required. Simon (1973) calls it *problem structuring*, Schön (1983) labels it *problem setting*. Such a structuring process involves the setting of boundaries for the design problem, and selecting the issues and relationships that will be addressed in order to impose on the situation a coherence that will guide subsequent *moves* (Schön, 1983). In other words, problem structuring is defining the so-called *problem space* by drawing upon knowledge, experience or external information (Simon, 1973).

To comprehend the role external information plays in the process of structuring design problems, it is necessary to have a clear understanding of how this structuring occurs. There are various levels of this understanding that may be proposed:

One, an initial *interpretation* of the design situation, a set of *constraints* or *requirements* that are given or generated during the process and all the *information* that is required to compensate for the missing information in the design brief.

Two, what the Gestalt psychologists proposed as the major impediments to the processes of problem solving in general, and to the access and use of information in particular. These are *fixation*, *transfer* and *representation problems.*

Finally there is the issue of *strategy.* Literature in design research proposes that two distinctive strategies can be recognized in the process followed by designers, namely *problem* focusing and *solution* focusing.

Regarding the first of these levels, this chapter discusses the first and the third elements: the initial interpretation of the problem, and access to information. It is argued that the way a design problem is interpreted initially has a durable conditioning effect that influences the whole process of designing, and this is followed by a discussion of the influence of information access on the problem structure. The second element, design requirements and constraints, deserves a separate treatment. Although it is noted in this chapter, it requires more extensive discussion than is possible here.

On the second level, that of impediments, a review of related concepts is presented and discussed. *Fixation*, being the most studied of the three issues proposed by the Gestalt theorists, is reviewed here mostly through literature, both in problem solving theory and in design research. Though the Gestalt School draws a clear difference between two main modes of fixation, *mental set* or *mechanized thought*, and *functional fixedness*, such a difference has received little attention in design research. We intend to address this issue.

The manner in which design problems are *represented* is closely related to both the initial interpretation of the design situation and the tools used to represent it. In design, there are only three ways of representing design problems, design intent and design knowledge. These are language, mathematics and graphics (though later in the process other means, like models and prototypes can also be used). Mathematics will not be addressed. Special attention will be paid to the use of language and the use of sketches as means to represent the design problem and the design intent. The problem of *transfer* (the ability to apply knowledge gained in one set of circumstances to a different set) is related to representation and will be discussed in that context.

The third level, that of strategies, is interesting for design practitioners as a way to describe what designers do, but is particularly interesting in design education, for it questions what type of competences we want to develop in design students, and how we prescribe for them how the design process should appear.

If two strategies can indeed be recognized, two questions come to mind. The first, particularly in an academic environment, is whether one strategy is better than the other. That is to say, if following a problem oriented or a solution oriented approach will lead to *better* results. The second is, naturally, how to recognize which approach is being favored in a particular design process.

Traditional design methodology suggests that focusing on problems instead of solutions is the natural way to proceed: analysis first, synthesis later. Designers, however, do not always follow this rule. Many studies suggest that whereas some designers try fully to formulate and understand the problem before attempting a solution, others jump very quickly to conjectures and use these as a way to explore both the problem and the solution simultaneously. Such behavior has been labeled problem and solution focusing respectively.

Solution focusing as a strategy has received far more attention in design research than problem focusing. The cause of this could be that solution focusing is very often associated with *early attachment* to concepts, a form of *fixation*. For this reason, it is considered a rather poor strategy. In design education and in conventional design methodology it is very often suggested that (existing) solutions should be avoided early in the process. This leaves the default assumption that focusing on problems instead of solutions is a *better* strategy and leads to better results; an assumption that is based on an intuitive view rather than on empirical investigation.

This chapter challenges that assumption. We do not subscribe to the idea that following a problem oriented approach will *necessarily* lead to better results than following a solution oriented one, as literature and common educational practice seems to suggest. It is argued that *the strategy* chosen does not have a significant effect on the quality of the results. We instead propose that *accessing* and *using* appropriate information is far more influential than the strategy followed.

This chapter is structured as follows. In the first section, we discuss some concepts associated with the notion of early ideas in the design process, taking as a starting point the attractive term of *primary generators* proposed by Darke in the late seventies. We discuss its relation to a particular form of fixation, *attachment to concepts*. The notion of fixation in problem solving literature and in design research literature is reviewed and commented on and is followed by a discussion of design representations.

In the second section, an empirical study is presented. In this study, we explore the process of problem structuring and show how different strategies can be recognized by analyzing the *initial interpretations*, the design *representations* and the *access to information*. We show how different strategies, design representations and information access interact with each other and influence the quality of the results of a particular design exercise. We conclude by suggesting which aspects are of importance in relation to information processing in design.

2.2 Early Ideas: The Genesis of Design?

Darke's Primary Generators

Though the tendency to focus either on problems or on solutions has been acknowledged in literature since the late seventies, it has been mostly based on anecdotal accounts gathered during interviews with designers. For instance, Darke (1979), after a series of interviews with architects (that included Spence on Coventry Cathedral and Utzon on the Sydney Opera House) wrote, *"the use of a few simple objectives to reach an initial concept was characteristic to those architects' approaches to design"*. She reported that in some cases a visual image comes very early in the process whereas in some other cases a certain amount of analysis takes place before the visual concept arises. She proposed that either the visual concept comes to mind before any rational justification for it has been developed, or the results of the analysis do not dictate following a particular concept rather than others. The concept or objective that generates a solution is what Darke called a *primary generator*. Later, when Donald Schön (1988) discussed similar ideas, he introduced the term *"generative metaphor"*.

The idea of a *primary generator* is presented also by Rowe (1987) and Lawson (1997). Rowe, in some empirical studies, found lines of reasoning *"based on*

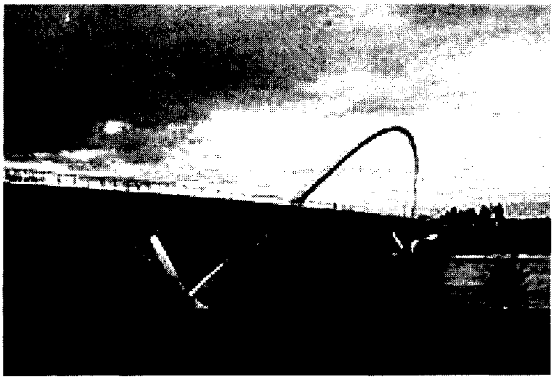


Figure 1. Santiago Calatrava's pont de l'Europe Orleans, France. The steel bridge structure employs a suspended inclined arch standing on clear pylons (www.calatrava.com)

some synthetic and highly formative design idea rather than on analysis of the problem" involving *"the use of an organizing principle or model to direct the decisions making process"* (p.45). These 'primary generators' sometimes have an influence that stretches throughout the whole design process, and can be detected in the final solution (Lawson, 1997).

Primary Generators serve a broader purpose than just starting the design process. In fact, as Lawson puts it, good design *"often seems to have a very few major dominating ideas which structure the scheme and around which the minor considerations are organized"* (p.194). These early ideas can change or can even be rejected as the designer gains knowledge during the process, but this change or rejection can be very difficult to achieve. Designers are sometimes very tenacious in pursuit of an idea even though it presents technical, economical or other types of difficulties (Rowe, 1987).

This tenaciousness can be of benefit for the project. Take for instance Utzon's design for the opera house in Sydney, considered impossible with the construction techniques available at that time, or Santiago Calatrava's innovative bridge designs, that seem to defy the rules of structural engineering. These examples, though, seem to be more the exception than the rule. Students and novice designers very frequently create more problems than they solve by pursuing innovative but inappropriate and impractical ideas.

Attachment to Concepts

Designers are known to change and negotiate goals and constraints actively during the design process. However, this change often results from trying to resolve difficulties encountered with a particular concept without having to start all over again (Cross 2001). Whether this reflects efficiency issues or is indeed a sign of attachment to a solution might be difficult to answer. Rowe (1987) observed that *"a dominant influence is exerted by initial design ideas on subsequent problem solving directions [...]. Even when severe problems are encountered, a considerable effort is made to make the initial idea work, rather than stand and adopt a fresh point of departure."* These ideas are comforting and reduce uncertainty or, as Lawson (1997) puts it, *"an early anchor can be reassuring if the designer succeeds in overcoming such difficulties and the original ideas were good"* (p.46). Other researchers that have considered the issue of early ideas have not been so enthusiastic. Broadbent (1988), for instance, called these initial ideas *"preconceptions"* giving the term a rather negative connotation.

Similar observations on attachment to early concepts have been found in Ball *et al* (1994). They proposed that when a solution was less than satisfactory, engineers seemed reluctant to abandon it and instead tried to develop improved versions until something workable was produced. Ullman et al (1988), in protocol studies with experienced mechanical engineers, found that they often pursue a single solution and, when problems are encountered, prefer to apply patches to the solution instead of trying a new approach. Guindon (1990) found the same in observations of software engineers.

Although designers often start structuring their design problems in terms of solutions, such problems are also structured using other strategies. For instance, Davies and Talbot (1987), in a series of interviews with 35 designers from the Royal Society of Arts faculty of Royal Designers for Industry, sought for evidence of the point of generation of the design idea or concept. They observed, among other things, that requirements act in many cases as the primary generators Darke was referring to. They said, *"In the context of a particular design problem, the very constraints of a problem may suggest unique solutions".* Therefore, focusing on other aspects of the problem, and not exclusively on possible solutions, is also a common behavior of designers.

Davis and Talbot showed in the same interviews, however, that sometimes solutions spring to mind when little or no analysis has been done, showing that the models of creativity proposed by Eindhoven and Vinacke (1952) (preparation, incubation, illumination and verification) did not always, or even usually, appear in that order. Designers, in most cases, speculate about (partial) possible solutions, and use the results of such speculations to define the problem and the solution at the same time (Kolodner and Wills 1996; Cross 2001; Suwa and Gero 2000). This is what Lawson (1997) called *"analysis through synthesis".*

Why do designers tend sometimes to focus on problems and sometimes on solutions? It is possible that education, experience and personal preferences such as idiosyncrasy and tolerance to uncertainty are reasons for the selection of one strategy or the other. The reasons for such behavior, however informative they might be, are less interesting for this discussion than the possible effects it might have on the design process and eventually, on its outcome.

The effects of focusing on problems instead of on solutions have not been explicitly discussed in literature. The studies on design strategies concentrate more on the tendency to focus on solutions. This is perhaps because the attachment to concepts early in the process is somehow considered a damaging, inappropriate behavior for a designer. In design education, for instance, students are trained to keep their minds open to as many different alternatives as possible. There are many occasions when students, and also professional designers, seem determined to generate as many different ideas as they possibly can, only to come back to their original ideas. Much anecdotal evidence suggests that moving in a large circle and eventually arriving back at the point of departure is a common design experience.

This is not necessarily a bad strategy. The initial, sometimes reactive, solution focus can serve as an anchor for a relatively quick and efficient navigation through related and workable alternatives. It can, however, also prevent the consideration of other alternatives and act as a sieve through which only supportive information is accepted and processed.

Figure 2 Duncker's classical experiment of the box and the candle

These initial interpretations are likely to have an influence (positive or negative) that stretches throughout the whole process. The problem of excessive attachment to them, even when they prove inappropriate, has been labeled *fixation* in design. We believe, however, that the term poses more questions than it answers, for there is no formal satisfactory definition of it, at least not in design research. Intuition suggests that there might be a link between the design strategies of problem and solution focusing and fixation. Are solution oriented designers more prone to fixation? Or is *problem focusing* a symptom of a different form of fixation? In the following paragraphs we review some previous work in the field and discuss these questions.

2.3 Conditioning and Fixation

The notion of fixation originated in the Gestalt theory of problem solving. Several researchers observed that problem-solving behavior was usually hindered by unnecessary assumptions brought along by the problem solver (Maier 1940, Köhler 1947, Schreerer 1963). Luchins and Luchins (1959, 1970) conducted experiments in which participants were asked to solve a number of word/number problems using a particular algorithm. The last problem of the series was not to be solved by this algorithm but instead by a simple and obvious alternative approach. Participants were so fixated on the given algorithm that they failed to solve the last problem. They called this type of fixation *mechanized thought* or *mental set* and described it as thinking which follows a previously laid-out pattern.

There is another type of fixation that is produced by strong familiarity with a certain topic or object. This type of fixation has been called *functional fixedness*. Functional fixedness means that our perceptions involving the use of everyday objects are rigid, and this rigidity hinders our ability to see how objects can be used in different, novel ways. As Abraham Maslow put it, *"It is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail"* (Maslow, 1966)

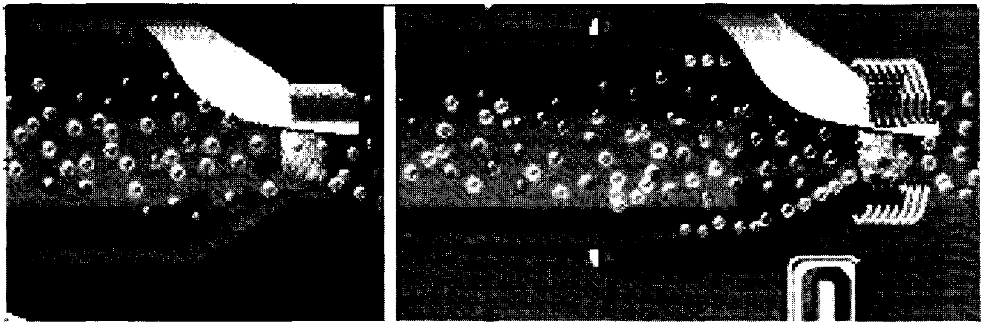


Figure 3. The first figure shows the abrasion particules cause in the nozzle. In the second figure it is shown how the magnetic field attracts the particles forming an auto protective layer that prevents abrasion.

A classic experiment on this type of fixation was the one devised by Duncker (cited in Mayer, 1983) called the candle problem. In his experiment, a number of participants were required to attach a candle to a board. Some participants were given a box containing candles, a box containing matches and a box containing pins. Other participants were given the candle, the matches and the pins outside of their boxes (see Figure 2). Duncker observed that participants in the second group were more able to find the solution to the problem than the ones in the first group. Dunker's explanation was that *"The placement of objects inside a box helped to fix its function as a container, thus making it more difficult for the subjects to reformulate the function of the box and think of it as a support"* (Mayer, 1983 page 56).

Another example of functional fixedness, this time from the field of design engineering, would be an abrasion problem. In steel-grit blasting, magnetic metallic particles (grit) are blasted through a nozzle. In the places where restrictions or changes of direction exist, the walls of the conducting pipe wear out. A typical solution is to use abrasive resistant materials, which is a well-known but expensive and temporal solution. A more *out of the box* solution would be to use a magnetic field that would make the same particles that are being transported form an auto-protective layer in the nozzle (see Figure 3).

Some years after the classical experiments on mental set and mechanized thought were performed, Weisberg and Alba (1981) looked at the problem of fixation again, conducting experiments on puzzle problem solving (like the nine dots problem or the cannibals—missionaries problem). Some participants in their experiments with the nine dots problem were told that the problem might have a solution if they extended the lines outside of the square formed by the dots. In other conditions one or two of the four lines were given. In both cases, it did not significantly improve the participants' performance. Their conclusion was that the removal of the unnecessary assumption (lines should be drawn within the area determined by the dots) did not result in an insight into the problem that led the participants to a direct solution. They suggested that the concept of fixation is superfluous: problem solvers are not excessively adhering to an idea, they just do not know what to do. *"If a person is working on obvious* *solutions, and if that person does not know those solutions will not work, this person is not fixated"* (p. 188). This proposes that fixation is closely related to a lack of knowledge and to a lack of problem solving (design) abilities.

Jansson and Smith studied the problem of fixation in senior students' and professional mechanical engineers' responses to design problems. Their premise was that knowledge of existing solutions of a problem can act as barriers to idea generation (functional fixedness). They conducted empirical studies and concluded that giving examples of an existing solution to designers might generate an undesirable premature commitment to this solution. They called this *"design fixation"* and defined it as *"a counter productive effect of prior experience on the generation of creative designs aimed at solving a realistic problem"* and proposed that such fixation effect could prevent designers from using all the knowledge and experience they have on solving the problem (Jansson and Smith, 1991; Smith et al., 1993; Smith, 1995).

In a series of experiments, replicating the conditions set by Jansson and Smith, Purcell and Gero (1991, 1993, 1996) explored the role of discipline and experience in the phenomenon of fixation. In a first experiment comparing industrial designers to mechanical engineers, they found that engineers showed signs of fixation, introducing in their concepts more features presented in the given examples. In contrast, industrial designers did not show signs of fixation in any of the conditions (with or without examples). They suggested that these differences might be due to differences in the educational programs. Industrial designers are trained to generate as many alternatives as possible keeping as far as they can from the known.

When given an unfamiliar problem with an unknown and innovative solution, engineers did create innovative solutions, but incorporated the underlying technical principle presented in the example in those solutions. In the same experiment, they found that industrial designers behaved consistently, producing for each situation a wide variety of solutions that were not substantially influenced by the given examples. They proposed that fixation is an effect of familiarity with the topic, the absence of domain specific knowledge and the tendency to rely on everyday knowledge, and concluded that designers might indeed be fixated *in being different.*

Both series of studies found evidence of mental sets and functional fixedness, although it was, unfortunately, not explicitly discussed. The difference between mental set and functional fixedness is important in problem solving and therefore relevant to design. Functional fixedness is a long term, difficult to break paradigm whereas mental set is situationally induced. Mental set is an attempt to apply previous methods to new problems that could be solved using an easier, alternative approach. Functional fixedness, conversely, reflects a reliance on previous knowledge about conventional use of objects or about everyday knowledge in general. For instance, it was difficult for Duncker's participants to think of using the box for a different purpose, as it was difficult for Jansson and Smith participants to produce spill-proof cups without mouthpieces. Mental set, on the other hand, indicates a fixation on the way of preceding, that is to say, an attachment to a certain *method.* This is for instance, the case of Purcell's and Gero participants, which by training kept producing alternatives even though some of them were inappropriate solutions.

The results of these studies suggest that fixation is indeed more than just a commitment to early ideas or a mimicking behavior that limits or blocks the output of conceptual design. Moreover, a commitment to an early idea can hardly be interpreted as *fixation* in the negative sense traditionally given to the word. In fact, committing to early ideas could be responding to other reasons, like efficiency, in a time restricted context, or be the result of skill, talent, intuition or just good luck. Sometimes designers *know* that an idea is right, and they know it with absolute certainty. For instance, one of the designers interviewed by Davis and Talbot (1987) reported, *"I always know when a design is right [but] I can't always put facts and figures against it"*. Some times this knowing happens so early in the process that you say, *"... that was easy; what went wrong?"* (p.21)

Other studies that have tried to prove this point include one by Cross and Clayburn-Cross. After interviews with outstanding designers (that included formula one racing car designer Gordon Murray and 'Dan', one of the participants in the 1994 Delft design protocols (Cross, Christiaans and Dorst, 1996), Cross and Clayburn Cross (1998) reported that these designers show a form of fixation in their 'generative idea'. Having established a frame for their problem, these designers can be obstinate in their pursuit of solution concepts that fit this frame. Previously, Darke (1979) and Lawson (1994) had reported similar findings in their studies with architects.

Interestingly, Purcell and Gero's (1996) findings with non-experienced designers contrasts with those reports. In their studies, non-experienced designers seemed obstinate in generating ideas. Similar contrast can be seen with Smith and Tjandra's results with senior industrial design students. Smith and Tjandra (1998) found that the performance of their participants did seem to be influenced by the willingness to reconsider early ideas. What they found is that the groups that performed the best were those that at a certain point chose to start from zero when they got stuck, choosing to overcome their own 'fixations'. That study, however, was not based on a design problem but in a puzzle-solving problem.

This difference between experts and novices is intriguing but understandable. Experience allows designers quickly to judge whether an idea has the potential to become a solution even without having to fully develop it. It is also experience that allows them to patch the idea and make it work in the case where something does not go well. Lack of experience or domain knowledge can cause novices to get stuck when something does not work and the idea is already half developed.

Other factors can also trigger fixation in design. In fact, the finding that drove Smith and Jansson to conclude that fixation consisted of a blind adherence to a concept was that some of their participants would apply certain carachteristics of given examples to their solutions, even if those characteristics were innappropriate for their design assignment. For instance, when asked to design a spill-proof coffee cup, some design students were given examples of other spill-proof cups. Although the requirements specifically said that the use of mouthpieces was not allowed (for users can seriously burn their lips), designers still designed cups with mouthpieces because the examples provided had them. Similar results were obtained with a bicycle rack and a measuring cup for blind users. In this sense, the adherence to a concept that included certain features of the given exemplars is indeed a blind one, because the brief stated that such features were forbidden yet this instruction was ignored. They argued that showing designers a potential solution before the design session would result in fixation, blocking access to other ways of solving the problem. Likewise, Christiaans and Van Andel (1993) found that design students presented with an image of a potential solution mimicked a number of features of that solution, even the incorrect ones.

Precedents and Exemplars

Designers very often put a considerable effort into looking at representations of previous designs that act as precedents in the design process. Taking such precedents or examples as referents is therefore not a counterproductive phenomenon; quite the opposite. Pasman (2003) proposed that the use of precedents in design is an ever present and important aspect of professional design practice: *"Being solutions to previous problems, these precedents provide designers with important frames of reference in the generation and development of new product forms" (p. 190).* As a matter of fact, the ability to see resemblances between problems, though apparently dissimilar, plays a significant role in science and by extension, in other type of problem solving activities. Kuhn (1977) called such abilities *thinking from exemplars* (p. 306) and proposed that such abilities are one of the main things students acquire by solving problems. Finding analogous problems (precedents) to tackle new situations seems therefore the natural thing to do.

The difficulty does not lie in the fact that precedents are used in the design process, but in the fact that they are not properly reflected upon, interpreted and translated into usable knowledge that can be applied to the situation at hand. This reveals yet another difficulty in problem solving, namely, *transfer problems*, that in addition to the two types of fixation previously described, hinders problem solving and designing. Transfer is understood here as the use of knowledge and skills learned to solve one problem in the resolution of another.

Not having enough time to provide examples of every possible situation during an educational program, the ability to transfer knowledge from appropriate exemplars to new situations is indispensable. For this transfer to operate properly, problems and situations in general must be represented properly. Representations are abstract entities over which more general operators can apply. Take for instance a common physics principle. Increase in the speed of a fluid causes a decrease in the fluid's pressure. That is the principle behind airfoils and venturies. A proper transfer of this knowledge means that a car designer in search of roadholding would decide to make the car as low as possible, because the smaller the volume under the car, the higher the air speed, the lower the pressure and therefore the bigger the grip force of the wheels to the road.

In design education, the ability to make representations, particularly of design intent, is treated more as a skill than as an important part of the process of thinking about a design problem and developing a design solution (Purcell and Gero 1998). Sketching is probably the skill that receives most attention, and the ability to make a full and appropriate representation of the problem situation is poorly considered and supported.

As previously suggested, the initial interpretation of the problem situation and the way it is represented, either verbally or in sketches, has an influence that extends throughout the design process. Therefore, how problems are represented and interpreted is important, and the proper abstraction required for reasoning depends on the appropriate representation. We cannot reason using elements of the physical world. All our reasoning is based on abstract representations (Maturana and Varela, 1998). For example, mental images are externalized in drawings. In design, sketches are used by designers to reason about and to restructure their problem space by reflecting on their actions. In this sense, sketch representations constitute an iterative loop of information for designers that responds to both internal and external pressures.

Figure 4. Plan view (ortographic projection) from Mesopotamia (2150 BC) is earlies known technical drawing in existence. (Carlbom & Paciorek, 1978)

2.4 Representations in Design

Representations are important for design, because design is a special case of problem solving that almost always contains visual imperatives, and also because representations are not exclusively meant to represent problems. They provide a way to a solution.

One of the main characteristics of design is the distinction between the specification and the delivery of the designed artifact. The specification precedes the construction and delivery (Goel and Pirolli, 1992). The consequence of this characteristic is that design intent must be represented in such a way that it can be constructed remotely both in time and location. This is not always the case, for instance, in arts and crafts, in which the acts of designing and constructing the object are frequently indistinguishable (as in pottery and painting).

There is more to representations than technical drawings and specifications. To represent means to create something (be it internal, as mental images or external, as drawings or mathematical equations) that stands in for something else (a physical phenomenon, an object, a person). The ability to represent is one of the most remarkable characteristics of human beings, for it denotes the ability to abstract. During the design process, design intent is represented externally in a variety of ways: sketches, technical drawings, technical specifications, etc. but also in the form of verbal explanations and written documents (Galle, 1999; Eastman, 2001, Chan, Hill and Cruz-Neira, 1999). It is through the external representations of design information that design intent can be displayed and communicated.

Design intent has always been represented using different methods and techniques. Some 2000 years BC there were already 2-dimensional drawings depicting buildings (see Figure 4). More sophisticated drawing techniques, like the use of perspective as a means to represent three-dimensional objects in a 2-dimensional surface, were already discussed by the Greek, but it was only during the Renaissance that they became widely adopted by artists and architects.

During the same period, the use of physical models was perfected as a tool to represent design intent. Later, in the 18th century, an Irish painter called Robert Barker created a 360° painting of the city of Edinburgh and called it a panorama (some refer to this technique as a 2.5-dimensional representation). However, 3-dimensional virtual representations of objects had still to wait until the late 20th century. With the arrival of computers and proper software, detailed 3-dimensional virtual models provided a way not only to represent design intention, but also to test, simulate and prototype design concepts.

Drawing and Sketching

Of these forms of representing design intent, drawing and sketching is perhaps the most ubiquitous one. Designers usually work with such complex objects that it is impossible to develop the whole process in only one cognitive step or without the aid of external representations of their visual images (with, perhaps, very few exceptions, like the famous Fallingwater design of Frank Lloyd Wright). Sketches and drawings appear then as a tool to extend their memory and as a support to abstract descriptions (visual ideas), presenting information that cannot be directly deduced from such mental images.

Sketches and drawings have then a double purpose in design. On the one hand, they make it possible to evaluate if, and to what extent, the intended function can be accomplished. On the other hand, they are a source of knowledge and inspiration for other alternatives and even for other completely different ideas (Muller, 2001; Goldsmith, 1994), making imagining, seeing and drawing three inseparable activities.

Drawings, and by extension geometry, are not exclusively tools to communicate ideas or to calculate or describe spatial positions. In the case of sketching, they allow a dialog between the designer and the designed object (Goldsmith, 1991; van der Lugt, 2001; Robbins, 1994) or, as Suwa and Gero (2000) put it, *"It is not until externalizing on paper the ideas of what they think might be a potential solution and inspecting them that designers are able to find new aspects of the problem and to generate new ideas"*. Unfortunately, in design education the sketching process is treated mostly as a skill, rather than as a powerful tool to structure design problems and to develop solutions. The emphasis is put on the ability to make realistic or even impressionistic drawings that express the intent of the designer. Very often these drawings ignore or contribute to the avoidance of difficult and inconvenient details. It could even be so that the quality of a line speaks to the designer of the essence of a form, and cause much manipulative effort in a attempt to maintain it. The focus is shifted from the object to be designed to the drawing to be designed. Johnson (1997), for instance, claims that architecture students choose external representations based more on their visual impact that on what they actually communicate. The designer becomes fixated in maintaining the drawn appearance of the object at the expense of feasibility and practicality.

In conclusion, the review of the literature has posed more questions than it has answered. To start with, the assumption that solution focusing as a strategy is weaker than problem focusing seems to be ill supported. In fact, the accounts of design practitioners seems to indicate that they very often follow what could be perfectly described as a solution oriented approach. Why, then, do we promulgate the idea, particularly in design schools, that such an approach should be avoided? So far, there have been no studies in which both strategies are compared in terms of the results produced.

The notion of fixation also appears to be far from clear, at least in design research. The initial studies in the field by Jansson and Smith did not suggest that fixation in design would be significantly different from that observed by Luchins and Luchins, Weisberg and Alba and the others. In fact, the spirit of such studies was to extrapolate the understanding of functional fixedness and mental set from puzzle solving to designing. This objective proved to be much more difficult that they originally estimated, for the nature of design problems is significantly different from the nature of puzzle and other well-defined problems.

The link between representations and fixation is intuitive but elusive. So far, fixation has been described in terms of blind adherence to concepts, or to features present in existing solutions. However, we believe there is more to it. In physics, for instance, the use of proper means to represent problems, like diagrams, seems to be a determining factor in the effective solution of problems and it is considered to be closely connected to expertise (Anzai, 1991).

We need therefore to get a better understanding of how those factors affect the process of structuring design problems and ultimately, the access and use of information. This was the main objective pursued in the empirical study presented in the next section.

2.5 First Study: The Flexible Work Space

The problem or solution focus of designers during problem structuring has been recognized by several researchers. However, this difference has been drawn mostly from retrospective accounts, and while 'solution oriented' designers have received a lot of attention, 'problem oriented' designers have not. This might be because it is thought that solution oriented *early representations* have a link to fixation and therefore have a negative effect on the design process, leaving the by-default assumption that a problem oriented approach would produce *better* results, or at least, that it will not have such negative effects. This, however, is purely speculative, for the effects of using either strategy on the process have not been compared empirically.

This section presents an empirical study, originally designed by Snoek *et al* with the intention of testing the effect of information type on the quality of the results (Snoek *et al* 1999). Our purpose was quite different from theirs, but the data allowed the kind of observations we wanted to make. We intended to see first, whether or not the two aforementioned strategies (problem focusing and solution focusing) could be observed. Secondly, we wanted to identify good indicators of those strategies. It was speculated that the way designers express their initial interpretation of the design brief, what we call *early representations*, would be one of those indicators. Thirdly, the results that *solution oriented* and *problem oriented* designers produced were compared. With these, we explored whether one of the strategies was significantly better than the other.

It was also the purpose of the study to explore which aspects are of importance in researching information processing in design, with the aim of defining further areas of study. Finally, the role information plays in problem structuring, was explored, and whether accessing more information leads to a better structuring of the problem and ultimately to better results.

All the analysis presented here was done on Snoek's data for the first time and on the original raw data. No reduced or summarized data was considered. The authors of the original study did not analyse their dataset completely due to a change of circumstance.

2.5.1 The Original Study

Although the purpose of the original study was different from the one in this chapter, the data contain the kinds of details that allow a second analysis. This second analysis focuses on the differences presented by the participants in their problem structuring strategies by describing their initial representations of the design brief, the type of constraints they generate and their use of the information system provided. It also indicates what effect such differences have on the quality of the results.

2.5.2 Participants

Participants in the study were 23 senior students from the faculty of Industrial Design Engineering (IDE) at Delft University of Technology (9 female - 39%, 14 male - 61%). They participated voluntarily from a group of 60 students who were contacted by E-mail. This group was selected on their marks for a third-year design course. In order to stimulate students to participate and to work on the assignment with dedication, the experiment was announced as a contest organized by a company in office furniture. The participants received one credit point for their participation in this experiment.

2.5.3 The Design Assignment

In order to test whether different designers would approach a problem differently, the design brief had to be formulated in such a way that it gave enough room for a variety of (possible) problem representations and a range of concept solutions.

The assignment was introduced with a text explaining the problems modern offices have dealing with floating personnel who do not spend all of their working time in the office. It was also stated that floating employees have to use what is called flexible workplaces. However, employees do not feel comfortable working in a place that they do not feel is their own. The text also emphasized topics like the role of information in changing environments, developments in the area of technology, the change in work culture that can be characterized as 'flexible', etc. The core of the design assignment was formulated as: 'the problem is that an employee must have at his disposal the things he needs for his

Table 1 Reliability Coefficient for Judges' assesement

Question	Reliability Coefficient *Alpha Cronbach*	Reliability Coefficient *After removing judge B*
Originality (Q1)	0.6334	0.6602
Appropriateness (Q2)	0.3912	0.5686
Attractiveness (Q3)	0.2177	0.1959
Similarity to exist. sol. (Q4)	0.6806	0.6917
Quality of the form (Q5)	0.6663	0.6279
Feasibility (Q6)	0.7556	0.8191
Ability to represent ideas (Q7)	0.2346	0.5024
Quality of the presentation (Q8)	0.5774	0.4423
Grade	0.5543	0.5881

specific task at any time and in any place. Also, he wants to be able to adapt the desktop to make it his own personal work station at any time and in any place.' Participants were asked to produce a design concept and to make presentation drawings of such concept for the company for which they were designing. See Appendix 2.1.

2.5.4 The Information System

Analogous to a previous study by Christiaans and Van Andel (1998), a hypertext information system was developed, which was available to the participants during the design process. The information in the system was organized in a hierarchical manner following what Norman (1991) called a "connected graph menu structure". Though the organization of the information was considered in the experimental design, it does not have any influence on the use of the system, at least not beyond that of facilitating access to more nested pieces of information by guiding the user in a logical way (de Vries, 1994, de Vries and de Jong 1997, 1999).

Users also had access to a simple search engine. Since the information was HTML formatted and put in a web server, standard functions of a web browser like bookmarking and going back to previously visited pages were available. Access to information outside the web server containing the prepared information was not available.

The information was classified following a simple division. On the one hand, there was information the authors of the original study called "typical industrial design information". This information consisted of articles about:

- the client (a company in office requisites),
- different competitors,
- interior (office) design,
- trends in office design and
- graduation projects of the faculty of IDE on office design.

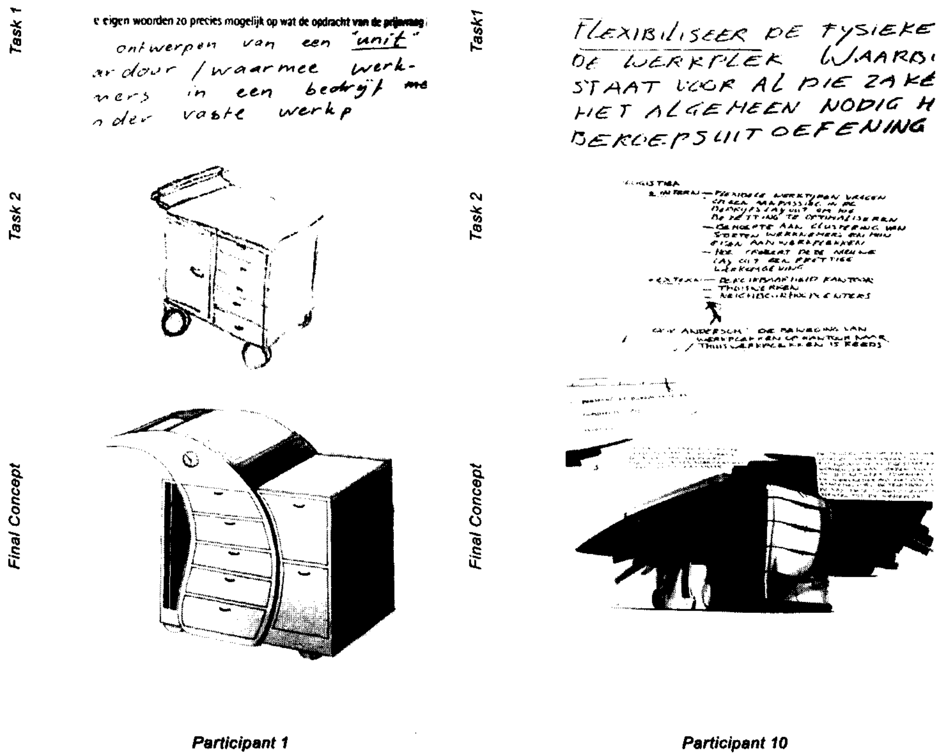


Figure 5 Examples of the design representations produced after tasks I and II and final solutions for two participants

On the other hand, there was information related to mobility, life style and labor in general. Snoek *et al* called this "context related information". Topics included:

- transport,
- labor issues and labor law,
- general trends in society,
- technology,
- culture, art and architecture and
- identity

All the pages were read by two faculty members and were placed by them on either "traditional industrial design information" or "contextual information". They agreed on the content of 82.5% of the pages. The pages in which there was disagreement were discussed and assigned to either category afterwards. A total of 450 documents were available, plus 100 navigation pages that contained no information but had links to other pages.

Table 2 Distribution of the participants according to orientation and gender

	Female	Male	Total
Problem oriented	5 (56%)	6 (43%)	11 (48%)
Solution oriented	4 (44%)	8 (57%)	12 (52%)
Total	9 (39%)	14 (61%)	23 (100%)

2.5.5 Procedure

Participants started at 1.30 PM, three or four participants at a time. They first received instructions about the procedure and they had to read the design assignment regarding the flexible office. Next, they were asked to perform two tasks consecutively:

- to write down the design assignment in their own words and as exactly as possible (Task I, early representation)
- and to write down their conception of the problem, i.e. to draw, sketch and/or write down everything about the problem they already had in mind on as much paper as they needed (Task II). Participants were given five minutes to complete Task I and 15 minutes to compete Task II.

The results of these two tasks will be referred to as *early representations.*

Each participant was given a separate office, a computer with access to the information system, and sketching materials. The design session was from about 2.15 - 9.45 pm, with an hour dinner break, and the next day from about 8.45 - 11.45 am – a total of approximately 10 hours design time.

During the design sessions the participants had to keep a logbook in which they had record every fifteen minutes the activities they were performing (sketching, consulting the information system, writing the report etc.). At the end of the second-day session, participants were asked to hand over their written material, sketches and drawings.

All the activity on the information system was logged on the web server. Log files included details of documents viewed, time spent on those documents and the time at which the documents were accessed. Unfortunately, due to the simple design of the system, if a participant went back to a previously viewed page using the back button of the browser, the browser displayed a page in its cache instead of making a new request to the server. These pages were therefore not logged by the system.

2.5.6 Analysis of the Data

The analysis of the data focuses on four aspects. Firstly, the *early representations* produced by the participants during tasks I and II. These early representations were evaluated by three independent judges, each of which received

Table 3 One-tailed Pearson Correlation matrix among the orientation and the different considered evaluation criteria (without judge B). †Correlation is significant at the 0.05 level. ‡Correlation is significant at the 0.01 level.

	Originality (Q1)	Appropriateness (Q2)	Attractiveness (Q3)	Sim. to exist. sol. (Q4)	Quality of the form (Q5)	Feasibility (Q6)	Ability to rep. Ideas (Q7)	Quality Present. (Q8)	Grade
Orientation	.132	.039	-.035	.072	-.119	-.048	-.092	-.128	.003
Originality (Q1)	1	.303†	.515‡	.856‡	.441‡	-.039	-.334‡	.332‡	.486‡
Appropriateness (Q2)		1	.648‡	.246†	.397‡	.625‡	-.184	.160	.601‡
Attractiveness (Q3)			1	.416‡	.604‡	.525‡	-.238	.307†	.715‡
Sim to exist. Sol (Q4)				1	.383‡	-.142	-.212	.193	.416‡
Quality of the form(Q5)					1	.399‡	-.484‡	.686‡	.781‡
Feasibility (Q6)						1	-.222	.290‡	.460‡
Ability to rep. Ideas (Q7)							1	-.451‡	-.359‡
Quality Presentation (Q8)								1	.559‡
Grade									1

copies of the texts and sketches. For each participant, judges were asked to answer the question:

"this problem formulation
- Allows enough flexibility for different solutions
- Drives the designer clearly in the direction of a specific type of solution."

Differences in opinion were discussed and upon agreement, a definitive assessment on whether they indicated a problem or solution inclination was given.

Secondly, the quality of the results was evaluated. Using the method proposed by Christiaans (1992) to assess the creativity of concepts, four independent judges (which were different from the ones used to assess tasks I and II) evaluated the results using eight different criteria. These judges were considered experts in evaluating design concepts, as they were all design instructors in the faculty. The eight criteria used were:

- originality (Q1)
- appropriateness (Q2)

Table 4 Correlation coefficients between total time spent accessing documents on 'typical industrial design information' and 'contextual information' and orientation (problem or solution focusing) and quality of the results (as an average of Q1, Q2, Q4, Q5 and Q6). ‡Correlation is significant at the 0.05 level.

	Orientation	Quality of the Results
Amount of 'typical information' accessed	0,119	0,132
Amount of 'contextual information' accessed	0,209	0,211
Total Information Accessed	0,219	0,415‡

- attractiveness (Q3)
- similarity to existing solutions (Q4)
- quality of the form (Q5)
- feasibility (Q6)
- ability of the designer to represent his ideas (in sketches) (Q7) and
- quality of the presentation (Q8)

Each criterion was assessed on a scale from 1 to 7. In addition, judges were asked to give a grade on a scale from 1 to10 to the concept.

Thirdly, the use of drawings and sketches, as well as the use of explicit design requirements and constraints was observed. The level of detail given in the sketches is considered an indicator of the level of commitment to a particular solution. In addition, sketches give an impression of the number of different ideas considered.

Even though the study was not specifically designed to observe the role of design requirements and constraints, many participants did explicitly produce a list of these.

Finally, the computer log files provided details of the kind of information accessed and the time spent on each document. The pages that were accessed for less than 8 seconds (considered the minimum time to be able to get an impression of the content of the document) were not considered in the analysis. The log files allow us to observe which document was accessed, when, and in what sequence. The total amount of time spent on the documents accessed for more than 8 seconds is the measure used for information access after having filtered the navigation pages.

2.5.7 Reliability of the Assessments

To compare how participants performed, means of the assessments of all judges have to be used. But comparing means is not useful when the assessments of the judges vary too much. For that reason, a reliability analysis using the Cronbach's coefficient alpha was used to evaluate the level of agreement among the judges on each of the evaluation criteria (See table 1)

The reliability coefficient also proved useful in testing the suitability of the terms used for evaluation. If α is too low for a particular evaluation criteria, it might be

Table 5 Differences in the sketches for problem and solution oriented participants.

	Problem	Solution
Timing	Late > 10 min	Early < 10 min
Detail	low	high
What is represented	environments	objects

that such an evaluation is highly subjective, or the term used in the evaluation is ill-defined. For instance, question 7 (ability of the designer to represent ideas), has an α of 0.23. This means that either this question has to be better defined for the judges or that it is not meaningful for the analysis, as all the judges seem to have very different opinions about it.

In the case of Question number 3, attractiveness, considerable variation in the judges' opinions was expected, as the concept of attractiveness is very individual. Interestingly, there was a high level of agreement on other criteria such as feasibility of the concept and originality.

Low reliability coefficients can also be due to one or more judges deviating too much from all the other judges. When looking at the reliability indexes, it was evident that judge B disagreed with the other judges in 7 out of 9 criteria of the evaluation. For this reason it was decided to eliminate this judge's assessment from the evaluation. The effect of eliminating that judge from the data is shown in Table 1.

2.5.8 Results

Early Representations

Two types of early representations were identified. One type focuses on descriptions of the problem as it is interpreted by the designer (problem-oriented). These refer to the context of the problem, e.g., the difficulties of having a desk for every employee even when they are not permanently in the office, or the difficulty of giving the work environment a more personal appearance when it has to be shared. The other type of representations deals with a description of the product that has to be designed (solution-oriented). Some representations were written using mainly nouns (e.g. "design of a *unit* that...", "Design of a *product*...", etc.), whereas others favor the use of verbs and adjectives ("*flexible* work stations", *enhance* work environment", etc.). Table 2 presents the distribution of the participants by gender and type of early representation generated. Gender and Orientation were not correlated ($r = 0.124$ $p = 0.573$). This indicates that gender is not significant in determining a solution or problem orientated approach.

Figure 5 shows examples of the representations generated in tasks I and II for participants 1 and 10 respectively as well as their final solution. Note the resemblance of the sketch of participant 1 to her final solution; note also the use of language in each case. The first writes about "the design of a 'unit'" whereas the second writes about "making the physical workspace more flexible".

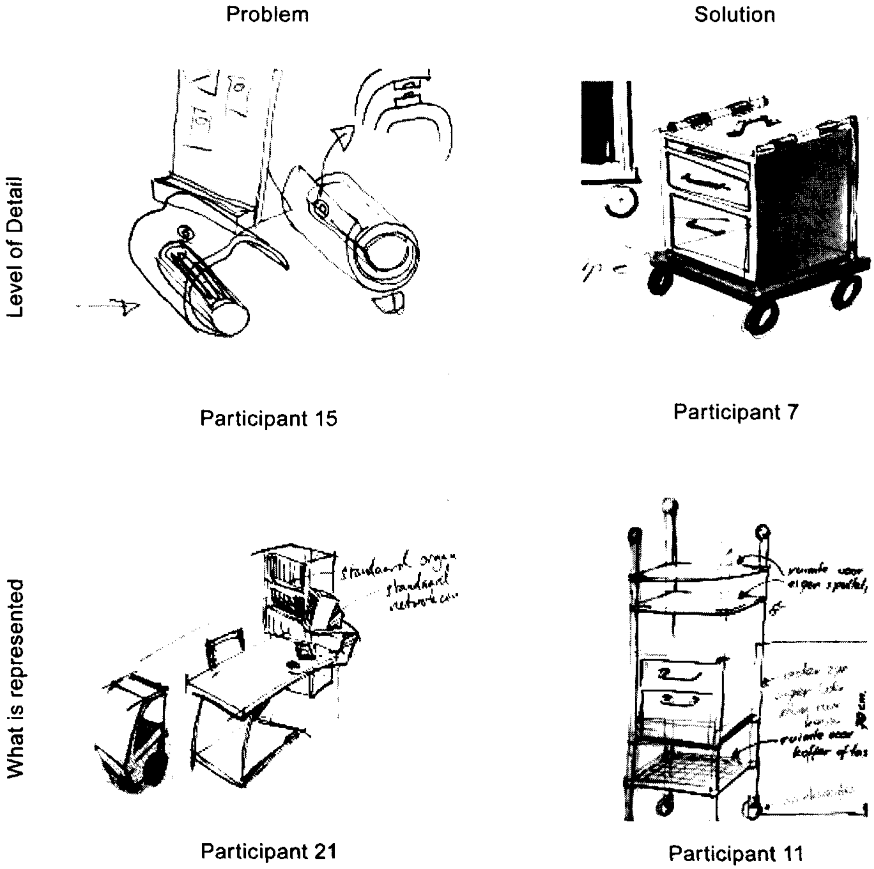


Figure 6 Examples of level of detail and what is represented in the sketches of several participants. All the examples are taken from sketches made after about 2 hours of design work.

Quality of the Results

The quality of the results (the concepts produced by the designers at the end of the design session) is measured using a number of evaluation criteria. Table 3 shows the Pearson's correlation matrix of the type of early representation generated by the designers and their performance according to each of the quality measures.

Even though there is variation in each of the criteria evaluated, such variation is not explained by the fact that participants decided to take a problem oriented or a solution oriented approach. This can be observed in Table 3, where it is clear that orientation does not correlate significantly with any of the criteria. It is nonetheless interesting to observe that the grades given by the judges correlate significantly with all of the evaluation criteria.

Table 6 Different ideas generated grouped by orientation and number of cases in which the first idea becomes the final concept.

	Different ideas (average)	First idea becomes final concept
Problem Oriented (n=11)	3	2
Solution Oriented (n=12)	4	6

Information Access

The most noticeable fact in the log files is that participants started, almost immediately after having completed task II, to browse through the database, following the links in the order suggested by the menu. This behavior changes after having spent some time using the system. The pattern switches from aimless browsing to more structured navigation, but only for some of the participants. Some designers keep accessing as many documents as possible, spending little time on each one. Others prefer to spend more time doing a careful reading of the (smaller) number of documents they access.

All the participants made use of the information system during the first day but only 7 out of the 23 used it on the second day. From the 10 hours available to complete the assignment, participants used between 10 and 167 minutes browsing or searching the information system. The mean time spent was 83 minutes, with solution oriented designers accessing, on average, slightly less information than the problem oriented ones. The type of information accessed was also observed. The so-called 'typical industrial design information' documents were accessed more times than the 'context related information' but this is not regarded as significant as it responds to the order in which the information was provided, with the 'typical information' appearing first in the menu.

Only part of the information available to the designers was used. For instance, only 260 out of the 450 pages that were provided were accessed at least once, the most accessed document being a report on the dimensions of workstations and the use of chests of drawers (27 times by 14 different participants). Out of the ca. 3500 accesses to the database, only 94 were the result of using keywords in the search engine.

Use of Sketches

The most visible difference between participants was in their sketches and drawings: not only the quality, which is a matter of skill, but also in their utility as a design tool. There are two dimensions in which differences can be observed, namely *timing* and level of *detail.* Timing refers to when in the process the designer starts sketching and level of detail indicates the amount of features that are identified and represented in the sketch. Table 5 shows the main differences and Figure 6 shows some examples. These results are only indicative of trends: no quantitative analysis was performed on this aspect of the data.

Different Ideas

Although there is variation in the number of different ideas generated by the problem oriented and the solution oriented designers, such variation cannot be statistically explained. The correlation factor between orientation and number of ideas generated is only -0,039 with a level of significance of 0,704. The number of different ideas range from 2 to 6. None of the designers produced one single idea. Table 6 shows the averages of the number of ideas generated and the number of cases in which the very first idea sketched became the final concept.

2.5.9 Discussion of the Results

Early Representations

One of the most interesting things to be observed in those *early representations* is the use of language. In this respect, the differences are syntactic. The designers whose representations were assessed as solution oriented were more inclined to use nouns. By doing this, they *named* their ideas. Naming ideas, particularly in such early stages of the process, has a tremendously constraining effect and could, in due course, be the *fixating* element that prevents the designer from considering other alternatives. These designers shifted their problem from the original assignment to *the design of an object*. The original problem, that floating employees do not perceive flexible workspaces as personal, became the design of a 'desk'.

Calling the solutions a 'trolley' or a 'backpack' focused their attention so much into that direction that for them, it was almost impossible to look for different alternatives. Similar results were found by Cross (1997), who mentioned how, in a team, as soon as one of the designers proposed that the solution for a particular problem could be a 'little vacuum-formed tray', the whole team focused on this idea, which eventually became the solution.

The problem oriented designers, on the other hand, favored the use of verbs and adverbs. In this way, the problem was not the design of an object but the design of a function, or the modification of an existing function. Their problem was interpreted as *"to allow the personalization of the workspace"* or *"to make current workspaces more flexible"*. These interpretations of the problem leave more room for a diversity of solutions.

Based on these differences, the three judges agreed that the *early representations* reflected an interpretation of the design brief that would either steer the design process too much towards a particular solution, or allow for a more ample spectrum of solutions.

Regarding the second task (Task II), the use of sketches also presents interesting facts. The solution oriented designers tended to represent objects in their sketches, whereas their problem oriented colleagues tended to sketch environments that would depict the situation described in the brief. This reinforces the observation concerning language.

These results come as no surprise, for the tendency to focus either on problems or solutions has been widely recognized in literature. However, the real interest lies in evaluating whether the expectation that problem oriented designers will produce *better* solutions is well-founded.

Quality of the Results

The quality of the results has been assessed using a number of criteria taken from Christiaans' (1992) method to evaluate the level of creativity of design concepts. These criteria have been modified to introduce other elements such as feasibility of the concept and appropriateness of the solution, as creativity is not the only measure for quality.

When the results were tabulated, it appeared that certain criteria such as attractiveness (Q3), ability to represent ideas (Q7) and quality of the presentation (Q8) were problematic. Attractiveness is a highly subjective criterion, based as it is on the personal preferences of the judges. For this reason, a low level of agreement among the judges was expected. Ability to represent ideas and the quality of the presentation evaluate the ability of the participants to draw and sketch and not necessarily their ability to design or to process and apply the information provided. Differences in the quality of the presentation might also reflect poor planning by the participant. A number of participants produced low quality or even no final presentation at all because they miscalculated the amount of time they had to spend developing their concepts. For these reasons, these three criteria have been discarded when comparing the performance of the participants. The rest of the discussion is based on the remaining six criteria.

For Purcell and Gero (1996), and for Jansson and Smith (1991), an early commitment to a design or a *blind adherence* to a set of ideas or concepts are both forms of fixation. For them, such phenomena would limit *"the output of conceptual design"* (Jansson and Smith). Given this, the expectations would be that the orientation displayed by the designers in their original interpretation of the problem would have a significant effect on the quality of the outcome. However, from the correlation matrix presented in Table 3, it is evident that such effect is not visible, not even in the grades given by the judges. In fact, orientation does not correlate with any of the evaluation criteria. What does this mean? Have designers perhaps reconsidered and decided, regardless of their initial view, to do more analysis on the problem? Or perhaps more problem structuring does not improve the designer's ability to produce *better* results? To answer these questions, it is necessary to take a closer look at the other elements of the problem structuring process.

Use of Sketches

As expected, solution oriented designers sketched more in their second task than problem oriented ones. Problem oriented designers seem to delay the start of sketching a bit more than their solution oriented colleagues. Their sketches provide less detail and in most cases, tend to depict an environment rather than a product. Contrastingly, solution oriented designers start sketching very early in the process and their sketches are much more detailed, indicating that they were more interested in developing their ideas than in further structuring the problem. For us, the fact that ideas were sketched, plus the level of detail depicted in those sketches, is a good indication of the level of commitment to a particular solution. Usually, little effort is put into ideas that the designer is not willing to pursue and more mature ideas are more difficult to discard. In the data, this is observed particularly in the solution oriented designers. They start sketching earlier, depict objects and give much more details in their initial sketches (See Figure 6). This indicates that designers who showed a solution oriented approach were more attached to their initial ideas. As they detailed them, it became more and more difficult to move on to a different one, even if they wanted to.

The quality of the sketches, which is different from the quality of the results, is another factor where variation can be observed. The quality of the sketches correlates highly with the grade given by the judges to the final concept. Nonetheless, the correlation coefficients with other criteria used to measure the quality of the concept, like feasibility, appropriateness and originality, albeit statistically significant, is rather low. This suggests that the quality of the sketches is not necessarily in direct relation with the quality of the designed product. Additionally, it leaves the impression that the judges might be very well inclined to judge better concepts when sketches are of good quality.

In some situations sketches can restrict, rather than enhance the designer's vision of the problem. The designer can use the drawings to *fudge* certain design aspects, using the drawings in an impressionistic way that sometimes, avoids the addressing of *inconvenient* details. These type of drawings are often much more attractive than the real object. This could tempt the designer to try to maintain that attractiveness, even if it is at the cost of practicality. The representation becomes the end, not the tool, and as more and more effort is put into the drawing itself, less and less attention is paid to the actual design of the object. The drawing, as Lawson puts it, replaces the object in the affections of the designer (1997). Additionally, these types of drawings might give the (false) sensation of a well-formed solution or a completed design task, making it difficult to move on and considering other possibilities. In this particular case, the drawing generated by the designer himself becomes a *fixating* element.

This does not mean that producing good sketches is bad. The ability to produce accurate sketches has a positive influence on the process of structuring design problems. Sketches, and in particular good sketches, play an important role in the task of re-interpreting the problem, as they allow designers to explore their ideas and to generate conditions or requirements that would otherwise have been difficult to foresee (Suwa and Gero 2000). In Verstijnen's (1998) studies, it was the designers with higher drawing skills who could profit most from the sketches they generated.

Different Ideas

Though it was expected that solution oriented designers would generate less ideas than problem oriented ones, no correlation between these two variables was found. However, for the solution oriented designers, without exception the final idea developed was present in the sketches created just 10 minutes after reading the brief and, in an important number of cases (6 out of 12), the final concept was the very first one sketched. Conversely, this was the case in only 2 out of the 11 problem oriented cases. This behavior, though, did not significantly reduce the number of concepts created by the solution oriented designers.

Kruger and Cross (2001) proposed a model of expertise of the design process in which they expected that 'problem driven' designers would generate few solutions, and that 'solution driven' designers would generate many solutions. However, when they tested the model with nine industrial designers, they found that both of them generated almost the same amount of solutions. These findings resonate with our own in this study.

Even though the solution oriented designers ended up developing one of the concepts they already proposed in the task II, a few minutes after starting the design assignment, they kept generating alternative solutions. This can be explained by the education they have received. Even when an idea is already 'the winner', design students are trained to generate as many ideas as they can, if only to satisfy an academic requirement more than to improve the quality of the results. Although this was not an academic assignment but a design contest, their training was reflected in their way of working. This can be compared to the conclusions Purcell and Gero (1993, 1996) came to after studying mechanical engineering and industrial design students, where they proposed that the fact that industrial designers keep generating alternatives reflects the fact that they are fixated in being different!

After some protocol analysis with design engineers Fricke (1993, 1996) proposed that generating too many or too few alternatives are both poor strategies. When the number of solutions explored was unreasonably small, designers became 'fixated' on concrete solutions too early. Conversely, when the amount of solutions explored was too large, designers had to spend too much time evaluating and comparing solutions rather than on a diligent development of a viable solution.

Fricke's observations echo our own. The participants that generated too many alternatives and the ones that developed the first idea they generated in Tasks I and II performed lower in Originality, Appropriateness and Quality of the presentation. The results of Purcell and Gero, Fricke and our own indicate that there is yet another possible fixating element, that is, *procedure* (i.e. conceptualize, analyze, synthesize, conclude. Creative, divergent thinking first, intelligent, convergent thinking later). This reflects results already obtained by the Gestalt theorists on puzzle solving. They called this phenomenon mechanized thought or mental set.

Design Requirements and Specifications

Adding requirements and constraints plays a key role on the structuring of the problem, for they are used to specify the design assignment (defining the problem space) and to describe and explore aspects of the desired solution (defining the solution space). A closer look at the process of generation of design requirements and constraints should give more insight into the process of problem structuring. Design requirements can be either provided in the design brief or can be dynamically generated by the designer during the design process. In this study, the assignment was written in such a way that no requirements were directly given. Instead, the brief described a problem and designers were asked to produce a concept to help the company tackle that problem. Most of the requirements were then introduced by the designers themselves.

The very nature of the constraints or requirements generated varies significantly depending on whether the designer takes a problem or a solution oriented approach. These differences are mainly expressed in the type of requirements and in the level of specificity. It is sometimes difficult to see whether a particular design issue is a design requirement (how the solution *should be* like) or a design specification (what the solution *is* like. For instance, compare what participant 11 wrote *"there must be a brake [on the wheels], otherwise it becomes very difficult to open the drawer"* with participant 3 *"make the workplace ready to use with little or no hand operations"*. The latter is a requirement that applies to a wide range of possible solutions whereas the former seems more like an extra condition to an already devised solution (a trolley with a drawer in this case).

The *timing* of the generation of requirements also varies. Problem-oriented designers produced their requirements throughout the entire process, whereas solution oriented designers tended to specify their solution at the very beginning of the session. This can be interpreted in different ways. The need to completely specify the situation in terms of requirements (or better, in terms of descriptions of a solution) very early in the process reveals either a difficulty in coping with uncertainty, or a strong commitment to an early concept, or both. Again, this can be compared with Kruger and Cross' model of expertise in design. They expected that *problem driven* designers would produce many requirements and *solution driven* would produce few. When they tested the model, they found that their expectations were incorrect, as *problem driven* designers produced less requirements than the *solution driven* ones, arriving at the same results as we did in our study.

Information Access

The initial objective of the study, as proposed by Snoek *et al*, was to observe the effect of 'information type' on the quality of the results. For that reason, they asked two judges to determine whether certain documents were what they called 'typical industrial design information' or 'contextual information'. Their assumption was that designers who accessed more contextual information would produce 'better' results, measured in terms of creativity, distance from existing solutions, etc.

Their findings were as they expected that 'traditional industrial design information' was accessed more than 'contextual information'. Our second analysis reveals, however, that this can be explained by the fact that 'traditional' information was put first in the information system, and as the designers started to browse, they did so following the menu item by item, favoring, of course, whatever was at the top of the menu. They also found that participants who accessed more 'context related information' performed better, and their explanation was that such a better performance was due to the extra contextual information accessed. They reached that conclusion even when the correlation between contextual information accessed and quality of the results was not statistically significant. Such a conclusion, however suggestive and interesting, seems quite premature.

What can be observed is that the *total* amount of information accessed had a higher impact on the quality of the results than the contextual information accessed. In fact, this measure correlates significantly to the quality of the results (as an average of Q1, Q2, Q4, Q5 and Q6). In Table 4 it can be seen that the correlation between the information access and the initial strategy chosen by the designers is not statistically significant. These results suggest firstly, that perhaps the difference between the two types of information proposed initially by Snoek *et al* is superfluous, and for the sake of this study unnecessary, and secondly, that the amount of information considered is more important than the initial representation of the problem. Here, it is recognized that accessing a certain document does not necessarily mean that the information it contained was actually processed and applied.

Looking at individual design process, interesting differences emerge as reasons for these results. For example, observing the information accessed by those participants that scored lower in the quality of the results reveals an unstructured browsing process. Browsing very quickly through a large number of pages seems to be the common pattern. Browsing is more explorative than searching. Searching denotes a purpose, and the intention to look for something in particular. Participants that produced better concepts accessed fewer pages but spent more time on each page indicating that they actually read, and perhaps processed and applied, the information in those documents.

Examples of existing products for flexible offices, like a trolley designed by an office furniture company in The Netherlands, were available in the database, but they do not seem to have had any significant impact on the results. There is no reason to believe that participants that accessed those particular documents became fixated by the examples contained in them.

An analysis was made of the sequence followed to access the information. In general, the order in which information was read followed the structure of the information in the system, but only at the beginning of the design session. This indicates that the participants were simply browsing without a target in mind, and intended to explore the information that was available to them. This might indicate that the use of the system is a result of the instructions, and does not respond to a true need for information. This behaviour changes after some time. Being acquainted with the kind of information available, the use of the system becomes more structured in the later stages, suggesting that the access is motivated by the work in progress. We have, however, no means to say exactly what motivated such requests, or how the information accessed was applied to the task.

2.5.10 Methodological Considerations

Selection of the Participants

Participants in this study formed a relatively homegeneous group. They were all students from the faculty of Industial Design Engineering, from the same year and based on their marks on design courses. Having all of them completed the same amount of design courses, they had about the same intermediate level of design experience. In practice, such an homogeneous group could never be formed. If designers from practice were taken as participants, they would be bringing all kind of different backgrounds and would have different amounts of experience. This would make for difficulty comparing the results obtained. The question would then be, what other factors play a role on the use of information for problem structuring?

Several accounts can be found in literature. For instance, Rowland (1992) reported that experts considered a problem as poorly defined with the amount of information provided and spent a lot of time structuring the problem. Novices, on the contrary, did very little exploration because they considered the problem well defined. Rowland's results are consonant with the findings of Atman et al (1999). In Atman's study, they compared freshmen with senior engineering students' use of information to structure and solve design problems. The results of this study was that, compared to the novices, the senior students *"gathered more information, considered more alternative solutions, transitioned more frequently between design steps and progressed further into the final steps of the design process"* which eventually lead them to produce better solutions.

Christiaans (1992) also found that the willingness to consider and process information, and the ability to do so, increase with experience. All these studies suggest that experience does have an influence on the use of information to structure the problem (see also chapter 1 for a wider discussion on the influence of experience on design problem solving). If they are right, the issue of information usage in problem structuring gains even more relevance in professional practice, as professional practitioners are more willing to consider more information and to spend more time in structuring the problem.

The Design Brief

Fricke (1993, 1996) proposed that the number of alternatives generated depend very much on the level of detail in the design problem as it was put in the brief. When the problem was very well specified, designers produced more alternatives. With a vague assignment (for the same task), the number of alternatives generated was lower. Fricke suggested that when the assignment is imprecise, designers have to generate a wider range of solution concepts in order to find a suitable solution. On the contrary, when the assignment is very precisely defined, the more active problem framing required leads faster to a solution.

Fricke's study confirms what is already intuited. The design brief does influence how the problem is approached. Since it was interesting in this study to see what strategies designers used to frame the problem, the brief had to be left as open as possible. The selected level of specificity chosen for the brief did not respond then to any other criteria than that of minimizing the number of given contraints. Though we did not compare using different level of specificity in the brief, like Fricke did, the wide range of different alternatives produced, as well as the observed differences in the problem structuring strategies indicate that the brief was appropiate for the objectives of our research.

Data Collection and Data Analisys

Research in the behavior of designers has used four distinctive strategies. On the one hand, protocol analysis and content analysis and on the other, process isolation and situated studies. The former two emphasize the transformational moves and representations used by designers. Process isolation assumes that the design process can be cognitively decomposed and finally, situated studies propose that a better understanding of the design process will be achieved by studying designers in their natural environments as integrated systems (Craig, 2001).

An understanding of the cognitive processes underlying the design process is not the particular interest of our study. For this reason, process isolation as a research strategy can be ruled out. The objectives of this study require the participants being a homogeneous group that cannot usually be found in design practice. Such a homogeneous group, with such a relatively large number of members can only be found at design schools. That makes difficult setting up studies in which they can be observed fully in a natural environment. That left us with protocol studies and content analysis as strategies for the purposes of this study, both of which present difficulties and opportunities. For example, three major concerns have been raised regarding protocol analysis. Protocols cannot capture everything, but only a part of the design process; thinking aloud might distort the design process and, in many cases, collecting protocols must be made in artificial settings.

Regarding the first concern, Ericsson and Simon (1984) proposed that the accuracy of the verbalizations in a protocol is task specific. If the task involves only the use of short-term memory (like some puzzle-solving), the accuracy is high. If, on the contrary, the task is more retrospective and requires the use of long term memory (like most design tasks), then the reported data can be wrong or some details can be missing, for protocol analysis relies heavily on utterances and sketches (external representations), which are the visible side of mental processes (internal representations). There is, however, not enough information about how accurately external representations actually map internal representations, or what the designer is actually thinking.

Some other researchers like Davies and Talbot (1987) e.g., asked à propos of this research strategy, *"what guarantee do we have that what people describe as their experience [...] actually bears any relationship to what is happening in their brain?"* None, they answered. Even if we trust that people would answer honestly our questions, they simply might have not access to their thoughts while they are in progress. Protocol analysis provides a very high level of detail on the mental processes of the observed participant. But it is not the mental processes of the designers what we are after in this study.

The second concern about protocol analysis deals with the interference verbalizing thoughts has on the thinking process. Researchers like Schooler and Engstler-Schooler (1990) have conducted experiments in which they demonstrate how verbalizing interferes with the visual reasoning. This is particularly dramatic in the case of analysis of individual designers, where they are instructed to think aloud. However, in the case of protocols of teams, the need to communicate with the other members of the team provides a more natural reason to verbalize ones thoughts. This will be exploited in a study over design requirement's generation that will be discussed in the next chapter. The third concern is the artificial character that has to be imposed to the design assignments to provide the necessary controlled, time limited setting required for videotaping a protocol. In many cases, such setting must be a lab, and participants must be given a brief that can be resolved in a very short period of time.

The second research strategy left to us is content analysis. It proposes that the content and structure of design representations are critical to understanding design behavior, and that such structure and representations can be revealed by certain analysis techniques. Content analysis appears as an adequate method for comparing the likeness and differences of different sets of representations (Thomas, 2003). These representations are not limited to written reports, but can be also sketches and verbalizations. Content analysis then allows as well the study of data collecting using the same techniques used in protocol analysis, but unlike protocol analysis, it does not intend to trace back cognitive structures. The high level of detail provided by protocols was not necessary in this study. Moreover, it would have been impractical having protocols of 23 participants working for 10 hours each. The data collected was then more suitable for content analysis techniques.

However, as protocol analysis is criticized, content analysis presents its own difficulties as well. It can be argued, e.g. that the ability of designers to represent their own ideas might bias the results. We acknowledge that indeed, such an ability to externalize ideas might have an effect on the data participants produced. For instance, one participant wrote *"shit, the whole set of requirements is in my head, I know what I want but I just cannot set it on paper."* (participant 9).

Both methods, protocol analysis and content analysis have pros and cons, but as long as we do not have the technology displayed in Steven Spielberg's 'Minority Report' movie, where thoughts could be projected on a screen for the behold of many, we will have to continue relying on the existing methods staying, to the best of our abilities, as close as possible to the data while making interpretations of it.

Finally, it has to be acknowledged that asking explicitly a designer to write down or sketch immediately after reading the brief whatever is in his head is not the most natural way of proceeding. Actually, the fact that the designer is explicitly asked to write his initial interpretation of the problem makes him commit his ideas on paper. We have proposed before that sketching or writing down ideas on paper makes more likely becoming attached to them. This could actually be the reason why the final concepts of some designers were indeed the very first one they sketched.

2.6 General Discussion

This chapter began by proposing that problem structuring or problem setting has three foundations: initial representation of the problem, the set of requirements and constraints (given or generated by the designer) and the information accessed. The objective was to explore these, first by observing the differences in the formulation of the initial representations and its effect on the final results, Second by making a first approximation to the problem of design requirements as a tool to structure design problems, and finally to examine the problems that might hinder the access and use of information as well as the impact the information accessed has on the results.

In this study, the observations made on the initial representations generated by the designers ranged from *abstract descriptions* of the problem to nouns or *actual names of objects* to be designed. A review of the literature reveals that this tendency to focus on problems or on solutions has already been acknowledged by other researchers, but based on retrospective accounts and not empirical observations.

Both problem and solution focusing strategies have positive and negative sides. Focusing on problems allows the exploration of a larger solution space (divergent thinking), the analysis of more contextual elements and focuses on situations more than on objects. However, this can cause difficulties to the designer. Having to manage a larger set of possibilities, designers are forced to organize and manage instead of carefully evaluating them. In addition, excessive problem structuring can be used as an excuse for doing any actual design work, and can sometimes be read as "I just don't know what to do". It could also reveal deeper difficulties, like problems understanding the brief.

Focusing on solutions can mean that having a concept to work with early in the process is reassuring. It can also help guide the process as it allows the designer to focus on more specific aspects. This strategy can respond either to efficiency concerns or to the need to avoid uncertainty in the process. Committing too early to a concept, though, has certain drawbacks. For instance, if problems appear latter in the process, it is much more difficult for designers to give up their concepts; instead, they will try to patch them to make them work. More so, having a concept to work on does not particularly encourage the use of information that might be available to the designer.

The use of design requirements, given or generated, as a tool for problem structuring could not be fully observed in this study. The results suggest, nonetheless, that there is a relation among the strategy chosen, the requirements and constraints generated and the quality of the results. The path followed to structure the problem by means of adding requirements and constraints serves as a confirmation of the strategy chosen.

Designers with a more solution oriented approach tended to produce requirements that are more specific, whereas problem oriented designers tended to produce requirements more general in nature that would apply to various solutions. This is an issue that requires more careful evaluation and discussion in future studies.

The access to information, its impact on the design process and the problems that might interfere with it was presented and discussed. It was observed that the access to information was influenced by a number of factors and that accessing information has a positive impact on the quality of the results.

From the Gestalt psychologist we know that three major problems can affect information processing whilst solving (design) problems: fixation, representation and transfer problems. In fixation, the designer shrinks the space in which solutions are considered. This prevents him from considering other alternatives and from accessing and applying information that is available to him. Transfer problems refer to the inability to translate knowledge from previous situations or new information to the current task. In representation problems, poor or incorrect representations of the problem can lead to inappropriate solutions, or no solution at all. A proper representation of the problem, on the other hand, can lead to an adequate solution more quickly.

The problem of fixation in design has received considerable attention by a small number of researchers, none of which has provided a satisfactory definition for it. In this chapter, we have proposed that there are at least two *forms of fixation* in design and that there are a number of *fixating* elements.

Perhaps the most visible form of fixation, or at least the one that has received most attention, is the early attachment to a concept, but designers can also become attached to certain kind of design representations, like impressionistic drawings and elaborate sketches. In this case, the designer attempts to maintain the attractiveness of the drawing at the expense of the design. In these particular cases of fixation, the fixating element is an *object*.

Another form of fixation is *procedural*. It refers to the tendency displayed by designers to adhere to a way of working, to a method. Although the data did not allow for an observation of this form of fixation, it has been observed in other studies (Fricke, 1993, 1996; Radcliff and Lee, 1989). Gestalt psychologists called these forms of fixation "mental set" and "functional fixedness" respectively.

The identified *fixating* elements, that is, the main factors that can cause the designer to become fixated, are the initial interpretation of the problem (the early representations), the use of language, and the inappropriate use of sketches. Other researchers have identified *precedents* or examples as another fixating element. In this form of fixation, designers' concepts mimic features of existing solutions. This has been called "fixation by exemplars". In our study, there are no reasons to believe that accessing documents containing examples of existing solutions had any fixating effect. However, other researchers claim that in certain design situations, such as stereotypical design tasks, designers tend to become fixated by examples.

Problem and solution focusing, as design strategies, have to be separated from the notion of fixation. The fact that a particular designer has chosen a solution oriented approach does not mean that such a designer will necessarily be fixated. Furthermore, a problem oriented designer could be fixated, but in a different way: focusing on problems instead than on solutions reveals perhaps fixation in a way of proceeding.

Fixation modes have to be separated from fixating elements more clearly. Designers can become fixated on (by) objects(mental set), and on (by) procedures (functional fixedness). These are *fixation modes*. Their own early concepts, preconceptions, impressionistic drawings, physical principles, methods, etc. can become *fixating elements.*

There are several fixation indications in the results of many of the participants but these cannot always explain the differences in the quality of the results. This can be interpreted in different ways. Fixation can be partial and temporal. Designers can 'fix' and 'un-fix' themselves several times during the process, or they can become fixated only on certain aspects, such as the solution principle (transporting the personal belongings every time a person comes to the office) but arrive at different solutions (a back pack, a trolley, etc.).

The total time spent in the information system did not correlate significantly with the quality of the results. However, individual information seeking behavior showed that participants who spent longer reading fewer documents performed better. This indicates that spending time *processing* the information has a positive effect on the quality of the results and that total time spent looking for information and the total amount of documents accessed are very poor measures. The quantity of documents accessed is also a quite inappropriate measure, for not all the information contained in those documents is carefully read and processed. The reasons behind the choice of using a document or not, or a part of it, or the reasons to consider a document relevant are of utmost importance for the development of proper information systems for designers.

Regarding the design process, a very visible difference in the sketchbooks was the amount of time devoted to problem structuring. In general, problem oriented designers were more willing to explore aspects of the design task, such as mobility issues, what it means to be flexible, what is personal and what 'personalize your space' means. They made extensive lists of what has to be transported when you move within and outside the office and in most cases, it was not until a lot of text had been written that they started sketching. This did not make a significant difference at the time of the evaluation of the results. Does spending much more effort and time on structuring the problem actually help improve the quality of the results? The answer we want to hear is yes, but the results show otherwise.

This does not imply that trying to structure the problem is not useful at all, but it raises interesting questions as why this happens. Were the 'winning' ideas of those solution oriented designers so good from the beginning? Or perhaps the problem oriented designers simply did not know what to do, and decided to continue exploring the problem space using this activity as an excuse for not doing any actual design work? Perhaps their *way of working* (analysis first, synthesis later) is obstructing their ability to generate more creative concepts.

The results also suggest that attachment to the early concepts will not always have a negative, limiting effect on the design results, as has also been expressed in the accounts of Utzon, Calatrava, the designers interviewed by Cross and Clayburn-Cross and by Davis and Talbot. Nonetheless, when our designers accessed and *processed* more information, the quality of their result seemed to improve. This indicates that whether designers chose a problem or solution oriented approach was less important to the quality of the results than accessing and applying the information that was available to them.

2.7 Further Studies

The study presented in this chapter allowed for a number of observations on the process of problem structuring, on the use of information systems and on the data collection methodology. It has allowed us as well, and perhaps that is the most interesting part, to identify issues that need to be addressed in the three aforementioned topics.

Regarding the problem structuring process, it is intuited that design requirements and constraints play a key role in structuring the design problem. This element was only superficially discussed in this chapter. There are two reasons for that. On the one hand, the setup of the study did not allow for a close observation of how designers used the generation of requirements and constraints during their process. The second reason is that we believe that this issue deserved to be treated separately, in a different empirical study. Chapter three presents a study in which eight groups of three designers each develop a list of requirements for two different tasks, the design of a system to transport luggage in a bicycle and the design of a walk-behind lawn mower, both to be used by elderly people. Such a study discusses how information is used to generate requirements and how identified requirements can act as triggers for information requests.

Regarding the access to information, we claimed in this study that the total amount of information accessed and *processed* was much more important that the strategy chosen by the designer (problem or solution orientation). We could not, however, make conclusions on how the accessed information helped them, what reasons they had to consider certain documents as relevant or how the information contained in such documents was actually used. This problems are addressed in chapter number four. in a study where ten individual designers face the same task used in this chapter. The focus of that study is, firstly, to observe if the results obtained regarding design strategies can be duplicated, secondly, to evaluate *why* or based on what criteria designers choose to use certain information and thirdly, to observe *how* the information they accessed and processed supported them in their design process.

Last but not least, the actual information systems used in the tests have to be reconsidered. The design of several proof-of concept systems will be addressed throughout the next three chapters.

3 Design Requirements

Abstract. *A remarkable characteristic of design problems is that there are no right or wrong solutions to them, just better or worse ones. The space in which solutions for a design problem can be found is a continuous one, whereas in many other types of well-defined problems, it is discrete, and often, binary. This characteristic is a consequence of the fact that design problems are ill-defined and underspecified. For this reason, active problem structuring is required. It was proposed in chapters one and two that problem structuring or problem setting, has three foundations: the initial representation the designer constructs of the problem, the set of requirements and constraints (given, or generated by the designer) and the information accessed. Chapter 2 emphasized the issues of the initial representations and the amount of information accessed whilst the present chapter focuses on the Design Requirements and the type of information accessed.*

3.1 Introduction

The design process involves the synthesis of solutions that satisfy a set of given requirements, but designers also put significant effort into altering and negotiating given requirements and *generating* new ones. During problem structuring, designers add requirements or re-formulate the problem in terms of the envisioned solution. This comes as no surprise, for the designer naturally interprets the problem situation through personal experience and biases. Reformulation of the problem can be done, for example, by changing the requirements or by manipulating the stakeholders' expectations.

Designers do this for several reasons. For instance, the designer can foresee, through his experience, that the goal set by the stake-holder will not produce the expected outcomes (e.g. in terms of functionality); he can then feel professionally obliged to point it out to the stake-holder. Another reason for the designer to change the problem situation, more human and frivolous, is to make it fit more closely into his expertise, knowledge and experience (Akin 1978; Ullman *et al* 1988; Goel and Pirolli 1992).

This manipulation of the design situation is possible because, in contrast with well-structured problems, the requirements of design problems are arbitrary and non-logical. Design requirements are either nomological (expressing basic physical laws of nature) or political, social, legal, economical technical etc. The latter constitute norms and conventions and can be negotiated whereas the former cannot. Even though nomological requirements restrict the possible solutions, they are non-constitutive of the design task. Moreover, the needs, intentions and requirements of the client and the solution itself are two different conceptual worlds (Meijers 2000) than can be manipulated separately.

Text books (Pugh, 1991; Sommerville, 1996, Sommerville and Sawyer 1997; Locopoulus and Karakistas, 1995; Beyer and Holtzblatt, 1998), standards (VDI 2221, 1986; BS 7373, 1998) as well as research literature (Kotonya and Summerville, 1998; Pohl, 1994; Robertson and Robertson, 1999; Ullman and Stauffer, 1988), suggest that the process of constructing a set of requirements is based on an incremental process, described as a cycle in which elicitation, analysis and validation take place. There are, though, a significant number of studies on opportunism in design (Visser, 1988, 1992; Lawson, 1997; Davies, 1991; Guindon, 1990), which seriously question the description of the process of constructing a set of requirements as a systematic process. Instead, these studies propose that such a process contains both systematic, incremental steps and abrupt changes in direction. Some authors like Maiden and Gizikis (2001, 2002) and Nguyen and Swatman (2003) propose that these changes happen as a consequence of sudden insight rather than of systematic deliberate effort.

The role of design requirements as elements of problem structuring has received very little attention and research in this area is scarce. Only a few authors like Lawson (1997), Mahler and Poon (1996) and Kruger and Cross (2001) have considered the issue. What is more, research on how the *sudden insight* Maiden and Nguyen mentioned is gained, or what makes the designer generate or alter requirements, is almost non—existant. For instance, Suwa and Gero (2000), one of the few that have researched the subject, based their conclusions on the observation of only one architect. The question of what triggers new requirements during the design process remains poorly described and discussed.

In their study, Suwa and Gero proposed, following Robbins (1994) and Goldsmith (1994) that certain aspects *discovered* by the designer in his sketches *triggers* the generation of new requirements. They show how sketches contribute to this process of 'invention' of design requirements and conclude that in about half of the design process there were bi-directional relations between the design requirements 'invented' and the 'discovery' of features in the sketches that were not intended when drawn.

More generally, it can be said that it is the generation of *alternative solutions* what triggers the generation of new requirements, and that aspects of these solutions expressed in sketches and drawings serve as mediators for the process. Designers then, use the tentative solutions generated to get a better understanding of the given design requirements and as they develop these tentative solutions, new requirements are generated.

A similar approach to Suwa and Gero's was followed by Dzbor (2000), who provided a knowledge-based tool to support the iterative process of developing design requirements. Both studies intended to provide empirical evidence of the anecdotical claim that in design, the problem and the solution evolve together.

This idea of the co-evolution of the solutions and the design requirements was exploited by Nidamarthi and Chabrakati (1997). They found, by studying the process of two designers working on a design brief, that these designers generate and use tentative solutions as a means to improve their understanding of the initial (given) design requirements, and that committing and developing these *tentative solutions* triggered new requirements. For their designers, the *solution-generated* requirements were much more influential in the problem solving process than the given requirements.

Tentative solutions are not the only triggers for new requirements. It was discussed above that contrary to what textbooks and research literature suggest, requirements are often generated as a consequence of sudden insight rather than as a result of a structured process. Aspects of these tentative solutions, when externalized (as sketches or utterances, for instance) can provide this insight. The study presented in chapter two suggested that information accessed could *also* provide this insight. Both, the alternatives generated and the information accessed acted as triggers for the generation of new requirements. It was concluded there that accessing external sources of information can also play an important role in the generation and negotiation of design requirements, and it was suggested that a closer scrutiny of the generation of requirements would provide a better insight into the process of structuring design problems.

Following those conclusions, two objectives for the study presented in this chapter were set. Firstly, to explore the interaction between the generation of design requirements during problem structuring and the use of external information sources. This chapter discussed the questions: What role does the information accessed play in the generation of new requirements? And, what role do new requirements play in the use of information?

Secondly, to examine the use of an information system that was particularly designed for this study. In this respect, this chapter questions what type of content is more accessed during problem structuring, what aspects of the interface need attention and what functionality should be included.

These objectives were pursued through a study in which a number of teams were asked to generate a list of requirements and a solution concept for a given design brief whilst having full access to an information system. The information seeking behavior of the participants will be fully described and discussed.

3.2 Second Study: The Bike Rack and the Walk Behind Lawn Mower

3.2.1 The Study

With the data collected in the first study, it was not possible to define which aspects of the information sought contributed to the generation of design requirements or if, on the contrary, it was the generated design requirements that drove the information seeking behavior. In this second study, the objective is to explore the interaction between generating and negotiating design requirements and the information seeking behavior of the designers. The information seeking behavior is evaluated using three different elements: techniques, strategies and type of information accessed.

The first element, technique, refers to how users access the information in the system. Two techniques are considered, namely browsing and searching. Both

Table 7 Participants in the study

		Level	Male	Female
Bicycle Rack	Bikes 1	Graduate	1	2
	Bikes 2	Undergrad	2	1
	Bikes 3	Undergrad	3	0
	Bikes 4	Graduate	2	0
Lawn Mower	Garden 1	Undergrad	2	1
	Garden 2	Undergrad	0	3
	Garden 3	Graduate	2	1
	Garden 4	Graduate	1	2
Total			13	10

reveal different approaches to information access. Browsing is exploratory. The user navigates through the information without a clear purpose, or just to become familiar with the type of content available; searching, on the other hand, is more focused. When searching, a user has to have a predetermined notion of what will be needed and what will be of relevance to the task at hand.

Strategies refer to whether accessing for information is structured or opportunistic. Structured access is the result of a process of defining the information needs prior to using the system. An opportunistic strategy is more of a *browsing to see what happens* approach. Finally, the type of the information accessed refers to the content of the documents accessed.

Participants

Participants in this study were 23 students from the faculty of Industrial Design Engineering (IDE) at Delft University of Technology, 11 graduate students and 12 undergraduates (57% males, 43% females). Participants worked in threes (with the exception of one team that was a pair). In order to reduce disruptions caused by having to work with unknown teammates, members of existing teams were invited to participate. They all had worked together on other design assignments for a period of about 17 weeks. The distribution of the participants by level of education, gender and assignment can be seen in Table 7.

The Design Assignments

As in the previous study, the design brief was formulated in such a way that it gives enough room for a variety of (possible) problem representations and a range of concept solutions. Since this study intended, along with the observations on information access and usage, to provide clues on how a brief is structured by means of generated design requirements, the design briefs had to be carefully worded. Little specific requirements were provided in the brief. The selection of the products was done on the basis that the products should be familiar to the participants and participants should not have previous experience designing this particular type of products.

Table 8 Information categories used in the information System

Bicycles	Gardening Tools
• Bicycles Accessories	• Gardening Elements
• Companies	• Companies
• Marketing and Economics	• Marketing and Economics
• How Bicycles Work	• Gardening
• Types of Bikes	• Types of Gardening Tools
• Norms and Legal Stuff	• Norms and Legal Stuff
• Bicycle Parts	• Component and Maintenance
• People and Lifestyles	People and Lifestyles
• Materials and Production Techniques	
• Ergonomics	
• Production Techniques	

Two assignments were used for this study, one a bicycle rack to transport luggage and the other a walk-behind lawn mower. Half of the teams worked on the bicycle rack and the other half on the lawn mower. The teams were divided so there were two undergraduate and two graduate teams working on each assignment (see Table 7).

The assignments given to the 'bikes' teams was 'Design a product for users aged 55 years or over that allows them to transport luggage on Giant Bicycles.' The assignment given to the 'garden' teams was to 'Design a walk-behind electrical lawn mower for users of 55 or more years of age'. Both assignments were expanded by a text of about 400 words with some information about the company for which the design should be made and the target group (see appendix 3.1 for the complete text of the assignment). The bicycle rack teams were designing for a real, well-known bicycle manufacturer in The Netherlands. The teams working on the lawn mower were designing for a fictitious company. The teams were asked to develop a list of requirements for the given assignment as well as a concept proposal.

The Information System

Similar to the study presented in the previous chapter, an information system was designed to be used by the participants. Since there were two different topics, two collections of documents were prepared in the information system. One collection, with about 250 documents, contained information related to bicycles and the other, with about 240 documents, contained information about gardening and gardening tools. In total, all documents added up to more than 2000 A4 pages.

The information system was developed over a LAMP platform. A LAMP platform consists of an Computer running an operating system (Linux), an HTTP server (Apache), a database engine (MySQL) and a scripting language (PHP).

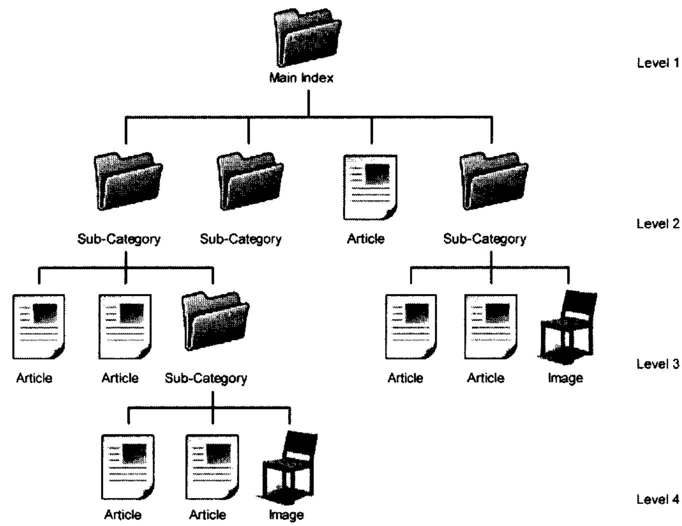


Figure 7 Levels of information in the CMS

The management of the content and the design of the interface were done using a Content Management System from Ez Systems (2003). The system was accessible using a familiar web based interface through a web browser (Mozilla). Chapter four contains more details about the technical aspects of the design and implementation of the CMS.

The documents were arranged in a tree-like structure, with a maximum depth of four levels (see Figure 7). This was decided to keep the structure as flat as possible. When the depth of the document tree is too big, navigation becomes difficult and the documents at the deepest levels are not accessed. It is possible to have any type of content in every level, i.e., it is possible to have articles, graphs and links to other (deeper) articles (see Figure 7). Out of the 240 documents on the bicycle collection, 29 were navigation pages. In the gardening collection, this proportion was 29/251.

Within this structure, the content was organized in categories as shown in Table 8. The choice of categories does not follow any particular logic. The idea was to make the information in the system as complete as possible; nonetheless, the information within each category is far from comprehensive. The information came from the web sites of renowned companies that manufacture bicycles, bicycle parts, gardening tools, components for gardening tools, etc. Other sources included graduation projects from IDE, books, materials selection software, ergonomics software and tables, gardening magazines, standards institutes, etc. All sources were carefully screened for the quality of the information they provided. All the content put in the system was collected with the assistance of five students. Part of the content on bicycles, came from a database developed by Christiaans and van Andel (1998) that was ported to the new CMS and updated with new articles.

Table 9 Number of documents of each type.

	Bicycle		Garden	
Product General	65	32%	69	31%
Product Specific	32	16%	46	21%
Users General	31	15%	29	13%
Users Specific	27	13%	37	17%
Comp. General	24	12%	41	18%
Comp. Specific	22	11%	0	0%

To evaluate the influence of the type of information accessed, the content of each document was assessed and given a content type tag. The tags used were Company, Users and Products. Additionally, each document was considered to contain general or specific information. In this way, information about the company for which the product is being designed is considered' company specific' and information about competitors, e.g., is considered 'company general'. If a document refered to other bicycle racks or walk-behind lawn mowers, it was tagged as 'product specific', conversely, if it refered to other bicycle accessories or other gardening tools it was tagged as 'product general'. Likewise, only information related to users of 55 years of age or more was considered 'users specific'. Examples of this type would be documents on arthritis, or accidents of elderly people.

The documents were read and tagged by two people that were not involved in the population of the database, this author and another faculty member. Differences in opinion were discussed and after agreement, documents were given a definitive place in one of the six categories. Table 9 shows the distribution of the documents in the database. About one third of the documents were in Dutch, the rest were in English. Since the lawn mower teams were designing for a fictitious company, there were no company specific information documents in their collection.

The search engine provided allows for a search on different types of documents (images, text articles, articles in the team's collection, comments, etc.). In addition to the navigation menu and the search engine, there was a full index of the collection of documents as another way to access the documents (see Figure 8)

Each user was issued a user name and a password so their transactions could be logged in the system on a per user basis. This identification token gave access to only certain areas of the system. In this way, participants working on e.g. the bicycle rack could only access information relevant to their topic. Some topics like materials and manufacturing process were, nonetheless, accessible to all participants. Additionally, this feature was used to allow members of the same team to collaborate while using the information system. A special folder was shared by all the members. When a member of a team found an article interesting, he could save this article in the team' collection. All members of the team could then access documents in the shared folder. The system then allowed the other members of the team to review those documents, creating a

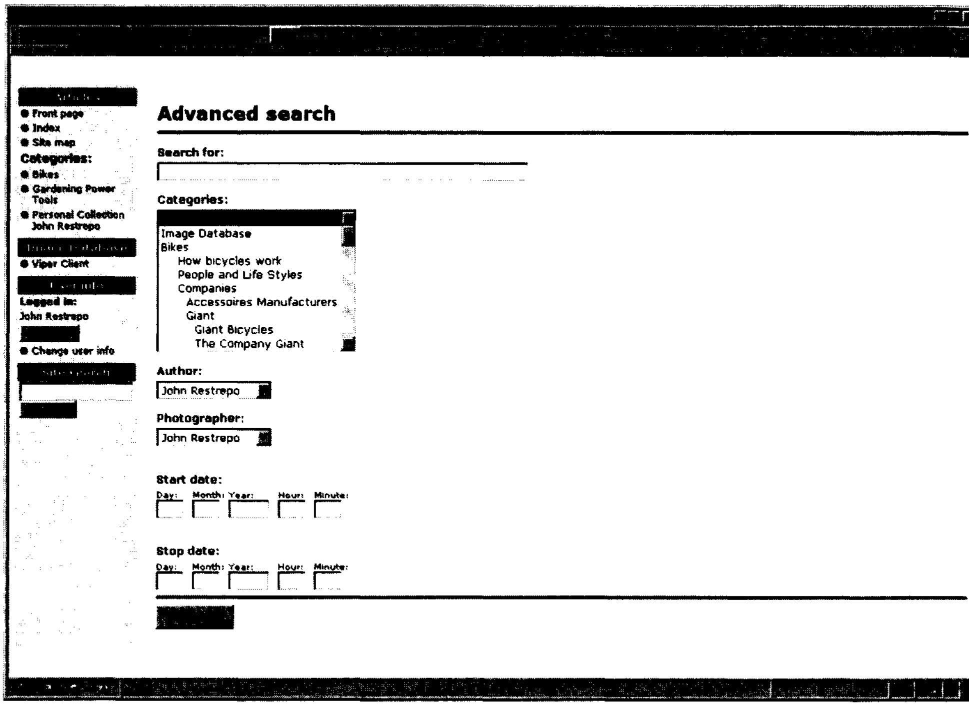


Figure 8 Screenshot of the search engine

tool for sharing information even when the team members were browsing the database in individual computers.

The information to log in the log files is also a key issue in the design of the system. Within the field of research on information use, one of the main difficulties is that proprietary software limits what can be logged. For this study, the selection of the CMS was by large influenced by the fact that it was possible to modify the source code to generate the log files in the format needed. A particular condition was to allow further automatic (statistical) analysis of the log files minimizing the amount of parsing required.

There were five different transactions possible in the system. Access to a navigation page (NaviPage), access to an actual document (ViewPage), searching, adding a document to the team's collection (Add2My) and reviewing a document from the collection (ViewMy). The log files contained information about every transaction, including the user ID, Group ID, total time spent in every transaction, type of transaction, link to the document and number of results if transaction was a search. Additionally, some information about the accessed documents such as its position in the system (level), text/graphs ratio, type of document (image, article, etc.) and type of content (Product, User or Company general or specific) was also logged.

A final consideration in the design of the system was the placement of articles in the categories. In the previous chapter, the possibility was suggested that 'typi-

Table 10 Where do requirements come from? The assignment, the Information System or the concept alternative con-sidered. The origin of some requirements is unclear.

	Assignment	Info. Syst.	Alternative	Undeterm.	Total
Bikes 1		3	9	6	18
Bikes 2	3	4	8	3	18
Bikes 3	2	7	15	8	32
Bikes 4		3	6	5	14
Garden 1	2	8	12	4	26
Garden 2	3	7	10	6	26
Garden 3	1	4	11	4	20
Garden 4	2	6	32	7	47

cal' industrial design information was accessed more than 'contextual' information because it appeared first in the menu. A great effort was put into the distribution of the six types of content throughout the structure of the system so that the effect of having one type of information appearing first in the menus would not introduce bias when controlling the total amount of information of each type accessed, as happened in the previous study.

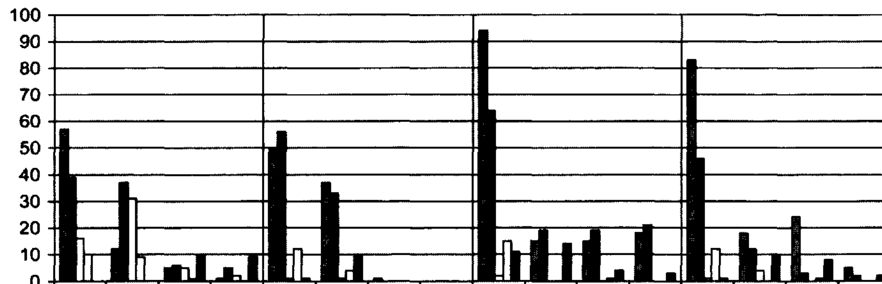
Procedure

The study was conducted in half-day sessions. Each team spent 4 hours working on the assignment. For these sessions, a research space was set up in one of our laboratories. Each participant had access to a computer. All of the computers were arranged in such a way that communication and interaction among the each designer was still possible. Additionally, there was a table with sketching material (markers, paper, etc). Participants were instructed to make use of the computers individually but to work on the development of the list of requirements and the concept as a team.

The session started with a short introduction in which the participants were informed about the activities. Then, each participant received a copy of the assignment and had a few minutes to read it. In the assignment, besides asking them to develop a concept for the given brief, they were explicitly asked to prepare a list of *requirements*. This was followed by a demonstration of how to use the information system.

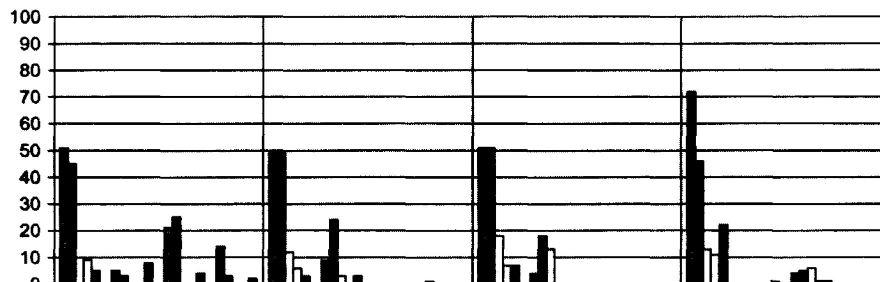
After this, all teams started working for two and a half hour segments with a quarter of an hour break in the middle. The session was closed with a 20 minutes interview. During this interview, questions about their background and previous experience with the given assignment were asked. The usage of the database, the content of the information and the usability of the interface were among the aspects discussed. Appendix 3.2 contains the research protocol that was followed.

Transactions Bicycle Rack Teams



	Bikes1 *				Bikes 2				Bikes 3				Bikes 4*			
	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q
■ navipage	57	12	5	1	50	37	1		94	15	15	18	83	18	24	5
■ viewpage	39	37	6	5	56	33			64	19	19	21	46	12	3	2
□ search	16	31	5	2	1	1			2				1	4		
□ add2My	10	9	1		12	4			15		1		12		1	
■ viewMy			10	9	1	10			11	14	4	3	1	10	8	2

Transactions Lawn Mower Teams



	Garden 1				Garden 2				Garden 3*				Garden 4*			
	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q	4th Q
■ navipage	51	5	21	14	49	9		1	51	4			72		4	
■ viewpage	45	3	25	3	49	24			51	18			46		5	
□ search					12	3			18	13			13		6	
□ add2My	9				6				7				11		1	
■ viewMy	5	8	4	2	3	3			7				22	1	1	

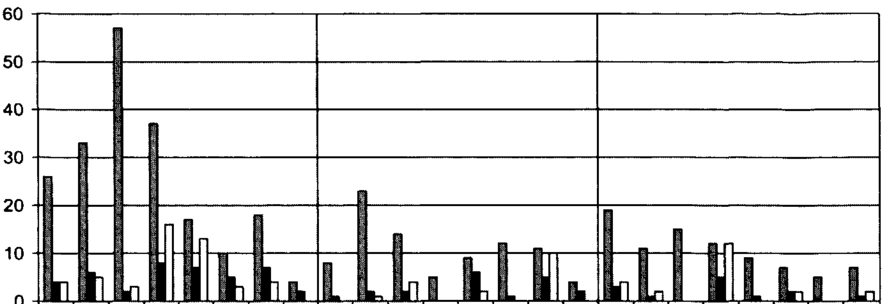
*Figure 9 Transactions by all teams detailed by quarters. Each quarter is about 45 minutes long. Groups marked with an * correspond to graduate students.*

3.2.2 Results: Generation of Design Requirements

Strategy

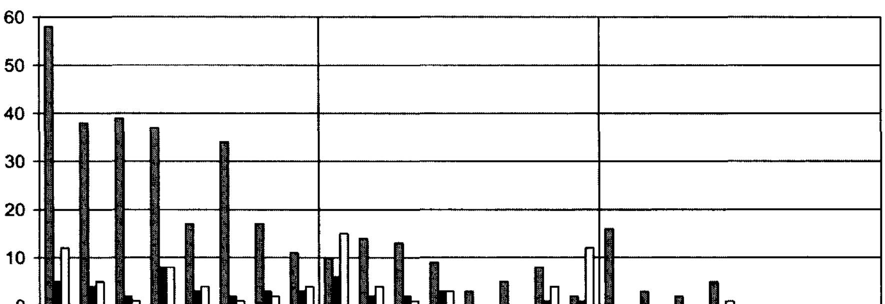
Observations of the first 30 minutes of the tapes reveal differences in the way the problem was approached by the teams. Teams Bikes1 and Garden3 started with a discussion of the important aspects to consider in a very broad

Bicycle Rack Teams



	Product								Users								Company							
	General				Specific				General				Specific				General				Specific			
	B1*	B2	B3	B4*	B1*	B2	B3	B4*	B1*	B2	B3	B4*	B1*	B2	B3	B4*	B1*	B2	B3	B4*	B1*	B2	B3	B4*
▩ viewpage	26	33	57	37	17	10	18	4	8	23	14	5	9	12	11	4	19	11	15	12	9	7	5	7
■ add2My	4	6	2	8	7	5	7	2	1	2	2		6	1	5	2	3	1		5	1	2		1
□ viewMy	4	5	3	16	13	3	4			1	4		2		10		4	2		12		2		2

Lawn Mower Teams



	Product								Users								Company							
	General				Specific				General				Specific				General				Specific			
	G1	G2	G3*	G4*	G1	G2	G3*	G4*	G1	G2	G3*	G4*	G1	G2	G3*	G4*	G1	G2	G3*	G4*	G1	G2	G3*	G4*
▩ viewpage	58	38	39	37	17	34	17	11	10	14	13	9	3	5	8	2	16	3	2	5				
■ add2My	5	4	2	8	3	2	3	3	6	2	2	3			1	1								
□ viewMy	12	5	1	8	4	1	2	4	15	4	1	3			4	12				1				

*Figure 10 Viewing and adding transactions for all teams specified by type of contents. Groups marked with an * are graduate students.*

way (client, user, racks and gardens) and began browsing the database. Each member of the team had the task to search on one of these topics. As they go through the database, they mention to each other elements they consider interesting and that might add to the list or requirements, but not in an explicit way (like committing it to paper). Examples of what they mentioned are the identity of the company (young and sportive), forces needed to ride a bike and the maximum force a 55 years old person is capable of exerting (arthritis). Only after having spent 40 minutes collecting information did these two teams start working on a concept. Both teams devoted the last half hour of the available time to compose the list of requirements, but this was *after* they had decided upon a possible solution.

Other teams, like Bikes2, Garden2 and Garden4 started discussing the initial list of requirements given in the design brief and some *possible solutions*. Later they began to browse the database. After about 20 minutes of browsing, they started working on the list of requirements *along* with the proposed solutions.

Explicit vs. non Explicit Requirements

A list of requirements for the given brief was explicitly asked for in the assignment, together with one or two concepts. It was expected that the teams would devote an important part of their time to writing a formal list of requirements. These expectations were not fulfilled. In most cases, the teams were more focused on the generation of alternative solutions and an explicit list of requirements was relegated to a second plane.

This does not mean that the teams did not *generate* new requirements during the process. They simply did not commit all of the generated requirements to paper. Sketching and designing a concept had priority over the list of requirements. In general, the process of *discussing and generating* new requirements was always associated with the developments in the alternatives being created.

Nature

The nature of the requirements generated also varied among the teams. There are requirements that refer more to what a solution looks like instead of expressing characteristics a possible solution should have. For instance, Bikes3 wrote, *"The click mechanism should be safe for hands and fingers"* whereas Bikes2 wrote, *"the accessory should be attachable without the use of extra fitting elements (a screw, for instance)"*. The former looks more like an extra condition to an already devised solution (a click mechanism). The latter gives more room for a wide range of alternatives.

Information Accessed

The tapes were analyzed more closely at those points were new requirements were generated. Such an analysis reveals that requirements come from different sources, namely the assignment, the information accessed in the database and the concept being sketched (see Table 10). An interesting point is that all the teams generated about the same amount of requirements, with the exception of Garden 4, which generated about twice as much as the average of the other teams.

A few requirements were transcribed directly from the assignment. Though there were very few explicit requirements in the assignment, a few were indispensable. For instance, those referring to the target group or to the type of product to be designed. However, these correspond to very few of the total requirements generated.

Some of the requirements were taken directly from documents in the information system. For instance, Bikes2 that *"it is desirable that the product do not give the impression that is was specifically designed for old people"* and Bikes3 *"the product cannot look as if specifically designed for elderly people"* This was explicitly stated in a document titled "Barriers for the acceptance of products by elderly people".

From the videotapes, it could be seen that these requirements were generated *always* after the access of a document containing the referred information. For instance, Garden3 wrote as a requirement that *"the lawn mower should comply with norms NEN3418 and 3419"* immediately after having seen the "Norms and Legal Stuff" folder. When questioned about specific cases during the interviews, participants mentioned that particular documents reminded them of issues they would otherwise not have considered. Other examples of the usage of particular information include the use of NEN norms for specific values, like the maximum permissible noise level for a lawn mower (Garden1, Garden2 and Garden3) or the maximum width of a bicycle with accessories (Bikes2).

Sometimes, teams accepted the information in the system with very little consideration as to its correctness or appropriateness. For example, Garden2 and Garden 3 proposed walk-behind cordless lawn mowers. However, both teams wrote in their list of requirements that *"the electric motor should deliver 5 H.P."* (Garden2) and *"it should have a 4.5 H.P. motor"* (Garden3). It seems rather exaggerated having such a big electromotor in that kind of product. Moreover, there are specific norms (available in the system) that limit the maximum power in such types of lawn mowers. Both teams took those values from a document that gave guidelines for the selection of gasoline-powered mowers

The information in the system played an important role in the generation of new requirements. However, most of the requirements came during the generation of alternative solutions (See Table 10). These results echo the ones presented in chapter 2 in this book and the results presented by Suwa and Gero (2000). Although as previously mentioned, some requirements are written to fit a particular solution, particular solutions also serve as triggers for general requirements. Examples of this are the sketches by Bikes3. While sketching an alternative solution consisting of a backpack with a mechanism that allowed the user to *click* fit it to the bicycle rack, they wrote in their list of requirements that *"the carrier should look as an independent product".* Though this was meant to be a requirement for the backpack solution, it can also be applied to other alternatives (like the little trolley of Bikes1).

Use of Language

The use of language also played an important role. For instance, when discussing safety, one member of team Garden1 mentioned, *"it should never be possible for the user to get in contact with the rotating knife".* For them, a blade (or knife) became the only alternative. This was not so for all the other teams, for they discussed several options for cutting the grass, including nylon strings. Similar observations were made in other teams, e.g., Bikes3 referred to their product as *"the system"* or *"the product"* in the beginning of their discussion. Their requirements always start as *"the product should not have a hip appearance"* or *"the price of the system [...]"*(Underlining is ours). However, when one requirement was mentioned *"minimum 30 liters must be transported in the container"*, all the new requirements generated made reference to a sort of container: *"container should be water-proof; corners must be marked with reflectors; etc."* This was a turning point in their process. They moved from detachable backpacks and panniers to a 'skis box' like product that eventually was their final solution. Indeed, a sort of *container*.

3.2.3 Results: Information Access

The information seeking behavior of the teams was explored from three different angles. Firstly, an analysis of patterns of usage, i.e., what techniques were used and how they changed during the sessions. Secondly, an analysis of the type of content that was accessed and thirdly, certain aspects of the functionality of the system were considered.

Since all the teams were instructed to browse individually, but to work as a team, and since there were tools in the information system that allowed them to cooperate, all the transactions were aggregated and analyzed on a per team basis. There are, however, some aspects of individual behavior worth highlighting.

Individual Differences

The first aspect is that, just as in the previous study, all designers started browsing through the system almost immediately after having received the assignment. This browsing, as in the previous study, is a more or less systematic exploration of the categories and subcategories in the menus as the links are followed in order of appearance. Such behavior can be explained by the experimental design. Having asked them to make use of the information system provided *forced* them in a way to become familiar with the interface and with the information it contained.

The second issue is that all designers accessed about the same amount of documents throughout the whole session (about 30). The exception were users garden24 and garden13 whom, though encouraged several times to use their own computers, decided to browse together with another team member. For the analysis and display of the data, the total time spent in the design assignment was divided in four segments of about 45 minutes each. The totality of valid transactions, disaggregated by group and by quarter can be seen in Figure 9.

Teams` Strategies

An interesting fact regarding the approach to the assignment was the way groups Bikes1 and Garden3 organized their process. In both groups, they discussed *before* starting to use the system what information they considered necessary to complete the assignment, and divided the identified topics amongst the members. This planning lead to significant differences in their use of the information system, as shown in Figure 9. Note the higher occurrence of search transactions in these two groups.

In the same figure, it is visible that when the search engine was used more, the amount of navigation pages decreased and the amount of documents added to the team's folder increased. What this indicates is that searching produces results that the team consider useful faster than simply browsing.

Techniques

All the groups started by accessing a high number of navigation pages. This relates to the fact that all individual members of the team started exploring the system very quickly in order to become acquainted with the information available. The rather large amount of navigation pages used, compared to the number of actual documents accessed, is an indication of an exploratory, unstructured browsing. In the subsequent quarters, though, this behavior changes. The number of documents accessed per navigation page used is significantly higher, as is the use of the search engine. Browsing becomes less explorative and more structured: *"lets find information about our target users"* (Bikes23) or *"go and see what standards we must comply with"* (Garden23). This change in behavior can be seen in Figure 9.

For all groups, the total amount of transactions declined steadily from the first quarter. In fact, some groups did not use the information system at all after the second quarter and when they did, they searched for specific issues using keywords or went back to the documents previously saved in the team's collection.

Type of Content

In order to establish what type of content was being accessed, all the documents in the database were tagged before the study. Each document was tagged as pertaining to one of three categories (Product, Users and Company) and assessed as containing general or specific information (See Table 9). Figure 10 shows the amount of documents of each type that were accessed, saved and reviewed by all teams.

The difference in the access to specific or general information about companies and about users is not very significant. The teams do not show a strong preference for either general or specific information in these categories. Note that since there was no specific information about companies in the gardening section, the lawn mower teams do not have transactions on this type of documents.

In the case of products, which is by far the most accessed type of information, the difference between specific and general is very visible. For this type of document, designers had a strong preference for general information. In fact, access to general information about products account for nearly half of all accesses to the system, even though these represent only 30 percent of the total of documents in the bicycles and gardening databases.

Even though there were 32 documents on examples of saddle bags, panniers and other devices and mechanisms to carry luggage in bicycles, designers seemed more interested in documents about bicycles in general, other bicycles accessories like lamps, and components such as brakes and pedals. In the case of the garden teams, there were 46 documents with examples of lawn mowers, most of which were walk-behind lawn mowers. However, designers were more interested in leaf blowers, hedge trimmers, branch shredders and other gardening gear.

Collaboration

The system was fitted with a mechanism to allow collaboration among the team members (the add2My tool). Figure 10 also shows the use of this tool. All users used the tool, with the exception of user garden32 (users garden 13 and garden 24 also did not use the tool themselves, but they were working on the same computer with a team mate). With very few exceptions, the documents added to the teams' collections were reviewed at least once, and in 87% of the cases, by someone different from the person who added it. All users, except one, added documents to the team's collection and most (19 out of 23), reviewed more documents from the team's collection than they added, showing that users were indeed reviewing not only their own documents, but also documents saved by other team members. This indicates that the team members were cooperating with each other and that the tool is a valuable addition to the software.

3.2.4 Discussion of the Results

Generation of Design Requirements

As mentioned before, the expectations were that the teams would generate a rather elaborated list of requirements for the given design briefs, since this was one of the things asked for in the assignment. However, this expectation was not fulfilled, not because they did not generate and discuss requirements, but because they did not explicitly present them in a systematic, orderly manner as expected.

The results very much contradict what is preached in methodology textbooks and in research literature. The process of generating requirements was neither smooth nor incremental. Instead, it involved both incremental steps and radical re-organizations. In very few cases did active debate among the team members result in a new requirement.

These rapid changes in direction and modification of the initial requirements happened in most cases as a result of sudden insight rather than of systematic effort and debate. Though insight often involves surprise, it cannot happen purely by chance (Mayer 1992). Suwa and Gero proposed already that this sudden insight can be a consequence of *discovering* unintended features of the product whilst sketching, once the ideas are visualized in drawings.

Our observations show that external use of information can also produce this *insight* that on several occasions resulted in new requirements. For instance, when team bikes2 wrote their requirement about the product not looking as if specifically designed for elderly users, this was information that was literally taken from a document in the database. During the interviews, the participants mentioned this document specifically and said that they would not have thought of the requirement had it not have been suggested in that document.

The dynamically generated requirements are used by designers to express what they consider the most important aspects of the design brief. This creation of design requirements *on the fly* seems to be triggered by prior knowledge or by knowledge acquired during the design process. Knowledge can be acquired during design by interacting with the designed object (Schön 1983) or with external sources of information.

Design requirements, like drawings and sketches, are powerful means for the exploration of the solution. On the one hand, requirements act as anchors for the design problem, helping reduce uncertainty and on the other, they allow for a description of possible solutions. In this sense, requirements serve as a bridge between the client and the designer and between the problem and the solution.

The access to information on the database was not, in most cases, motivated by a particular need for information. The requirements that show direct relation with information in the database were generated when, inadvertently, a user came across certain information that reminded him of something. Not all the accesses to the information system resulted in new requirements nor were all of them motivated by already generated requirements. The use of the system was opportunistic, rather than structured and motivated.

There are interesting examples of exceptions to this. For instance, team bikes3 needed to know how wide the accessories on the bicycle could be. They looked for this information and since they could not find it, arbitrarily used a value of 0,4 m. Something similar was mentioned by Bikes4 during the interview. Only team Bikes1 used the correct value (0,75) but not because they were looking for it, but because they *accidentally* found the correct value in a standard.

Some teams, like Bikes2 and Garden3 showed a lot of confidence in their own knowledge. Soon after having started reading in the database, they had the impression that they had read the whole content of the database and decided not to use it anymore. During the post-interviews, it was evident that a lot of the information in the database was unknown to them. They gave as a reason that they thought that the *design* of a product was much more important than re-formulating the brief, generating a list of requirements or getting more information about the assignment.

Information Access (Techniques)

Two different *techniques* to access the information in the system can be seen. On the one hand, there is browsing, a technique of navigating through the system following either an explorative or an organized, structured pattern. In the beginning, it is understandable that browsing is explorative. This can be seen in the very high amount of navigation pages accessed before actually opening a document. In this pattern, the user becomes familiar with the system and with the information that is available to the team. A systematic, organized browsing technique will require of the user little navigation before finding the required documents.

The second *technique* is searching. Searching, as an effective technique to finding information, is more complex. It requires the user to have a predetermined notion of what information is required to perform the task. This predetermined notion relies on the user's internal and existing knowledge of the subject area and an understanding of the situation.

The results back up this statement. For instance, Bikes1 and Garden3 have a significantly higher number of search transactions than the other teams. These two teams took the time to identify the information that would be needed and divided the topics amongst their members.

Organizing the teams' work and planning what to search for made them more able to make use of the search capabilities of the system. Conversely, the other six teams did not make the effort of defining such a goal; they had to rely on what occurred to them during browsing.

As the team progressed in their assignment, becoming more familiar with the system and with the brief, browsing became more efficient, because less navigation pages were necessary to access a document. Additionally, users tended to continue accessing documents of the same type for longer periods. Switching less between categories indicates more focused browsing.

Information Access (Content)

Differences in the type of content accessed reveal very interesting facts. When the information is about users or companies, there is little difference in the amount of general or specific information accessed (with a slight preference for specific information). During the interviews, designers pointed to the fact that the information in the system was too limited, and that even though they wanted to access information about some other products they were familiar with, that information was not available. One participant said, *"For my luggage carrier, I thought about using wheels, like those used for inline skates. However, there was no information about skates, or any other product that was not bicycle related in the database"* (user Bikes11).

These three observations on the type of information strongly suggest that designers need more than just precedents of the same products they are designing, for part of their struggle is to come up with *different* ideas. What is required is a mechanism to provide them with strong support to satisfy their needs for information about a wide range of existing solutions to particular sub-problems. Solutions that come, very often, from similar products, but more inspiringly, from apparently unrelated domains. A highly accessible collection of products could provide this kind of support. Chapter 5 discusses the design and implementation of such a system.

Timing

Access to the system decreased steadily as the session progressed. The designers concentrated on collecting information at the beginning of the session (1st and 2nd quarters). The rest of the time was used primarily for brainstorming and development of the list of requirements and the concept. However, further accesses to the system made use primarily of the documents saved in the teams' collection and on searches for specific information. The access to the system was therefore more selective and focused. The reason for this could very well be a function of the design education received at the faculty. Their training is based on analysis first, synthesis later. This is reflected in their way of proceeding and in their usage of external information sources.

Use of the Search Engine

The keywords used to search the database also provide valuable information. Since there were documents in Dutch and in English, users very often tried keywords in both languages. After filtering out duplicates (same word used several times or in different languages) and misspelled words, the total amount of keywords used is very low (39 in 128 searches, out of 1713 valid transactions). This can be read as an indication of either poor domain knowledge and/or a very poor design vocabulary. Obvious words like elderly, bicycles or grass, which were given in the brief, hardly qualify as 'knowledge' of the 'domain'. A third reason is, of course, that they did not know what to look for.

Relevance Indicators

Literature suggests that saving or printing a document is a good indicator of the importance a user might have given to it (Song *et al* 2002). A review of the most added documents (add2My) and the most reviewed ones (viewMy) reveals that documents containing information about products in general score higher than the others do.

The total amount of time spent in (reading) a document has also been suggested as an indicator of relevance. However, as the length of the documents range from 0 (only images) to 1946 words, a different measure needs to be used.

The reading speed of a student from university should be around 300 words per minute (Taylor Associates, 2004). Assuming than reading from a screen is more difficult than reading from a book, a threshold of 250 words per minute is considered appropriate. In exactly 50% of the Add2My transactions, the user spent sufficient time reading an article to pass the 250 wpm threshold. This value is significantly high, as the totality of the documents added to the collection was re-read later. Moreover, the documents in which participants spent the longest were the ones retrieved from the team's collection at the end of the session.

Adding documents to the collection and the time spent in the documents can both be good indicators of relevance. However, these indicators cannot explain *why* the document was considered relevant. Chapter 4 discusses the criteria used by designers to assess the relevance of documents.

Usefulness of the Information System

During the interview, the focus was on the content, the usage, the format of the information and the system itself. Three of the eight groups discussed that using the system, as it is now, limits the creativity of the designers. The information contained is too brief and too condensed. A user mentioned that should they have not had the database, *"I would have gone to a shop to buy four magazines"* and another said *"when browsing a magazine you can find information that you could never find in the database. These things can to a great extent stimulate the process"*. Bikes4 referred to the analysis phase as *"searching for something you cannot describe"* This makes the database not very useful for innovative projects *"because its content is very close to the design brief"* (Garden 3)

However, the teams said that the database was very useful for analysis. It is a compilation that contains the kind of information that is otherwise very difficult to find, like technical details, ergonomic data, target groups profiles, etc. One disadvantage is that the documents were collected by someone else, and the content is therefore decided by what that person thought was important. *"You have to trust the thoroughness and good criteria of the compiler"* (Bikes 3). Users should be able to add constantly their own content.

Some of the examples in the database were, according to the designers, inspiring, though often those examples were not related to the assignment. For instance, team Bikes2 reported, *"after having seen a trolley with wheels, we decided to use wheels on our designs as well. We would have liked to have more images of products other than bikes."*

The Information System

Since the users were not very familiar with the interface, it took them some time to get used to it. However, the fact that it uses a standard, familiar web browser to display its front end helped. This might also explain why navigation seems quite unstructured in the beginning of the sessions.

The add2My facility was very well received. Participants perceived it as a *"very good way to communicate with your team mates. You do not need to discuss constantly what to do because you can keep track of what they are doing by looking at what has been added to your collection"* (Garden2). However, a common complaint was that not all the content in a document is important. When a long document containing a small piece of important information is added to the collection, the other members of the team cannot realize immediately *why* that document was added or considered important. They suggested that it would be good to allow users to make composite summary documents with snips from other documents.

Lastly, providing an information system together with the brief generated high expectations in the users. This can lead to frustrations when they, e.g., cannot find a particular piece of information or when the use is not rapid. Sometimes users even stopped using the system because it did not meet their expectations (Bikes2)

3.3 General Discussion

Before this study, the expectation was that both tentative solutions and new requirements would motivate designers to access more information. This expectation was based on several studies with professional design engineers that have shown that information is requested when the designer becomes *aware* of a lack of knowledge, but more often, to complete or *confirm* facts that arose during the design process (Hertzumand Pejtersen, 2000, Kuffner and Ullman, 1991, Fidel and Green, 2003). This expectation, however, was only partially met. Instead, the information on the system was used primarily in an opportunistic way. That is to say, it was the information accessed in the system what triggered new requirements.

More than acting as a means to further explore an issue, or to complete or confirm facts, the information accessed by the designers acted in providing the insight that sketches did in the studies of Suwa and Gero (2000), Dzbor (2000) and our own, reported in chapter 2 of this book.

The information accessed in the system was used to stimulate the creative side of the process, and influenced the way designers perceived the *ideal* solution, leading in some cases to new requirements. In a few cases, nonetheless, designers did consult the system to verify the appropriateness of a new requirement, or to look for specific values (like the maximum width of a bicycle or the required power to cut the grass), but it was the tentative solutions what triggered most of the new requirements. The information system was used mostly when the designers did not have a solution to work on and when they did, the system was almost forgotten. The expectations were that the information system would provide them with some sort of inspiration. Having a concept to work on did not particularly encourage the use of external sources of information.

Although having specific *factual* information can serve to support decision - making during conceptual design, the decisions made during this stage are rarely of such a nature as to require very specific information. For instance, the documents containing information about materials, manufacturing processes and costs were hardly used. Conversely, documents with information about products accounted for more than half of the total accesses to the system. Information about *precedents* is more accessed and deemed as more useful by the designers in our study. Our designers said that information on unrelated products can act as powerful inspiration sources for their designs.

One interesting aspect that appeared in the results was that our designers were willing to accept and use information in the system even in those cases where the information was incorrect or inappropriate. Their lack of experience and general knowledge can possibly be blamed for this. However, the fact that the system was considered an authoritative source played a very important role. A strong factor in the assessment of the relevance of information is the level of confidence in the source. This has been confirmed empirically in several studies (Hertzum and Pejtersen, 2000; Choi and Rasmussen 2002).

The system was fitted with a search engine that was hardly used. It was proposed that in order to search, the user has to have an idea of what to search for. In our study, this was hardly ever the case. During the interviews, one of the participants defined the analysis phase of the design process as *"searching for something you cannot describe"*. This difficulty is not unfamiliar to most users that have used search engines and it might explain the low usage of the search engine in the system.

If what the user is looking for is more abstract, such as an example of a particular product with a particular form, material, or color, the problem is even bigger. Even in the case where such examples can be completely and accurately described, not being certain about what to look for would make very difficult to find the right example. One user mentioned the he would just go to browse through magazines until he found what he was looking for. Many designers said that they do not know what they are looking for until they find it. This process of searching for something you cannot describe is time consuming, inefficient and frustrating but can, at times, serve as a powerful means to generate novel ideas.

Knowledge encoded in products speaks more to designers than knowledge encoded in words or tables, but searching for this type of content is difficult. An ideal system would allow a flick-through-four-magazines kind of browsing with a more oriented search. The design and implementation of such a system is the center of discussion of chapter 5.

A last word in this general discussion goes to the data collection and data analysis methodology used in the studies presented in chapters two and three. The measures used to assess information use proved to be inadequate. The amount of documents accessed or the total amount of time spent in the system are not accurate indicators of the actual amount of information effectively considered and used. This happened because the source of these data was the log files in the computer. Log files reflect, but do not explain behavior. We can observe what documents, in what sequence and for how long they were accessed by the designers, but we cannot explain the designer's purpose, whether the document was actually read and comprehended or if the information was actually used. For this reason, the data collection methodology to be used in the next study has been re-designed.

4 Assessing Relevance : Designer´s Perception of Information Usefulness

Abstract: *This chapter focuses on the criteria used by the designers to assess the relevance of accessed information. It proposes that relevance judgments are cognitive, situational and dynamic: that they depend on the designer's previous knowledge and understanding of the situation, on the particular information needs to perform a task and that they change as the designer progresses in the information seeking process. It shows, through an empirical study, how these relevance criteria are used in determining the usefulness of information, and discusses how this information is used in the design of a flexible workspace.*

4.1 Introduction

The issue of information processing in design has been important in the studies of design cognition. If we consider design as a problem solving activity, we must necessarily think of it as an information processing activity (Newell and Simon 1972). This makes it difficult to separate the studies that refer specifically to the accessing and processing of information in design from the rest of design research. For instance, Eastman (2001) uses the term "design cognition" to refer to the study of "human information processing in design", covering a large number of issues such as problem structuring, design representations, sketching, knowledge structure, etc.

As has been stated previously in this book, one of the cornerstones of problem structuring is information access. Choices made by designers depend on their understanding of the problem and its context, on their ability to structure both problem and context and consequently, on their success in obtaining proper information about the problem and about the context (Hertzum *et al.* 2000).

Eastman (2001) proposes that a designer's conception of a design and its context is built up over time, using information from the designer's existing knowledge and experience, and from external sources of information. However, designers tend to favor and to rely more on prior knowledge and experience than on external sources of information, either because they are not aware of the information they might need or because they are not motivated to consult the external sources. This lack of awareness (Cross et al., 1994; Court, 1997) produces as a result many designs being generated without the benefit of information that does exist and that is available to the designers.

The information seeking behavior of designers, and in particular of engineers, has been studied for at least 30 years, yet the results of these findings do not constitute a consistent body of knowledge (Pinelli, 1991; Pinelli, *et al* 1993).

The literature is fragmented and dispersed in a number of publications in different disciplines that have shown interest in the subject. For instance, cognitive neuroscience (Goel and Pirolli, 1992), mechanical engineering (Ullman, 2002; Court, 1997; Court *et al* 1997, 1998, engineering design (Hicks *et al* 2002), new product development (Szykman *et al,* 2001; Rodgers *et al,* 2001), educational science (de Vries and de Jong, 1997), Knowledge Management Systems (Ahmed *et al,* 2003; Wallace *et al* (2004), Artificial Intelligence (Song *et al.* 2002) and Information Science (Hertzum and Pejtersen, 2000; Fidel and Green, 2003; Majumder, *et* al, 1994) to cite only a few.

All of these studies have concentrated on a limited number of issues: the nature of the problem spaces and the information required to specify them (Goel and Pirolli, 1992), the requests of information by design engineers (Kuffner *et al* 1991), the effect of information technology on new product development (Court, Szykman, *et al,* 2001; Rodgers, 2001), information sources used by design engineers (Court *et al,* 1998), information management (Majumder *et al,* 2004), documenting the design process (Rittel and Weber, 1973), accessibility of the information (Hertzum *et al,* 2000), the structure and format of the information (de Vries and de Jong, 1997), the information-seeking behavior of design engineers (Pinelli *et al,* 1993; King *et al* 1994) the accessibility of the information (Hertzum *et al,* 2000), sketching and systems to support sketching (Goldschmidt, 1991; Gross, 1996)

Ullman, Curt and Culley (1998) have studied the information requests of mechanical engineers since the late 80's with the intention of establishing the requirements for the ideal information system for mechanical engineers; and Pahl and Beitz (1984), Rzevski (1985) and Rouse (1986) have tried to determine how to measure the usefulness of information in design engineering. They have proposed that such measures can be categorized in the following areas: medium and format of presentation, location of delivery (accessibility), timeliness (availability), accuracy, relevance and cost. Medium and format refer to the delivery method (computer system, paper, etc.); accessibility is a subjective measure of the effort that a designer needs to make in order to access such an information source. Relevance is the perceived degree to which information meets the designer's information needs, that is to say, the perceived usefulness of a retrieved document. This chapter focuses on relevance as perceived and judged by the designers when interacting with computer based information systems.

Research in the field of information access by designers and engineers has the objective of improving the accessibility of the information, which is the degree of difficulty involved in finding and/or getting a piece of information. Many studies have found that accessibility is the factor that most influenced the engineers' selection of information sources (Pinelli *et al* 1993; Leckie *et al,* 1996; Fidel *et al,* 2003). The perceived accessibility of the source is assessed using many different parameters. Fidel *et al* (2003) proposed, among others, familiarity, format, physical closeness and interactivity. When the information source is computer based, another factor affecting the perceived accessibility is relevance. The effort required to find and/or get a document is reduced when the system provides the maximum number of relevant documents and the minimum number of irrelevant ones (Borlund, 2003; Schamber, 1994).

The concept of relevance is a complex one, and requires at least two degrees of intellectual involvement. One relates to system-driven relevance and the other to human-driven relevance (Saracevic, 1975; Swanson, 1986; Harter, 1992). The system-driven approach views relevance as an objective, static concept and determines it using two parameters: the ratio of the relevant documents retrieved to the total amount of relevant documents in the system (recall) and the ratio of the documents to the total amount of documents retrieved (precision). Recall poses a big problem, because the absolute number of relevant documents in a system cannot be determined without the evaluation of each of them. However, it can be estimated by calculating the overlap of the results in different searches, or by comparing the results of the same search in different databases.

The human-driven view recognizes that relevance is subjective, cognitive, situational and dynamic. Relevance is subjective because it cannot be considered a property of the information itself, instead, it has to bee seen as an attribute endowed by the designer to the information in a certain situation. But it is also cognitive: it depends on the designer's knowledge and perceptions, and it is situational, for it relates to the designer's need for information to complete a particular design task. Additionally, relevance is dynamic, the user's perception of relevance changes as he progresses in the information-seeking process (Schamber, 1994, Saracevic, 1975, 1996).

This chapter is based on the designer-driven approach to relevance. By means of an empirical study, it investigates not only which documents are considered relevant and how they affect the designer's perception of the design process, but also how these relevance judgments are constructed.

4.2 Third Study: The Flexible Work Space (ii)

The objective of this study is to explore the various criteria affecting relevance judgments about (design) information through the design process. For this purpose, relevance will be understood as the designer's perception of the usefulness of the information accessed. To achieve *this objective*, the following research questions are proposed:

- What role does the information provided play in the manner in which designers structure the problem?
- Which criteria are used by designers to assess the relevance of the information accessed?
- Does the relative importance the designers assign to criteria before accessing information change after accessing it?

These questions are discussed via a study in which a number of senior design students were asked to generate a solution concept for a given design brief whilst having full access to an information system. The design brief used was the same as used in the study presented in chapter 2, on the problem of floating employees and flexible workplaces. They were working for a fictitious company called 4H. For a full description of the brief see chapter 2 and for the text of the assignment see appendix 2.1.

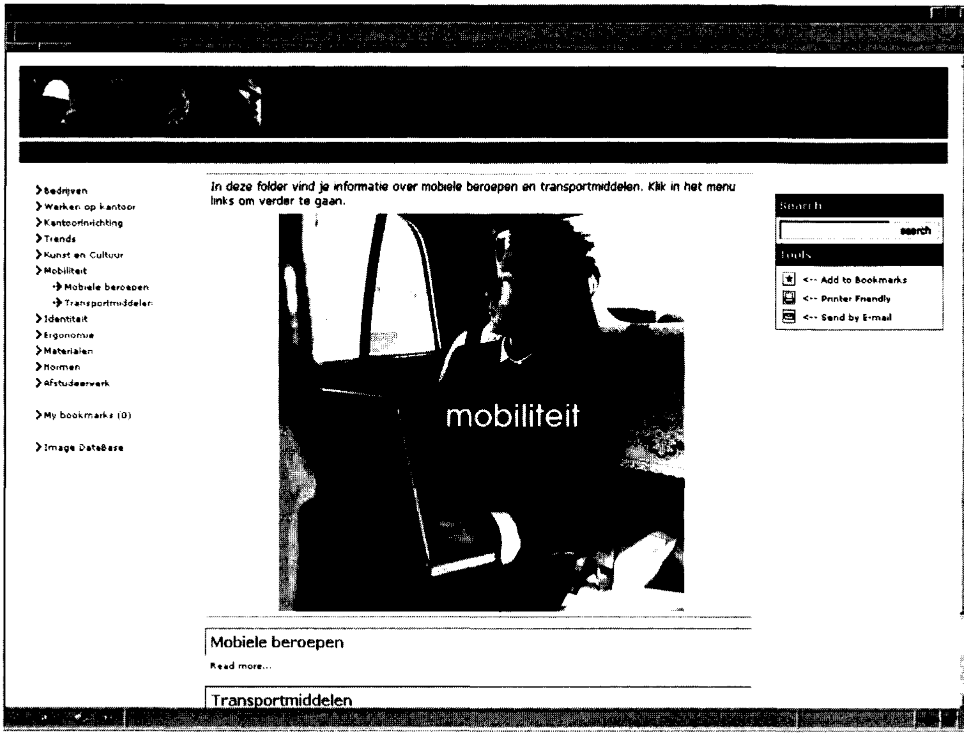


Figure 11 Screen shot of the improved interface to the CMS

4.2.1 Participants

The participants in this study were 9 senior students (4 male, 5 female) that participated voluntarily from a group that were contacted by e-mail. The selection criteria was that they must be working on projects involving product development other than office furniture, and that they have been working for at least three months on their graduation project at the time of the study.

4.2.1 The Information System

For the study presented in chapter 3 an information system was developed using a commercial Content Management System (CMS) over what is called a LAMP platform. (Linux, Apache, MySQL, PHP). The CMS was the same as the one used in the previous study, but several improvements were implemented.

Although the functionality and the quality of the interface of the system used in chapter 3 was carefully designed, there were still usability problems that produced too much noise in the results. In a computer system, the focus of attention of the user should be upon the task, and not upon the tool. This is what Winograd and Flores (1986, 1989) meant when they referred to the Heideggerinan notion of 'thrownness'. Heidegger proposed that we are 'thrown'

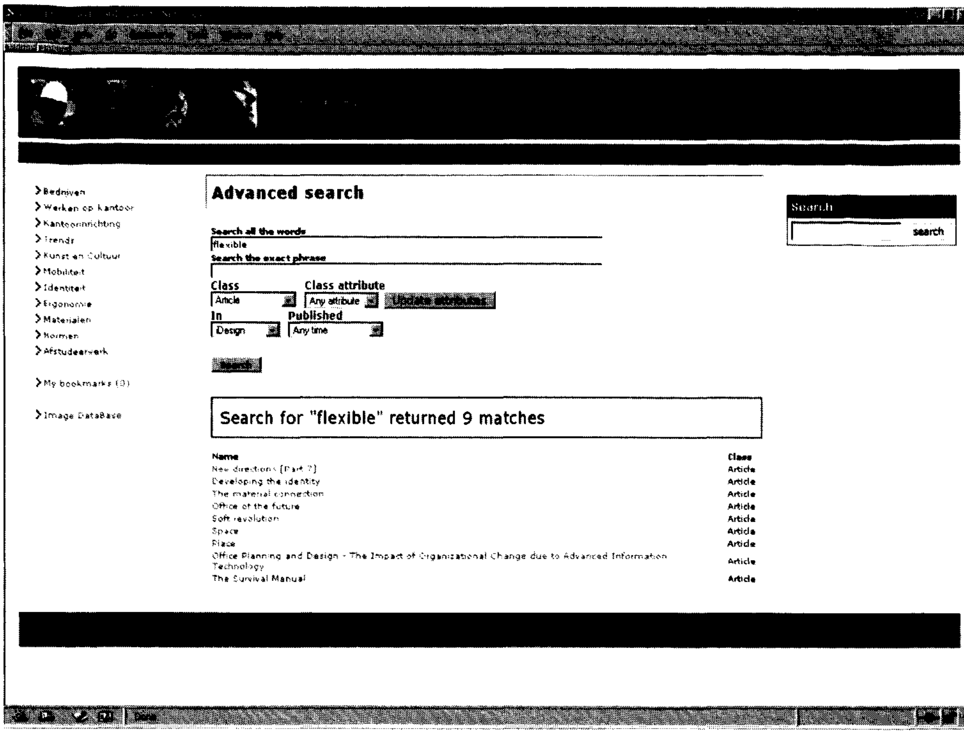


Figure 12 Screen shot of the improved search engine showing the results of a query

into the situations of everyday life and rarely have the time or the will to reflect upon (alternative) courses of action. It is not possible to be impartial observers, detached from the world in which we live. Instead, we act and make judgments using heuristics which are based on our experience. When faced with situations where experience fails to provide us with an appropriate guide for action, we experience a kind of breakdown which makes it difficult or impossible performing a task.

Even if it is only for experimental purposes, designers expect the software to be ready-to-use. On several occasions during the previous studies the users made remarks about the information system, the design of the interface, the layout, the speed and overall performance and ultimately, the quality of the results when the search engine was used. This indicates that the users not only make judgments on the information but also on the information retrieval process, therefore the importance of having information systems with 'transparent' interfaces, that match the designers' experience with other (similar) information systems and that allow the user to interact with the system by focusing on the task and forgetting about the tool.

The interface of the system was improved in four ways. First, the overall graphical appearance was significantly improved. A designer was hired to develop the layout, colors and typography of the front end (see Figure 11). The second aspect was the functionality such as the one click *add to my personal collection* feature and the *related documents* toolbox. When the designer is consulting a document, the system suggests similar documents, presenting them in a list on the right side of the screen. This functionality is based on relationships between documents that are predefined by the editor of the collection.

The third aspect in which the system was improved was on the content of the database, which is based on that used in the study reported in chapter 2. This content was updated and significantly enlarged. The collection consisted of more than 1000 documents covering aspects of furniture design, office furniture manufacturers, trends, mobility issues, legal issues, ergonomics, office interiors, etc. The information amounts to about 4000 A4 printed pages. About 70% of the content is in Dutch. This was done purposefully, as it is expected that information would be read and understood faster if it was in the designer's native language.

The last aspect was the search engine. In this version the search engine has an advanced search mode that allows the user to search by class (articles, folders, images, files, etc.) and by class attribute (title, keywords, abstract, content). See Figure 12.

The CMS used was also modified to produce log files containing the details needed. These log files were formatted as comma separated values (CSV) to allow easy parsing and importing into other analysis software like Excel and SPSS. The details contained in the log files were:

- Date and time
- remote IP address
- User name
- Transaction: possible transactions are view, search, download, add bookmark and view bookmark
- Title of the document
- Type of document: article, file, folder
- Path: path in the browsing structure.
- URL: Universal Resource Locator of the document.

All the other design considerations discussed in chapter three such as the depth of the browsing structure, the identification of the users, the possible transactions and the position of the documents in categories throughout the system were left unchanged.

4.2.3 Selection of the Relevance Criteria

The design of the study considered seven criteria that could be used by the designers in their assessments of the relevance of the information. These criteria were derived from what designers said during the interviews of study three and from other studies on relevance found in literature. For instance, Barry and Schamber (1998) conducted a series of studies on relevance and showed that, despite differences in terminology, there is a considerable overlap in the criteria mentioned by users as determinant in judging relevance. Schamber and Bateman (1996, 1999) found that users on average use only 10 different criteria to determine the usefulness of information.

The seven different criteria selected were based on the results of the studies by Schamber (1991), Barry (1994), Bruce (1994), Bateman (1999) and Choi *et al* (2002) and from the remarks by designers in the study presented in chapter 3. These criteria are:

- Topicality: the information relates to the design assignment
- Accuracy: the information accurately reflects what the designer is looking for.
- Suggestiveness: the information suggests new ideas or provides new insight to the designer.
- Novelty: the information is new to the designer.
- Helps to clarify the problem: The information helps the designer clarify important aspects of the design problem (presented in the design brief)
- Appeal of information: the information is interesting and attracts the attention of the designer.
- Technical attributes: format, use of language, illustrations, color, perspective, etc.

It is acknowledged that relevance judgments can be influenced by criteria other than the ones presented here, and it was expected that designers would mention other criteria during the interviews.

4.2.4 Data Collection Methodology

In order to understand both the criteria used by the designers to determine the relevance of the information accessed and the influence of this information in the design process, it was necessary to use a variety of data collection methods. This study made use of video recording, direct observation, logging, and interviewing before, during and after performing the design task. These interviews were semi-structured.

The first interview allowed the collection of data regarding the designer's perception of the information that would be necessary to complete the assignment. In the same interview the designer was asked about the criteria he thought he would use to determine which documents from the information system would be deemed as relevant.

With the intermediate interviews, conducted every 40 minutes, the intention was to learn about what information the designer found interesting and how it influenced the design process. In the same fashion, these interviews informed us about how the information needs of the designers were shaped and changed as he gained more knowledge on the topic and as the design process progressed.

During the final interview, the focus was on the designer's perception of what was important in the documents he considered the most relevant for the assignment. To evaluate this, the designer was asked to pick three documents that were the most influencing or the most relevant and to discuss a series of questions on why these documents were so important and how they influenced the design process.

All the interviews were videotaped and all the transactions in the information system were logged in a log file. In addition, the researcher, who was sitting in a separate space when the designer was working on the assignment, had access to a computer screen duplicating the designer's. The objective was to observe on which segments of the accessed documents the designer spent most of the time. Log files reflect, but do not explain behavior; nor do they give a full account of which aspects of a document were the interesting for the designer. In some cases, the designer would spend a long time on a large document, but read only one or two paragraphs. In general, people tend to locate in the center of the screen what they are reading, and to locate the cursor close to where the attention is. These indicators were used to mark segments of the documents that would have otherwise not have been visible on the log files for later discussion with the designers.

This technique proved to be useful in predicting which documents or segments of a document were considered important by the designer. For instance, if a designer made notes of a document while still on screen, the researcher asked him in the next interview what it was that he found interesting on that document, what kind of notes he made and what he used the information for. Since the interviews were conducted every 40 minutes, it was easy for the designers to remember. It also allowed for a detailed discussion of every document that the designer worked on. For instance, if the researcher noticed that a designer was making notes or sketches whilst reading a document, he could ask "I noticed that you made notes about this document, what was so important about it?" These discussions allowed insight into how the information was being used in the design process. Nonetheless, a possible research concern is that these interviews could distract the designers in such a way that the process becomes more artificial. However, we believe that these pauses are not unnatural. It is not uncommon to take pauses, have a coffee and a chat with colleagues. These interviews are in any case less intrusive and distracting than asking the designer to think aloud. (See also Rooden, 2001)

To evaluate the influence of the information on the designers' perception of the problem, they were asked to write what they considered the problem was (task I) and to write and/or sketch everything they had already in mind about aspects of possible solutions (task II). During interview IV, they were asked again what their perception of the design problem was *after* having used the information on the system. Transcripts of their responses can be found in appendix 4.4.

4.2.5 Procedure

The participants were invited to our lab at the faculty of Industrial Design Engineering, one at a time, for sessions that lasted half a day (see appendix 4.5). In the lab there was a computer for the designers loaded with an information system. On a different table, separated by a folding screen, there was another computer where the researcher could see the same images as on the designer's computer. The researcher could also see if the designer was sketching, writing or only using the system. All the designers were given sketching material: markers and paper. A video camera was set to tape the interviews, but the designer was not taped during the design sessions.

After a short introduction explaining the nature of the study, the designers had some time to read the design brief. They were then given an instruction on how to use the information system. This activity replaced the 'distracting activity' used in the study presented in chapter 2. Immediately afterwards they were asked to perform two tasks. For task I they were asked: "Write in your own words what you think the assignment is". For task II they were asked "Draw, sketch and/or write all that you (think you) know about the assignment and what associations come to mind. In short, everything that is going on in your head". They had 5 and 10 minutes respectively to complete these tasks.

After these tasks, an interview was conducted. In this interview the participants were asked to describe what information they thought they needed to complete the assignment, and to propose what keywords they would use should they have to use an internet search engine. Additionally, in this interview they were questioned about how they would assess whether a document was relevant. After the interview they could begin working on the assignment. The forms used in all of the interviews can be found in appendixes 4.1 to 4.3.

Forty minutes into the assignment the designers were interrupted and interview II was conducted. The second segment of the session started and 40 minutes later the third interview was conducted after which, the third and last segment of the session took place. The intermediate interviews (interviews II and III) inquired about what the designers had been doing, what information they had found and how they planned to continue. They were also asked about what information they considered they would need to continue with the assignment. During the whole procedure the researcher kept a log file of the actions of the designers, such as when they sketched or made notes after seeing a document. This information was used to prepare the questions for the intermediate interviews.

The designers were given signals 20, 10 and 5 minutes before the last segment was due to be finished. At the end, the fourth interview was conducted. The total time for the study was about 4.5 hours per designer.

4.2.6 Analysis of the Data

The analysis of the data focuses on three aspects. How designers use information to structure the problem presented in the brief, the criteria used in relevance judgments and the use of the information system.

The analysis regarding the influence of the information on the designers interpretation of the design problem was evaluated with the help of the results of tasks I and II, interview IV and the accounts given by the designers throughout the session. In this study, the actual results of the design process are not considered, for the time given to complete the task (120 minutes of net designing time) is only enough to form a better image of the assignment, and not to produce complete concepts of reasonable quality.

The criteria used to assess the relevance of the accessed documents was determined from two sources: the grades given to each criterion and the remarks explaining this choice of grade. For each of the proposed relevance criteria, the

Table 11 Summary of transactions by all designers

Action	Des 1	Des 2	Des 3	Des 4	Des 5	Des 6	Des 7	Des 8	Des 9	Total
view	36	26	28	30	59	49	26	41	63	358
search	7						2			9
download					2					2
add bookmark	3				4		1	1	1	10
view bookmarks					2					2
Total	46	26	28	30	67	49	29	42	64	381

designers were asked to give a grade in a scale from 1 to 7 and to explain their assessment (see appendixes 4.1 and 4.3). These grades are used to guide the discussion and to show trends, but the designers' remarks are more important to evaluate the differences in opinion. Two researchers observed the tapes individually, paying special attention to those documents that deviated from the trends as shown in the scatters in Figure 13 to 19. The documents that deviated from the general trend were discussed and in some cases, a new review of the data was necessary. The results section shows numerous examples as evidence to support the conclusions.

In relation to the use of the information system, the main source of data was the log files. These were collected and parsed, then all of the documents accessed for less than 8 seconds were filtered out. The value of 8 seconds is arbitrary, but it is reasonable to think that in less than this time it is not possible to get an impression of the content of the document to determine whether it is worth reading it. All the times spent in a document, as reported by the log files, were adjusted with a log file kept manually by the researcher. Sometimes the user simply left the last document open on the screen and switched to another activity like sketching or writing. This causes confusion and, if not corrected, potentially misleading.

4.2.7 Results

Information Needs

During the first interview, designers were asked to express their information needs with the following question: "what information do you think you will need to complete this assignment". And during subsequent interviews they were asked "knowing what you know now, what information do you think you will need to continue working on this assignment" Their remarks were grouped into categories and are presented in Table 12.

Use of the Information System

The nine designers generated 527 transactions. After removing those related to viewing of documents for less than 8 seconds, 381 transactions remained. These transactions are summarized in Table 11. Only 59 documents were accessed, from the about 1000 available in the system.

Table 12 Information needs of the designers as expressed during the first interview.

		Designer								
		1	2	3	4	5	6	7	8	9
The company	What other products do they make			♦					♦	♦
(4H)	Who are their clients					♦				
	Who are the competitors					♦				
The clients	Corporate identity				♦			♦		
of 4H	Type of offices		♦				♦			
	Corporate culture		♦		♦					
The user	Behavior			♦	♦		♦	♦	♦	♦
	Group behavior		♦		♦	♦				
	Working at the office	♦						♦		♦
	Identity		♦		♦	♦				♦
	personalization of workplace		♦		♦			♦	♦	♦
The task	Furnishing the office									
	How to store things	♦					♦			
Design	What has been designed already									
	By this company		♦		♦			♦	♦	♦
	By its competitors				♦		♦	♦	♦	
Miscellaneous	What is flexibility		♦		♦					♦
	What is identity		♦							♦
	Mobility					♦	♦			

Table 13 Summary of the proposed and used search keywords

Designer	Proposed	Used
Des 1	Office, flexible work, desktop	Storing/Storage, personal stuff, own identity, creating own identity
Des 2	Users, work, target group, job constraints, task performing	
Des 3	Examples of other workplaces, ergonomics	
Des 4	Users, company, office work, office design	
Des 5	Flexible work, flexible workstations	
Des 6	Office design, Gispen	
Des 7	Flexible workstation	Cubicle offices, office gardens
Des 8	Office furniture, flexible workstations, office, desktop, flexible archiving systems	
Des 9	Flexible workstations, office furniture, trolleys, flexible work, desktop	

Table 14 Overview of the most relevant documents evaluated during the post-test (Interview IV)

Designer	Document	Content	Time Reading	Book-marked
Des 1	Doc 1	Mobile Professions: Examples of workplaces such as busses and excavator cabins.	01:11	
	Doc 2	Storing: Examples of storing systems, briefcases and crates	01:47	♦
	Doc 3	Reconnaissance of the concept of 'personalizing'	04:39	♦
Des 2	Doc 1	The office of the future: Where is it going? Discussion of trends in office design	03:44	
	Doc 2	In-depth interviews with users of flexible workplaces	05:00	
	Doc 3	Ways and means of expressing identity	04:26	
Des 3	Doc 1	Discussion on the irrelevance of geographical location in modern office tasks	05:28	♦
	Doc 2	Fitting up the workplace. Guidelines for office furnishing	01:48	
Des 4	Doc 1	Text on the differences between the north American and north European traditions of office buildings and interiors	05:20	
	Doc 2	Images of 'personalized' workplaces	04:13	
	Doc 3	Text on how Levis offices are organized	07:11	
Des 5	Doc 1	In-depth interviews with users of flexible workplaces	13:27	
	Doc 2	Examples of different office layouts	05:45	
Des 6	Doc 1	Examples of different office layouts	08:26	
	Doc 2	Example of a trolley designed by Gispen	01:45	
Des 7	Doc 1	Examples of different office layouts	14:00	♦
	Doc 2	Fitting up the workplace	01:41	
Des 8	Doc 1	A storage unit in the a workplace context	01:59	
	Doc 2	Properties of different materials	01:50	
Des 9	Doc 1	A storage unit in the a workplace context	07:57	♦
	Doc 2	In-depth interviews with users of flexible workplaces	08:24	♦

The designers started browsing through the structure provided, in an attempt to explore and become familiar with the system. During the first interview, they were asked for the keywords they would use in a search engine such as Google. This question was very difficult to answer and most of them had to think for a minute or two before answering. This indicates that keyword searching requires a very precise idea of what to look for, and since this question was asked just after having read the brief, the designers could not express their information needs in this way. In fact, instead of keywords, they expressed concepts, such as *"I would look for what is already designed"* (Designer 5) or, *"I'd try to go to see what information I can find on this 4H company"* (Designer 7). Some examples of the keywords they proposed during the first interview are summarized in Table 13. From the 9 designers only 2 used the search engine. The

Table 15 Number of pages accessed on each information category.

		Designer								
		1	2	3	4	5	6	7	8	9
The company (4H)	What other products do they make		3	3		2		4	3	3
	Who are their clients									
	Who are the competitors									
The clients of 4H	Corporate identity				6					
	Type of offices				1					
	Corporate culture									
The user	Behavior					1				1
	Group behavior									1
	Working at the office		7		3	12	9		7	16
	Identity									
	personalization of workplace	1								
The task	Furnishing the office	13			6	1		8		8
	How to store things	4						3		
Design	What has been designed already	1							1	
	By this company		9	16		9	12	3	6	5
	By its competitors				8	10	17	8		
Miscellaneous	What is flexibility									4
	What is identity	7	9		4	8	3			9
	Mobility	2			1	1		1	1	4

information expressed as necessary for the assignment was not necessarily the same information they accessed later. Table 15 presents a summary of the number of pages that were accessed by all designers in each of the categories defined in Table 12.

Relevance Criteria

In order to test if the relevance criteria changes as the information is being used, the designers were interviewed at two stages. The first stage, the pre-test, was conducted after they had read the design assignment, but before they could start looking for information. For the second stage, the designers were asked to point out which were the two or three documents that they considered the most important or that influenced them the most. They were then asked a number of questions about *why* these documents were important and *how* they influenced their design process. (see interviews I and IV in appendixes 4.1 and 4.2 respectively).

Choi et al (2002) conducted a study similar to this one. In their study, they used averages of the users' responses to questionnaires where they had to grade the criteria from 1 to 7. During our interviews it became evident how difficult it was for the designers to decide what grade to give to each criterion for all questions. For instance, when asked if document 1 was relevant to the assignment,

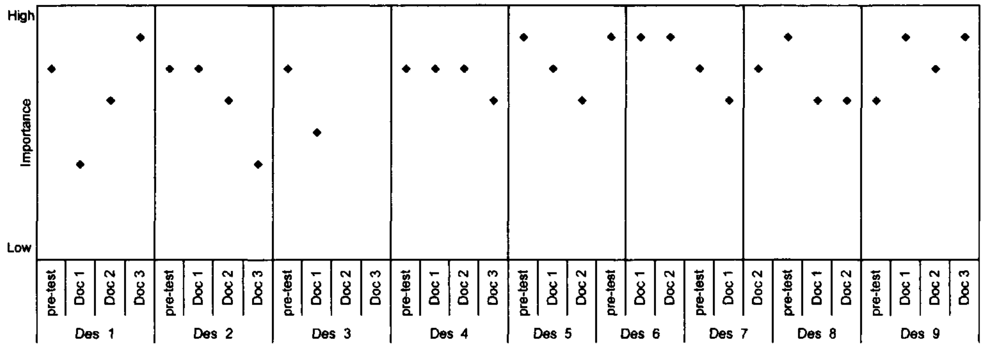


Figure 13 Perceived importance of 'Topicality' during the pre- and post-test

Designer 6 mentioned that *"I discovered my question [the problem in the brief] when I saw this document"* yet, when asked later if this document helped him understand the problem he graded it with a 5 in a scale form 1 (low) to 7 (high). This illustrates the difficulties with using averages.

While the approach taken by Choi and his colleagues could be useful in showing trends over a large number of participants, it does not explain *why* their participants have made those choices. Moreover, as it will be illustrated later in this section, the perceived relevance of a document is determined by the user's particular needs for information and can be influenced by a number of *situational* aspects. For these reasons, the designers' in our study were not asked to fill in a *pro forma* to rate each criterion. Instead, they were encouraged to give, along with the ratings, full account of their judgments. The selection of the documents to discuss was always done by the designer himself. All the documents discussed during interview IV are summarized in Table 14.

The information relates to the design assignment: Topicality

The first question put to the designers during the pre-test was whether they would expect information on flexible workspaces (the topic of the design assignment) to be relevant. All of them ranked this criterion very highly, as shown in Figure 13. During the post-test, topicality continued to be an important criterion for judging the relevance of documents. A few exceptions to this are Doc 1 accessed by Designer 1 (Mobile professions) and Doc 3 access by Designer 2 (ways and means of expressing identity). The first document presented examples of other professions requiring mobility, and in which the users expressed a wish for personalizing their devices. Examples are bus drivers and crane operators. The second document presented examples of 'personalizing' in other contexts: it contained photos of how youngsters decorate their scooters, or certain social groups express their identity by dressing in a particular way.

These two designers considered those documents as having little relation to the topic of the assignment, yet, they thought that they were relevant. One of them considered that his problem was (as expressed during the first interview) *"The design of a system that offers employees the possibility of creating a personal work environment"*. With a problem so defined, it is easy to imagine that

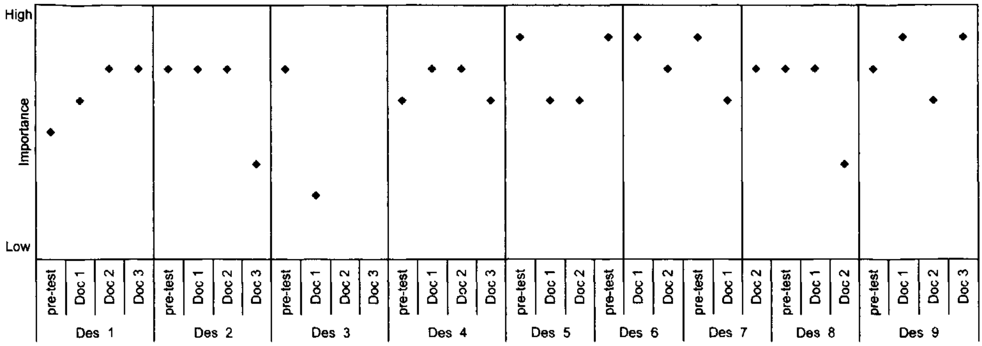


Figure 14 Perceived importance of 'Accuracy' during the pre- and post-test

examples such as the ones presented in this document are considered to be out of the topic. Designer 1 rated Document 1 high, as it can be seen in the subsequent figures, on other criteria such as suggestiveness and Accuracy. In the same way, Designer 2 graded document 3 high on suggestiveness.

The information meets the designer's needs: Accuracy

Before the designers started their information search, they imagined that the documents had accurately to represent their search intent; this opinion changed after the interaction with the system. However, serendipitous (opportunistic) encounters with information were frequent and useful. In common with the designers in the study (presented in chapter 2), these designers did not approach the information system with a clear intention in mind, or with a clear question. Instead, they used the information in an opportunistic way. For instance, talking about document 2, designer 5 said *"I was surprised that I found this document in the database, I was not looking for it."*. Designer 6 said about document 2, *"This is good, but I was really not looking for it"*.

The assessments of the 'accuracy' depends also on the designers' intentions. For instance, when using the search engine, which is an indication of a particular purpose, the quality of the results are assessed on how close they match what the designer expected. Designer 2 said *"[...] when I can say 'that's just what I was looking for', that's the best way of defining relevance"*

The information suggests new ideas or provides new insights to the designer: Suggestiveness

During the pre-test, designers speculated that they would consider documents that would suggest new ideas, or provide them with new insights, would be relevant. In general, it can be said that it continued to be an important aspect in the assessment of relevance of the documents tested during the fourth interview. There are a few exceptions to this. Take for instance document 2 by designer 6, an example of a trolley designed by Gispen, a Dutch furniture manufacturer. Although this is a prototypical solution, the designer indicated that, even though this document was relevant to the assignment, it did not contribute to the development of the solution.

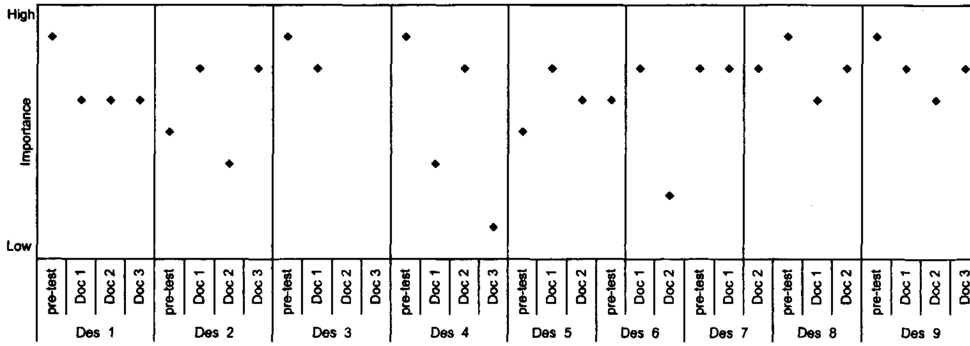


Figure 15 Perceived importance of 'Suggestiveness' during the pre- and post-test

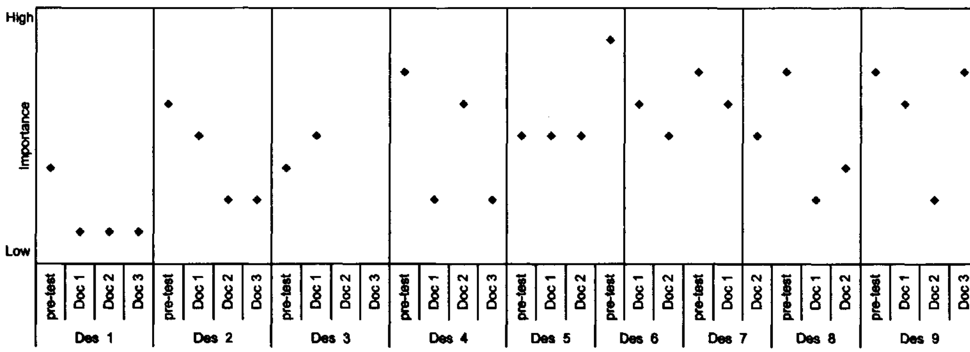


Figure 16 Perceived importance of 'Novelty' during the pre- and post-test

In the case of document 3 by designer 4, it also was not helpful in the development of the solution, but it was, according to this designer, very important in helping him understand the problem presented in the brief. This document refers to three paragraphs that are contained in a much larger document and explains, from the company's point of view, the aspects related to floating employees.

The information is unknown to the designer: Novelty

The opinion on whether documents containing new information would be relevant is very divided, as it can be seen in Figure 16. It is interesting, however, to note that in all cases the relative importance given to this during the fourth interview was lower than in the pre-test. It is interesting because it indicates that the designers expected to learn new things from the information accessed, and therefore expected documents containing unknown information to be highly relevant. Three designers (1, 5, and 6) mentioned that this criterion would be important but only if it is related to the assignment, making reference to the criterion 'topicality'.

This expectation was not fulfilled, as very little of the information provided was completely unknown to the designers. Still, the information was considered rel-

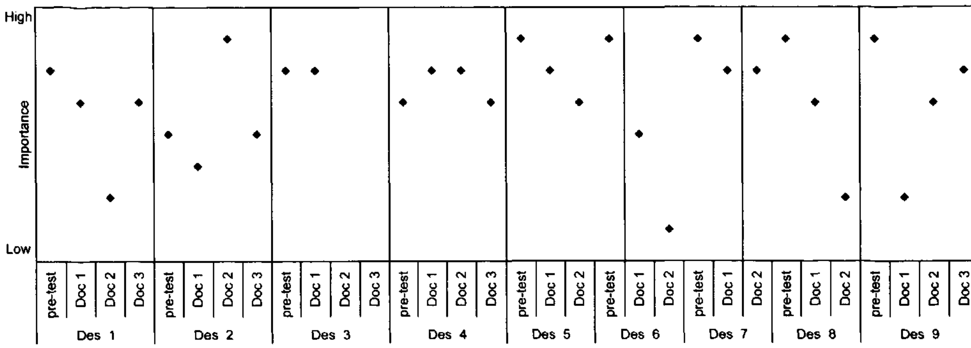


Figure 17 Perceived importance of 'helps clarify the problem' during the pre- and post-test

evant because it either allowed them to consider aspects that would not have otherwise been considered, facilitated making associations to other domains, or served as a confirmation of what they already knew. For instance, designer 2 said during the third interview *"What do I need to know? Not much really"* Later during the last interview, the same designer said *"[...] I used the information to back up my own ideas"* In a similar fashion, designer 1 said that *"To me it was Important to confirm how important is their own identity to the users [of flexible workspaces]"* and Designer 5 said about document 2 *"This is not really new, it is more a confirmation..."*.

The Information helps the designer clarify the problem

The perception of the designers, after having read the design brief, was that it was difficult to grasp. This is reflected in the great variety of interpretations they wrote of the problem as a response to tasks I and II. When asked about this criterion, they all responded that it would be very important to have some information that would help clarify the problem. However, in very few cases were the documents considered as relevant assessed on the basis of their capacity to help in understanding the problem. This is illustrated in Figure 17, where it is clear that in the majority of the cases the documents received lower scores in the post-test than in the pre-test.

Two cases that do not follow this trend are worth discussing. These are the cases of designers 9 and 2, who accessed the document 'in-depth interviews with users of flexible workspaces' (document 2 for both designers). Designer 9 had already, after the first segment of the study, some ideas about the solution to develop. Her solution consisted of a rucksack-like device that would allow the user to transport personal documents and a laptop after having used the flexible workstations. During the second segment, she accessed a document containing in-depth interviews with users of such systems in which these types of solutions were highly criticized. She said then *"I have to start again from scratch. This made me realize that the problem is much more complex and that this solution is not feasible"*.

Designer 2 mentioned that from this document he realized that *"three relevant questions need to be answered: (1), what is the content that needs to be per-*

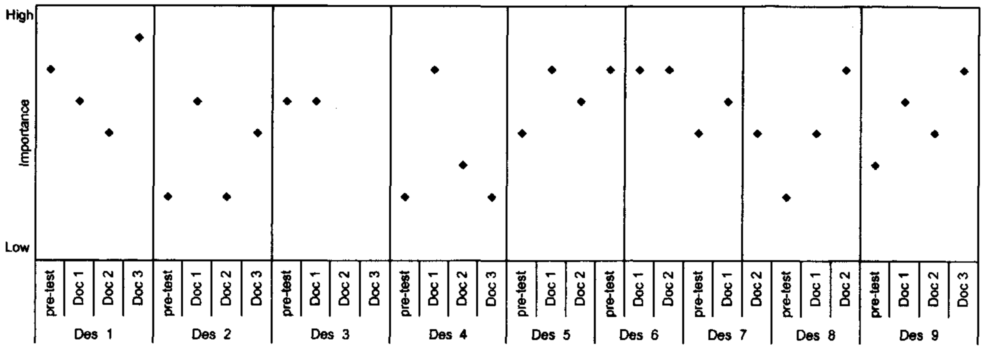


Figure 18 Perceived importance of 'Appeal' during the pre- and post-test

sonalized; (2), what to do with the papers, documents and books that need to be carried and (3), what does the work look like [sic], what do people do and why when they decide to come together in a specific area".

The information is interesting, I like it: Appeal

Appeal is a subjective measure of a sympathetic response to a document. Though it is related to other aspects such as how the document looks (technical attributes) and how the document influences the designer, there are some aspects that cannot simply be put into rational terms. Of particular interest are those documents that, though relevant, were not appealing to the designer. An example is document 3 by designer 4. This was a very long document (over 12 pages). Skimming through the document, this designer saw a paragraph discussing how a corporation organizes its offices to support a floating body of employees, which he considered interesting. However, the document was *"kind of dark, it is interesting at points, but the important information is difficult to extract [...] I did not like the document, but I found this paragraph useful and inspiring".* When different designers accessed the same document, they had different opinions about it. Take for instance documents 2 and 1 by designers 2 and 5 respectively. Being the same document, their judgment on the appeal of the information is very different (see Figure 18).

The information media is of high quality: Technical Attributes

Technical attributes refer to the quality of the documents in terms of use of language, format, graphical content, clarity, easiness (to read) in the case of textual documents, or aspects such as color, perspective or emotional response in case of graphical documents (pictures/images). Technical attributes is the perceived quality of the document in all aspects but content (which is considered to have been discussed with the previous criteria.

With the exception of designer 2, all the other designers considered this to be an important aspect in judging the relevance of a document: *"What is important is the content, if you are really interested, the format does not matter".* However, this designer was not consistent with this observation in his latter responses.

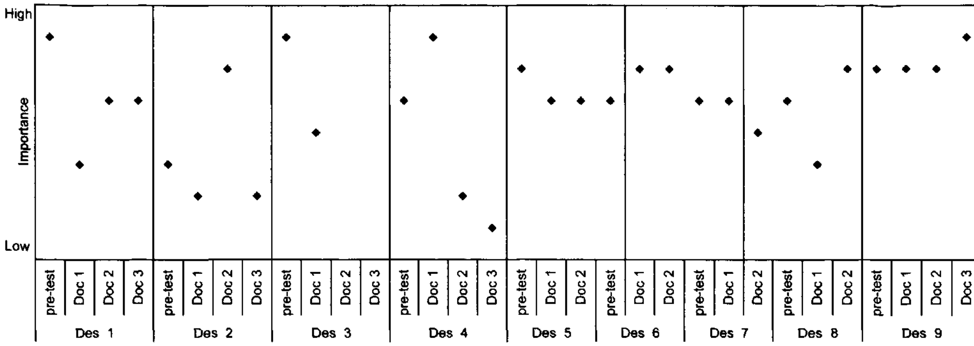


Figure 19 Perceived importance of 'Technical Attributes' during the pre- and post-test

For instance, he graded documents 1 and 3 very low on technical attributes because *"They contain too much text, are long and difficult to read".*

Other relevance criteria mentioned.

Besides the criteria already discussed, the designers had the opportunity to express other factors they would consider important in assessing the relevance of information. Some times these remarks came spontaneously, without the researcher specifically asking for it, in the middle of the discussions during the interviews.

The most mentioned factor was reliability. Designer 3 mentioned that "*The reliability of the source is important. Scientific articles are more reliable".* Designer 2 mentioned that *"It is important that the source is well known. I trust more universities than commercial companies, because they conduct independent research".* The reliability and authoritativeness of the information source was also mentioned as an important aspect by designers 4, and 7. Whether the source was known (the designer has used the source before) or has a good name (is a scientific journal or a 'big' university) was also mentioned by these designers. In some cases, such as the examples presented in chapter 3, the authority of the source is considered so important that even when there are obvious faults in the information, the designers were willing to consider and use it.

Appropriate level of detail: whether the designer wants to have a broad overview of certain aspects, or a more detailed description, is a factor affecting relevance judgments. It could be that the document is so detailed that it becomes lengthy, difficult to read and uninteresting.

"What do I have to do to use this information in my assignment? How can the data be interpreted and applied?" These questions, with differences in the wording, were posed frequently by the designers. They refer to a relevance criterion that could be called 'ease of use'. Some of the information in the system was easy to understand and the information was readily transferable to the task. Examples are a document that contained a summary of the aspects users consider important in flexible workstations, or a document with offices layouts. Other documents like the ways and means of expressing identity, or the document comparing the European and American traditions in offices required a much more active interpretation and were more difficult to apply.

The source is 'real' or 'interactive'. Most designers mentioned that they would have liked to go to an office with flexible workplaces to talk to people, to interact with them and to ask them questions. Although this is not so much a judgment on the information itself as on the information source, it is considered here because of the high number of occurrences (7 out of 9 designers mentioned it at some stage).

Does the relative importance the designers assign to criteria before accessing information change after accessing it?

Bateman (1999) found that the criteria used by her participants on relevance judgments changed very little as the users progressed in the information seeking process. Our results, however, showed that designers change some of the criteria whilst keeping some others relatively constant as they interact with the information sources.

Take for instance topicality. This criterion was given high importance during the pre-test and was still very important during the post-test. Only in a few cases, when designers came across useful information in the system that they considered was not related to their topic, did this criterion become less important. However, other criteria such as novelty were considered relevant in the pre-test but only if the document was on the same topic.

Accuracy was ranked highly in both the pre- and the post-test. Irrespective of whether the designer is able to make clear his intentions or his information needs to the system, the relevance of the results will always be evaluated in terms of the extent to which the information meet the user's information needs.

When an information system is presented to the designers prior to an assignment, it creates great expectations (see also a discussion on this in chapter 5). These expectations are not always met. For instance, during the pre-test most designers said that they would consider as highly relevant documents capable of giving them new ideas or insights. However, in only 24% of the responses obtained in interview IV on this criterion did the designers consider that the document was important because it gave them new ideas or suggested new ways to a solution.

In the case of novelty, the expectations were even harder to meet. It was expressed that a document containing information unknown to the designer would be considered relevant if it was also ranked highly on topicality. A review of the scatter presented in Figure 14 reveals that with only two exceptions, documents were ranked lower in the post-test than in the pre-test. This leads to the question, if the information was already known to the designer, why was that document still considered relevant? The answer is speculative, of course, but it seems to be a good indicator that, at this stage of the process, the information is used as a means to underpin decisions or to back up their own knowledge rather than to learn new things.

When new information is found and considered relevant, it is usually the product of chance. In order to get new information, it is necessary to be aware that one does not know. The opportunism with which our designers used the information, the fact that they did not use the search engine and the unstructured way of browsing in the beginning indicate that they were not aware of what was needed to complete the task.

On the question of whether the information helped in clarifying the problem presented on the design brief, the responses are very scattered. Since this was an important aspect of our research, we looked very closely at the tapes at the points where they discussed this question. During the pre-test, this criterion was ranked very highly by all designers; however, the evaluated documents were not.

A close evaluation of the answers suggest that the information played a bigger role in understanding and structuring the problem than the designers were willing (or able) to recognize. Instances of this are the case of Designer 6, who said that a document helped him *"find the problem"* yet graded that document low on this criterion. The document he referred to contained a table summarizing aspects to consider in the design of flexible workstations, product of the research of a master student who graduated on the subject. Another case is Designer 1, who gave a very low grade to document 2 on this criterion. While reading this document, this designer made a list of elements that are always in the workplace. During interview I she confirmed that this list was made from information in this document. She wrote:

"What I need to take with me"	
Pens	
Notebook	
Paper	
Post-it	
Folders	*Take with me*
Books	
Magazines	
Laptop	
Agenda	
Covert/case	
Paper bin	*Stay in the workplace*
Chair	

Towards the end of the second design session, she came back in several opportunities to this list (not to the original document) to check that she did not forget anything. It can be said that the document helped her in an indirect way to frame the problem, yet she did not report this during the interview. What this shows is that the way the information helped them understand and structure the problem is not very evident to the designers.

During the pre-test all designers except number 2 ranked highly the criterion on technical attributes. With a few exceptions, technical attributes was considered an important factor in assessing the relevance of a document during the post-test. Technical attributes became a less important criterion in the assessment of relevance only in those cases where the document contained information that was considered very important. For instance, designer 2 considered documents 1 and 3 of low technical quality because *"they are long and do not have any graphics, diagrams or even clear headings"* but graded them highly on other criteria such as suggestiveness and accuracy and explained that *"even then, they were interesting and appropriate for my assignment".*

Preferred criteria: Are some criteria consistently perceived as more important than the others?

One of the intentions of this study was to see if the relevance criteria would be significantly different across different participants. Though relevance as a concept is personal and situational, designers use more or less the same criteria in their judgments. During the entire exercise the participating designers kept topicality as the most important criteria, ranking it highly both during the pre and the post-test. Accuracy of the information, followed by 'helps clarify the problem' and suggestiveness, are the other criteria over which there is agreement: Relevant documents scored highly on topicality, suggestiveness and accuracy. In criteria such as appeal, novelty and technical attributes there is less agreement.

In conclusion, the designers agreed on the criteria that have the highest impact on the relevance judgments, whereas on the criteria that have the lowest importance they have different opinions. In the same way, the criteria with the highest importance tended not to change as the designers progressed in the information seeking. These observations indicate that there are some static criteria that is not influenced by situational factors, and that some other criteria shape the user's perception of relevance depending on the information that is actually available.

How does information affect the designer's perception of the design problem?

The designer's perception of the problem changes as new knowledge is involved. This knowledge not only comes from the information system, but also themselves. The information in the system serves as a trigger for new issues (see study in chapter 3). For instance, Designer 9 said that *"the problem of the flexible workspace is not moving things, but making the place feel like your own"* This was actually a remark from a user reported in the document "In depth interviews with users of flexible workspaces". Designer 6 also mentioned that *"I thought personalizing was just putting up the photo of your wife, but it is more than that".* This was also information taken from a document on identity at the office.

This is important because it changes the designer's focus. For instance, designer 9 had already plenty of sketches of a back pack that would give mobility to the users, but when she read the document, she had to start from scratch because *"I just read that users hate this type of solutions".*

4.2.8 Discussion of the Results

Use of the information system

When, in order to solve a problem, a person seeks for information, it is apparent that this person already has a notion of what will be needed to solve this problem (Saracevic *et al,* 1988). This preconceived notion relies on the user's knowledge of the topic and on his understanding of the problem. The use of the information system reveals that when they started using the information system, the designers had little idea of what was needed to complete the task, but as they gained knowledge on the topic, the random, explorative browsing typical in the beginning, was eventually replaced by a more structured approach. This is reflected in the log files in two ways: the user browses only one sub-category (materials, norms, identity, etc.) every time he approaches the system and spends more time in each document. This mode of browsing reflects a purpose, in opposition to an unstructured browsing, which is reflected in many different categories being accessed in a short period of time and in the skimming of documents. Browsing is easier because it does not demand so much from the designers in contrast to searching, where it is necessary to have a good idea of what to look for. Browsing allows the construction of the questions and, as the designer gets familiar with the information in the system and with the topic itself, more specific queries are possible.

It was interesting to observe that 6 out of the 9 designers started browsing quickly, trying to find examples of solutions to the problem stated in the brief. Those pages with images of other solutions were frequently visited, whereas the documents with only text were quickly dismissed. It is interesting because this is similar to the behavior displayed by the designers in the studies presented in chapter 3. During the first interview information about other similar products was the one most required. This suggests the need to provide designers with this type of information during very early stages of the design process. This aspect is extensively considered in chapter 5.

Compared to the other studies in this book, the total time spent on the information system was relatively short, as were the number of documents accessed. However, the average time spent in each document was higher than in the other studies, reflecting a more careful reading of the information. This can have two causes. One, it is impossible to completely conceal the intention of the study and even though the designers did not know the true objectives, they could realize that it was about the use of information. This might have made them approach the system more carefully and might have influenced their behavior. The other reason could be that, since the information put on the system was so carefully selected and organized, they soon found important documents they felt like reading.

Some designers started the process making notes or sketches and not by using the system. After interview II, where they were asked about this behavior, they started using the system. Some other designers mentioned that they would not have started immediately looking for information but since the system was there, they felt like using it. The use of the information in this study is, in those cases, the result of having being (tacitly) instructed to do so.

In some cases, the designers use the information system as an excuse for not doing any design work. This is a consistent finding in our studies (chapter 2 and 3. See also Cross *et al,* 1994). For instance, designer 2 said *"I did some research because I considered important, but also because I cannot think by sketching".* The expression 'I need to know more' is in many cases an euphemism for 'I do not know what to do'

The objective of developing an information system for this study is twofold. First, to test a technological platform, in this case, the CMS of EZ systems and to explore the value of some added functionality such as suggesting similar documents, the bookmarks, etc. Second, to use it as a research tool. The opportunity to modify aspects of the system such as the log files generated, having separated content and layout, and the flexibility to add functionality allows the researcher to do things that cannot be done (at least not so easily) with legacy software. It is not intended to prescribe how such systems have to be in design environments. For this study, we have compiled more than 4000 pages of documents related to flexible workplaces. Such a task is not realistic for every topic or design brief in a design company, but as a research tool it allows studying information processing in design without the problem associated with availability and accessibility of the information.

A difficulty in comparing the results of all the documents accessed is that not all designers accessed the same documents. In fact, there is very little overlap in the documents accessed. Table 16 shows the number of documents that have been accessed by different users: 25 documents were accessed by at least one user, only 13 documents were accessed by 2 different users and only 1 document was accessed by 7 users. No document was accessed by all users.

Perception of relevance is situational, dynamic and multidimensional

The perceived relevance is always situational. That is to say, it depends on the user's intentions and needs for information. It changes, not only when the task changes, but also within a particular task. This point is illustrated in our data: even though all the participating designers have the same task, they did not assess the accessed documents in the same way.

The designers understanding of the design task has a great influence in his relevance judgments. For instance, for Designer 1, the problem was *"to invent a system that offers the opportunity to employees to create a personal work environment in several workstations in an office building".* When the problem is formulated in those terms, a document with information about a similar situation but in a different context like construction or transport is more difficult to relate to the 'office environment'.

Contrasting with this example is a designer that proposed that the problem was *"allowing the personalization of tasks, places and objects".* This designer found a document on ways and means of expressing identity and recognized it immediately as relevant. To this designer, the concept of personalizing was not limited to the workspace, and therefore he was not afraid of showing interest in a document that demonstrated the concept of personalizing on other elements outside of the office such as scooters and ways of dressing.

Table 16 Number of documents accessed by different users

Number of different Users	1	2	3	4	5	7
Docs	25	13	10	4	1	1

This perception of relevance is dynamic; it changes during the process and what is considered irrelevant suddenly becomes relevant. One of our designers mentioned that *"I found this document browsing and at that time I thought it was not relevant. Now I need it and have to search to find it again"* (Designer 7). Other studies that have also shown the dynamic character of relevance criteria include Bateman (1999), Bruce (1994), Robins (1997), Tang and Solomon (1998).

The multidimensional character of relevance refers to how relevance can be perceived and judged differently by different users, even when it refers to the same document, and to the multiple criteria used by the same user to judge a document. For instance, new information was considered relevant only if on the topic. Suggestive information was considered relevant even when it did not score highly on technical attributes and usually when it also helped in understanding the problem. The multidimensional character of relevance has been acknowledged by Borlund (2003) and Schamber (1994).

Relevance indicators

Literature proposes a number of indicators to determine whether a user has found a document relevant (for a review see Song *et al.*, 2002). The time spent on the document is one of them (Cheng, 2000; Morita *et al,* 1994 and chapter 3 in this book). In this study all the documents that were considered relevant were read for more than 1.5 minutes, but not all the documents in which the designer spent more than that time were ultimately considered relevant.

Bookmarking a document is also considered an indicator of relevance. In this study all but 2 documents that were bookmarked were at the end picked up by the designers as the most relevant. However, not all the documents that were regarded as the most relevant were bookmarked. Other tools such as printing and sending the document by e-mail, which were also available to our participants, have been regarded in literature as good indicators that the user found the document relevant. In this study those tools were not used at all.

In short, all the indicators of relevance that can be logged automatically by the system would have been inadequate in indicating which documents really were of importance to our designers. Being present during the design session allows the researcher to use other indicators, for instance, whether the designer makes notes/sketches during or after reading the document. However, the best indicator we have are the remarks of the designer, which is ultimately the only way that one can really tell what he thought about the information.

4.3 General Discussion

The design of information systems for designers requires not only the technical aspects of storing and retrieving the information, but also aspects related to the user's information needs and searching behavior, because the success or failure of the system ultimately depends on the system's ability to meet the designers' needs.

Design documentation tends to focus too much on the technical aspects of particular solutions, whereas information on the context of the design is not so easily available. This aspect is illustrated in table 12 where it is clear that the most requested information is on users, and is reflected in the results of the study presented in chapter 2. In this study the designers mostly requested information on products and users. In the same fashion, the most requested (visual) information in the studies presented in chapter 5 was on contextual aspects of the task (See figures 10 in chapter 3 and 24 in chapter 5).

The choices made by the designers depend largely on how they understand the task and its context, and, in consequence, on how successful they are in obtaining information about this context (Hertzum *et al* 2000). Hence, the importance of creating information systems capable of supporting the vagueness of the queries posed by designers during problem structuring. Getting understanding of the type of information needed by designers as well as of how this information is judged is an important step towards the development of computer systems to support designers in this task.

The fact that there are situational and static criteria to judge relevance has implications for the design of information systems. The main static criteria were topicality and accuracy. These two criteria are largely used to improve the performance of information retrieval systems in terms of recall and precision. However, as was discussed throughout this chapter, the situational aspects constitute an important part of the relevance judgments. How to design information systems that acknowledge these aspects is an important challenge both to information researchers and to computer scientists.

5 Give me an Example: Supporting the Creative Designer

ABSTRACT: *In thinking of a solution to a problem, the designer has a vague image of the form that will embody the solution. Creating collages, sketches and other types of (external) visual representations are used to help in shaping and establishing this image. For this, designers make extensive use of design precedents. Many of the existing computer tools to support designing with precedents suffer from a serious drawback: they rely on textual descriptions that have to be added to the collection of images prior to using the system. This approach brings along a series of difficulties: it is impractical for large collections; considers only the viewpoint of the editor; fixes descriptions in time and restricts attribution of meaning. This chapter presents an approach that eliminates the human mediated description, indexing and organizing of large collections of design precedents. It explores both theoretical and technological aspects of the use and handling of design precedents. On the theoretical side, it discusses questions related to how to represent design precedents in such a way that they can be effectively used in design education and in design practice. On the technological side, it shows how to implement such representations in a computer program so that it eliminates the problems associated with human mediated indexing and description.*

5.1 Introduction

Creativity is not only the creation of completely new, innovative solutions to a problem. It also comprises the adequate use of existing knowledge in new situations. This is particularly significant in design. In product design, the level of newness at form and usage level has decreased over the years. Innovation is more visible at sub-system and component level and in manufacturing processes (Pugh, 1990).

Palh and Beitz (1996) suggested that the type of product determines the type of design activity. They proposed three types of design activities: original, variant and adaptive design. In *original* design, new and original solutions are proposed for new or old problems; the distinguishing factor is that it involves a new solution principle. In *variant* design, the function and solution principle remain the same. Only sizes, materials or arrangement of an existing solution are changed, whereas in *adaptive* design, a known solution is adapted to a new or changed task. The solution principle typically remains the same, but original design of parts, components or assemblies are generally required.

Design re-use (which maps to variant and adaptive design) has become a major concern in the design research community. Many systems to support design re-use have been developed. The objective of those systems is to store the *design rationale* along with the results of a design process so aspects of both the process and the solution can be re-used. This type of information, which contains details of the solution principles, parts, components, materials, assembly and manufacturing processes, etc. can act as precedents in a design process. However, in this chapter we will concentrate on other, less detailed type of precedents that are typically used by the designer in the form creation process: Images of existing products.

Why Using Precedents?

In thinking of a solution to a problem, the designer has a vague image of the form that will embody the solution. Creating collages, sketches and other types of (external) visual representations are used to help in shaping and establishing this image. When making collages, for instance, the designer needs just one image that represents a concept, but often he does not know himself what image it will be. On many occasions, designers simply flick through magazines or image databases: as one of the designers that participated in our studies said, *"searching for something you cannot describe"*, trying to find the precedent that carries the kind of knowledge needed to formalize the idea. This visual thinking and visualization of ideas is a process that is inherent to conceptualizing solutions in form and material (Muller, 2001; Goldschmidt, 1991; Schön, 1983, 1992). At this stage of the design process, visual information is preferred over linguistic information for it fits better the designers' way of thinking. The designer knows, thinks and works in a visual way (Cross, 1982).

Using images of existing products, as well as physical samples, is a common way of exploring possible solutions. Precedents, being solutions to previous similar problems, provide the designer with the frames of reference for the generation and development of new product forms, and using them is an important aspect of design practice (Pasman, 2003). In fact, many design studios have their own repository of samples of materials, physical objects, videos, glossy magazines, etc. Designers actively use these elements as sources of knowledge, to generate an image of the possible solution space, to get an impression of modes, styles, trends, applications of materials and production/assembly techniques, or just as sources of inspiration (Ashby and Johnson, 2002; Restrepo *et al*, 2004 and Chapter 2 of this book).

These collections of precedents form a domain-specific knowledge base that aids the designer in the form creation process in a way different from formal rationality. Formal rationality proposes that knowledge can be put into a collection of abstract, generally applicable principles as in, for example, mathematics and physics. In these disciplines, knowing certain abstract rules that can be applied to a great number of different situations eliminates the need for learning how to resolve every imaginable situation (which would be impractical, if not impossible). This is the reasoning that inspired Altschuller's theory of technical problem solving TRIZ (Altschuller, 1984, 1996). Knowledge, however, comprises more than generally applicable rules. It can also consist of concrete, specific experiences. Generally applicable rules suit domains with well-defined problems. In creative design, where problems are ill-defined, such general rules are either not always applicable, or completely non-existent. Instead, transfer of knowledge is based on cases (Spiro *et al*, 1987), making precedents very important in design education.

In design education, precedents are used in a number of different ways. For instance, to illustrate the results of using certain materials or manufacturing processes, to compare differences in styles or design movements or to discuss the effects of changing the spatial relations among components, to monitor trends, or as sources of knowledge and inspiration . (Schön, 1988; Oxman, 1990, Ashby and Johnson, 2002).

All the knowledge encoded in these precedents is decoded and transferred by the designer to the current situation. Kuhn (1977) called this process 'thinking from exemplars'. However, in spite of being critical to design, the process of transferring knowledge from precedents to current design situations is still poorly understood and poorly supported.

Many researchers have developed systems that allow designers to search for precedents in image databases with the objective of supporting this process. In most of these initiatives, images of products are stored in collections along with textual descriptions of them. This metadata is later used by the system as an index to filter the data during a particular query.

This filtering approach can be sufficient if the designer has a good idea of what to search for (a keyword is usually necessary) and if the search criteria are well defined, e.g., if the designer is interested in vacuum cleaners, tigers, vehicles or applications of certain materials. However, the search criteria cannot always be expressed in such a straightforward manner.

In addition to their use as a means to explore possible solutions, as a source of knowledge and as a source of inspiration, precedents are used as referents in the codification of messages that have to be transmitted by a product. For instance, if a designer intends to design a product that looks sturdy, sportive or elegant to a certain social group, salient characteristics of other products that are considered sturdy, sportive or elegant by that social group serve as a starting point for the exploration of new forms. This exercise requires not only a good understanding of the codes to be used, but also access to a large number of referents (e.g. products containing those codes). In this case, the filtering approach is no longer adequate. The reason is that images (or what they represent) do not have an intrinsic, fixed meaning that can be completely captured in words by the editor of an image collection. Instead, as will be discussed throughout this chapter, the meaning of an image is characterized by three factors: It is contextual, it is differential and it is situational (Santini *et al* 2000).

From these reflections, two research questions can be proposed. One, how to represent design precedents in such a way that they can be effectively used in design education and in design practice?. Two, how to implement such representations in a computer program in such a way that it eliminates the problems associated with human mediated indexing and description?.

In the next sections both technological and theoretical aspects of handling design precedents will be discussed. Firstly, current research initiatives are reviewed in the light of the approach they take to represent precedents. Secondly, some aspects associated with the processes of meaning attribution and image interpretation are discussed. Then follows a description of a system that uses a "query by example" approach to support the use of precedents in design. Finally, the results of a series of studies in which the system was tested with 46 senior design students are presented, and the implications for the future development of similar computer tools are discussed.

5.2 Computational Support for Precedents

The practice of collecting design precedents has existed even before the arrival of computers. For instance, a well-known collection of precedents is the collection of buildings compiled by Durand (1800). In this collection, images are drawn in standard projections and are presented without any comment. More recently, Clarck and Pause (1996) presented a collection of precedents together with analytical diagrams to be used in education and Schneider (1994) published a collection of floor plans intended for professional architects. There are also several publications with design examples; for instance, the 1000 chairs book (Fiell *et al* 2000) or the design magazines T3 and Items.

Though designers have made prolific use of these collections, as well as their own personal ones, there are several powerful reasons for wanting computer support for them. The institutionalization of knowledge the most obvious one, but there are others. If the designer is for instance composing a collage to construct an impression of style features, kinds of forms, colors, materials, textures, etc., finding the right images can be a difficult, time consuming task, even if they are organized in catalogues like the ones previously mentioned.

Several researchers have considered the issue and tried out alternative solutions. For instance, Muller and Pasman (1996) created a database with design precedents that was organized following a typological structure (extensively discussed in Muller, 2001). Their argument is that when images are organized into categories that follow a typological structure, images that share certain salient characteristics are put together and *"because of the mutual characteristics of the images in the field, the knowledge that is embodied in this typification will become explicit"* (p.124).

The difficulty using their system is that if images are organized in such a pre-established structure, the editor/maintainer has to determine beforehand which categories to use and has to organize the images accordingly. Browsing through such a structure becomes increasingly tedious as the designer moves deeper into the lower level of the structure. For instance, if a designer wants to have examples of organic products, he has to know that it is an ordering feature of an element called shape within a dimension called plasticity. Additionally, as they concluded themselves, this organization of the images in categories is difficult to achieve and requires significant expertise.

Oxman and Oxman (1993, 1994) developed a system called memorabilia, which is a database with examples of important architectural designs. In this system, images of buildings are stored along with 'design stories', which are a description of the aspects that make those buildings significant. The texts are taken from architecture magazines and books and the index of the database is the lexicon used in the texts. Ashby (2003) tried a similar approach, but this time using images of products from a design magazine. The images were indexed with the adjectives used in the magazine to describe the product. The limitation of this method is that it considers only the point of view of the editor of those books or magazines.

A more sophisticated way to store architectural precedents was developed by Fleming and Aygen (2001). Their system, called SEED, allows the retrieval of precedents in two ways. One, as a *prototype*, with standard properties that apply across projects. For example, a kitchen and the space requirements typically associated with it. The other as a *case*, representing a specific solution for a given set of requirements. This latter way of storing/retrieving precedents is closer to a formal Case Based Reasoning system (CBR), as the intention is to store the design rationale along with the images. The former method proposes prototypical solutions to certain well-formed problems. As it has been discussed previously, well-formed problems are rarely encountered early in the design process.

Other tools like the Electronic Design Assistance Tool EDAT described by Akin *et al* (1997a), DYNAMO presented by Heylighen and Neuckermans (2000) or the CDAT by Vroom (2003) are closer to conventional Content Management Systems (CMS) than to specific tools to support designers in looking for design precedents. In all these systems, the user has the responsibility of maintaining the information in the system, which could be anything from simple texts to multimedia content. The user not only has to generate the content, but also the metadata to describe, index and retrieve it. These systems provide means to catalogue and organize information, but do not offer special support for retrieving it.

Research conducted by Nakakoji *et al* (1999) resulted in the development of IAM-eMMa and EVIDII, two tools whose objective is supporting designers in finding visual images that would be useful for their creative design task. IAM-eMMa uses knowledge-based rules constructed by other designers to retrieve images related to a design task. That is, one designer describes his design using aspect-value pairs, that acted as 'requirements' during the design process. Aspects can be "atmosphere, audience, media, objects, etc." Possible values for each aspect are defined by the designer of the system beforehand. The EVIDII system allows designers to browse through images according to associations of those images to adjectives like 'warm, refreshing or pretty' put in the system by the editors of the collection.

The difficulty of using these systems lies in the fact that they rely not only on fixed associations between images and adjectives, but also on pre-determined rules to set design requirements. In the example given by Nakakoji *et al* (p.169), *"atmosphere"* can only be described using four different adjectives: *"cheerful, warm, sad and cold"*. While this simplifies the indexing process of the images, it also significantly restricts the possibilities of generating different interpretations.

Pasman and Stappers (2001) also decided to let the users describe the precedents themselves. In ProductWorld, the users have to store, organize, index and retrieve the images. Using an interactive interface, the user gives to the system a set of images and organizes them by similarity. Then, the user has to assign a label to each set of samples. However, the actual process of populating the system, grouping, labeling and indexing the samples is so intensive and time consuming that it becomes impractical for large collections. The authors reported, though, that this process provided valuable insight to the students that participated in the testing of the system, suggesting that it would be suitable for use in design education.

A system that does not use language as metadata is the Iconic Browser (Tsuda, 1989). The idea is to use icons (from a limited collection) to describe images. Later, the user would use the same collection of icons instead of keywords to search the database. The same query by icon approach was used later by Aslondgan *et al* (1995)

The development of a pen based drawing environment (Gross, 1996) allowed searching for images in architectural databases in a different way. The user makes rough sketches of buildings that show the main relation between the buildings components and attaches these to the image of the building. Instead of using texts or icons, the image is then described by a sketch. When the user needs to search for an image, all that needs to be done is a sketch representing what has to be sought. The system then tries to match the sketch drawn to the sketches stored in the database (Yi-Luen Do, 1998). But then again, it is necessary to describe the information in the database using sketches. This approach is called query by sketch.

These last two approaches purport to escape the difficulties brought along with the use of language for indexing images. By using icons or sketches, it is only possible to conduct a search based exclusively on a limited set of geometrical features, and still needs additions by a user. These metadata do not provide sufficient detail to search on a full set of geometrical features, like texture, color or spatial relations. All systems discussed so far require the addition of metadata to the images in the form of 'design stories' (Oxman, 1994, Ashby, 2003), affective associations (Nakakoji *et al*, 1999), requirements (Fleming and Aygen, 2001), icons (Tsuda, 1989; Aslondgan *et al*, 1995) or sketches (Yi-Luen Do, 1998); or need to be classified within a predetermined structure to browse through (Muller and Pasman, 1996; Clarck and Pause, 1996; Schenider, 1994). These approaches have some serious drawbacks.

The first drawback is a practical one. To be useful, a database with precedents has to have a significant amount of images. Describing and indexing each image is a time consuming, labor intensive, expensive task. The second drawback is related to the way images are understood and interpreted. Attribution of meaning is very personal, subjective and situational and can hardly be determined beforehand by the editor of a collection.

These shortcomings could very well be the reason why none of these initiatives have left the research environment to become a successful commercial product. The high costs associated with the indexing of the data and the amount of maintenance required to keep it up to date, are major obstacles for the assimilation of these technologies in industry.

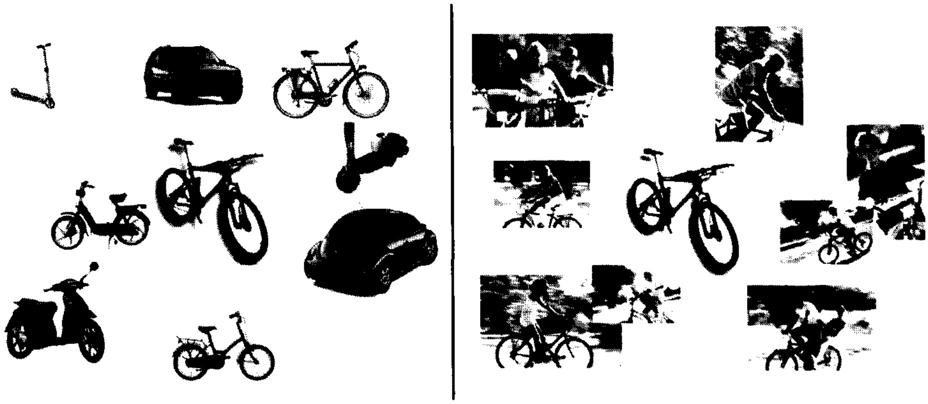


Figure 20 The image is interpreted in the context in which it is placed. Left, the bicycle is a transportation mean whereas in the right, it denotes recreation.

The next section briefly sketches some theoretical aspects regarding attribution of meaning and their implications in the design of a system to handle design precedents.

5.3 Attribution of Meaning

Meaning cannot be derived entirely from the content of the image. The interpretation of an image is not based exclusively on matching patterns stored in our memory, as when we recognize a cat, a chair or a car, but on other factors: we recognize an angora cat, an elegant chair or a sports car. This attribution of meaning is rooted in complex cultural and social conventions. This implies that the relation between the signifier and the signified proposed by Saussure (1988) cannot stand alone, it can only exist in a system of oppositions and differences. In a similar way to linguistic signs (words), meaning emerges when the sign (the icon, the word or the image) forms part of a system; when it is placed in a context.

The meaning of an image is differential. That is, it becomes more evident by comparing it with other images that share common characteristics with it. Consider for instance the images presented in Figure 20. On the left side, a bicycle is depicted along with other images, some of which are bicycles and some of which are not. In this context, the bicycle suggests 'means of transportation'. However, if the same image is placed in a different context, it suggests a means of recreation.

In a collection of images, the metadata used to describe the images cannot be fixed, for the way products are perceived changes with time. The meaning and interpretation of a product can change due to changes in its use, e.g., a mobile phone was a communication device, now it is a gadget with games and video cameras, or a fashion accessory, as in the new Nokia wearable phone Medallion II (Nokia, 2004).

The way a product is interpreted can also change due to changes in other products imitating or opposing it, or changes in technology, materials, etc. For instance, when plastic products were no longer a technological miracle (because any company could produce them), they began to be perceived as cheap and ordinary. Only when companies could produce microtextures, transparent and matte plastics in the nineties, were they able to become exclusive again, such as the kitchenware by Authentics. The implication is that the metadata added to the images in a collection of precedents has to be dynamic. It also means that the collection has to be continuously updated and maintained.

These observations have significant consequences for the design of systems using precedents. Using some intrinsically determined meaning to index and retrieve the information from the database, as in all of the systems previously discussed , does not support the contextual, differential and situational character of meaning attribution. Using a filtering approach is, therefore, not an appropriate option. This motivated the development of a system that uses a Content Base Image Retrieval (CBIR) approach for searching and indexing.

5.4 Developing a QBE System to Handle Design Precedents

A review of the current research on information systems to support the use of precedents in design has demonstrated the difficulties inherent to the process of describing and representing precedents adequately. Subjectivity, inflexibility, high maintenance costs and the dependence of expert knowledge are amongst the problems mentioned.

A system that does not require a previous description of the data it contains (metadata) would need to be aware of the *content* of the information it processes. Recognizing the content and retrieving text documents based on content and not on metadata is a most demanding task. But if the document is an image, then we are referring to one of the most formidable challenges of modern computer science: Content Based Image Retrieval Systems (CBIRS) (Müller, 2001)

In a CBIRS, the system would automatically create a low level representation of the images it contains. This representation is based exclusively on properties of the image, such as color, texture, shape, spatial relationships, etc. However, the system cannot map this low level representation to the full semantics of the image. Even recognizing that the image contains a TV, a car or a phone, i.e., recognizing a small part of the semantics, is still an unresolved problem.

If CBIRS are still so immature, how can they contribute to the issue of indexing and retrieving precedents in design? The answer is twofold. First, CBIRS allow the automatic creation of a low level representation of the image that is used for indexing purposes. Second, this representation, being based exclusively on properties of the image, is culturally independent and does not represent any particular point of view. In a CBIRS, the search is done using a seed that, in contrast with other systems, is not based on language. If a user needs an image, all that is required is to feed the system with an image that resembles what the user is looking for. This approach is called query by example (QBE) The next section presents a series of studies whose main objectives are to:

- explore different ways of (automatically) representing design precedents
- test the suitability of the QBE approach to handle large collections of design precedents
- learn about the criteria used by the designers to assess the relevance of the visual material used during the design process
- design a proof-of-concept system for research and demonstration purposes.

The three studies were planned as follows: The first one tests the suitability of the technology, queries the manner in which designers describe visual information and provides information for the design of better interfaces for the system. In the second study, an improved version of the interface is tested. This study discusses the usability problems of the interface and proposes ways to improve the system. For the third study, the interface and the content of the database are revised. With an improved, fully functional research tool, the focus of this study is on the criteria used to determine the relevance of the collected material. Finally, a general discussion on the results and the possible application of the technology to design education are presented along with a series of recommendations for further development of the system.

5.5 Fourth Study: Testing the QBE Approach

Besides testing the suitability of a QBE approach to access large collections of design precedents, the intention of this study was to learn *how* designers decide on the images they use an on what basis these images are selected.

With this objective in mind, a study was set up in which a number of (student) designers were asked to compose a collage for a particular design assignment using a proof-of-concept QBE system. This section describes this study and presents and discusses the results.

5.5.1 The QBE System

The selection of a CBIRS is a difficult task. Most of the existing systems are either commercial products developed for specific applications (such as airport security) and therefore expensive and not suitable for more general applications, or are immature developments product of research at university level, and therefore difficult to implement. Besides conditions such as accuracy and use of adequate image recognition algorithms, there are other requirements such as performance and ability to handle large collections.

In addition, it is also a condition that the system follows a client-server architecture. This would allow the separation of the server code that does the indexing, the image recognition and the actual retrieval, and from the Graphic User Interface (GUI). It was also a requirement that the communication layer between the client and the server is open so new GUI's are easily developed.

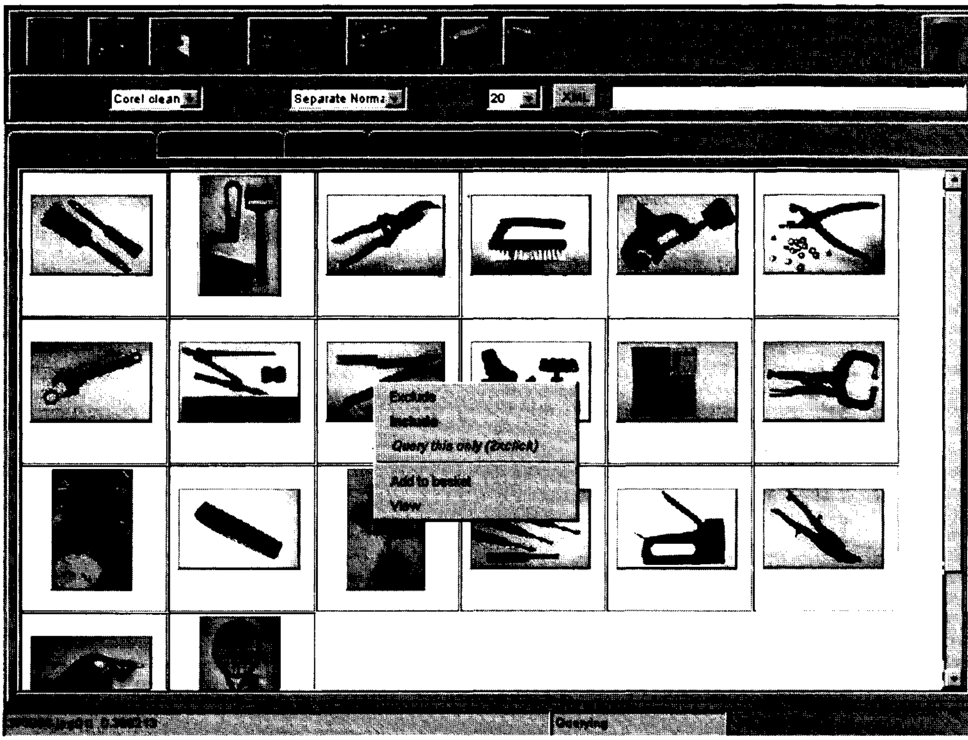


Figure 21 Screenshot of the Snake Charmer Interface showing a query on the Corel 6100 collection.

The system selected complies with most of these characteristics. It is server-client oriented, the communication layer between client and server is XML based and it is possible to extend its capabilities by adding user defined plug-ins. This allows for testing different interfaces without having to modify the server code.

The first time the technology was tested in our laboratory was using a very simple HTML based client written in PHP, based largely on the PHP interface written by Nicolas Chabloz, a student of the Computer Vision and Multimedia Laboratory at the University of Geneva. The simplicity of the interface means that it was necessary to greatly compromise the interactivity: the way of giving feed back to the system was difficult and the overall appearance was not appealing to our first pilot participants (13 in total). A Java based interface written by Zoran Pečenovic and Wolfgang Müller, also from the Computer Vision and Multimedia Laboratory at the University of Geneva, called the *SnakeCharmer*, was then installed and tested with three pilot participants. This interface was the one used for this study (see Figure 21). This section will not report on the results of the PHP tests. Only the studies conducted with the Java interface will be described.

In this interface, the designer initially gets a random set of images by pressing the dices button in the toolbar. When a relevant image appears, the designer asks the system to find similar images. This is done by using the *include* entry in the contextual menu (right clicking over the image). This is called giving *posi-*

tive feedback. All the irrelevant images, those containing undesired features are marked using the *exclude* entry in the contextual menu. This is called *giving negative feedback*. All the relevant images that appear can be stored in a personal collection using the *Add to basket* entry. It is also possible to browse through the search history.

For this study, a collection of 3,000 images of products was compiled. About 1,000 of those images came from the collection of designed products at the faculty if IDE (the collection that today belongs to the Henri Baudet Institute). Another 1,000 from the IDE Virtual Design Museum and the rest from various internet sources. The only way the designers could access those images was via the Query by Example interface. That is, there was no browsing mechanism and it was not possible to search using *keywords*.

5.5.2 Participants

The participants in this study were 12 senior students from the faculty of Industrial Design Engineering (IDE) at Delft University of Technology (8 male 66%, 4 female 33%) that participated voluntarily from a group of 45 students that were contacted by e-mail. The selected participants were chosen based on their performance on the course Design Project 4. They were invited to our laboratory, one at a time, to work on a small design assignment and to hold an interview. They received a small present as a reward for their cooperation in the study.

5.5.3 The Design Assignment

In order to test how different designers would use the system to collect visual information, they were asked to design a product. The assignment was formulated as the design of a telephone for young, highly educated people living in west Europe. The target group and the conditions were further explained by a text of about 300 words. This text indicated that the people in the target group have a lot of high tech equipment in their work environment and that for the house, they would like something more sober, elegant yet modern.

The participants were asked to compose a collage that expressed the character they wanted to give to their product. No further instructions were given, so they had the freedom to compose a collage that illustrated the target group, that served a starting point for an exploration of form, color, materials, or whatever other use they could think for a collage. They were asked to collect at least ten images, with no maximum limit. For the task of collecting images, they were given 30 minutes.

5.5.4 Procedure

The study was conducted in one and a half hour sessions. Each participant spent 30 minutes working on the assignment. There was a 30 minutes interview and the other half an hour was spent in introducing the study and training the participant in the use of the system. The participants were invited, one at a time, to our laboratory. A computer was set up with the software, a table with sketching material (markers, paper, etc) and video camera that was used to tape all activities. The camera was aimed at the computer screen and recorded the remarks of the participants.

The session started with a short introduction in which the participants were informed about the activities. Then, each participant received a short demonstration of how to use the system. Following this they were given a small training assignment. They were asked to make a collection of five images that they considered related to each other in whatever way. They were also asked what the relation was. In this way, the participant was forced to think about certain criteria to use in the searches. For instance, they could search products with the same geometry, the same color, the same function, etc. (this was not suggested during the experiment, and is mentioned here for illustration purposes only). For this task, the participants had 10 minutes.

After this training, the assignment was given and they started working. For the collection of images to compose the collage the participants were allowed 30 minutes. During this time, they could make notes and sketches. They were also asked to indicate why they decided to give positive or negative feedback to particular images or why they wanted to add them to their personal collections. These protocols were later used to determine what criteria they used to judge the images. Each time the participant performed an action, the action and the time stamp was noted in a log book. This logbook was used later to search the tapes for those segments of particular interest.

Finally, all the participants were interviewed. During the interview they were asked about their experience with search engines, their perception of the software in general and the interface in particular and the content of the collection. They were also asked for what purposes they would use such a system. This interview took about half an hour per participant

5.5.6 Collection and Analysis of the Data

The participants were videotaped and the tapes were fully transcribed. In order to determine in what manner designers talk and describe the pictures they consider during their *actions*, all utterances were tabulated. Afterwards, three researchers, including this author, observed independently the list of utterances and classified them into categories. No list of topics was given as a starting point. The opinions of the three researchers were compared and differences in opinion were discussed. After agreement, each utterance was put in one of the categories. Table 17 presents some examples of the results.

The possible actions a participant could perform with an image were:

- Include. This was giving an image as example for the search (first image) or using images from the results to give positive feed back to the program.
- Exclude. When the participant uses an image from the results to give negative feedback to the system, indicating that this sort of image should not appear furthering the results.

Table 17 Summary of the utterances organized by category (with examples of the utterances)

Category	Example of utterance
Function	I do not want a chair; is not a product for in house use, this is a telephone, I do not want more bikes, no watches, etc.
Color	appropriate color, sharp color, too colorful, boring white, etc.
Material/Texture	smooth, shiny, slimmer, chromed, because of the material, material makes it elegant, etc.
Form	rigid, stony, (not) organic, angular, awkward form, rounded, flat, simple, geometrical, rectangular, form not too bad, etc.
Time	old-fashioned, passé, (not) classic, antique, trendy and modern, etc.
Style	elegant, sober, stylish, sporty, hi-tech, expensive, funny, boring, fancy, groggy, trendy, fluid, robust, too high tech, etc.
Non-specific	Looks good, for the contrast, hmmm, nice, too intense, this thing we should not have, this is not, this is not it, interesting, etc.

- Search. Pressing the search button after having composed a query
- Add. When the participant considers that an image from the results could be useful and therefore saves it in the personal collection area.

The assessment of the interface and the assessment of the potential of the technology was done by observing the use of the software. All incorrect uses of the functions of the interface were marked, including those not mentioned or not noticed by the participants. During the experiment, the researchers made notes on some of these problems and later asked the participants questions about them. Participants were also given enough room to discuss/propose issues they considered important about the software during the interviews. Due to a problem with the videotape, the data of participant 9 could not be analyzed.

5.5.7 Results

One of the expectations when this study was set was that the designers would use a rich vocabulary for describing the images. They were asked to make clear what the reasons were for their actions (including, excluding and adding images). This was unfortunately not the case. On the contrary, very few reasons were given for the actions over the images, limiting to a maximum of one per image and in some cases, not even that. If the non-specific utterances are removed, the ratio is even lower. (see table 18).

All participants, with exception of 3, 7, and 11, gave one or less than one reason per image. This is illustrated in table 18. Note that when the non-specific utterances are not considered, the ratio of utterances per image is significantly reduced.

When the participants selected images without mentioning a particular reason, the researchers asked about it. Often, they could not give an immediate answer,

Table 18. Number of images considered, number of utterances and number of utterances per image. U/I = Utterances per image during the first and second half of the test.

Participant	N° of Images	N° of Utterances	U/I	U/I (w/o non specific) Total	U/I (w/o non specific) 1st half	U/I (w/o non specific) 2nd half
1	19	19	1	0.68	0.33	1
2	25	26	1.04	1	0.46	1.24
3	25	44	1.76	1.28	0.75	1.52
4	44	29	0.66	0.64	0.07	0.77
5	29	33	1.14	1.03	0.21	1.24
6	32	34	1.06	1.06	0.37	1.25
7	34	54	1.59	1.12	0.57	1.29
8	54	38	0.7	0.65	0.28	0.76
10	38	30	0.79	0.71	0.63	0.87
11	30	41	1.37	1.37	0.81	1.57
12	41	25	0.61	0.59	0.49	0.73
Mean	33.73	33.91	1.07	0.92	0.45	1.11
sd	9.98	9.88	0.38	0.28	0.23	0.30

and had to think about it for a few moments. This occurred particularly in the first half of the assignment. This suggests that the selection of the images is very intuitive, and that verbalizing the intentions is difficult. It is perhaps for this reason that the participants found the QBE approach promising: Not having to use language to formulate the queries eased the task. One of them (participant 3) mentioned that *"it was difficult to start, we had some keywords from the assignment, but finding products that represent what we want was not easy"*. Other participant said that *"I do not really know what I am after, but I could see that this image belongs to the assignment"*.

Initially, the descriptions of the images were vague or non-existent. Most of the utterances were *"I do not think this fits with the others"* or *"hmmm, nice"* and came in most cases after the researcher asked for the reasons for an action. Only participants 3, 7 and 11 consistently gave reasons without intervention of the researcher.

Towards the end, the non-specific utterances became less common. This can be observed in the last column of table 18. When only the second half of the assignment is considered, almost all participants have a utterance/image ratio above 1.

5.5.8 Discussion of the Results

The objectives of this study were threefold: To test the technology, to learn about the designers' criteria to select design precedents and to lay out a list or requirements for the development of a new interface.

Table 19 Frequency of the utterances per category

Participant	Criteria							Total
	Style	Form	Function	Time	Material	Color	Unclear	
1	2	2	1	6	1	1	6	19
2	6	3	2	3	8	3	1	26
3	17	14		1			12	44
4	5	14		1		8	1	29
5	11	3	7	7	1	1	3	33
6	10	13	8	1	2			34
7	18	10	4	1	4	1	16	54
8	7	10	4	12	2		3	38
10	1	6	8	7	1	4	3	30
11	15	6	2	8	6	4		41
12	1	7	12	4			1	25
Total	93	88	48	51	25	22	46	373

Suitability of the QBE Approach

Regarding the first objective, the results are promising. It was possible to test the automatic indexing, using low level representations of 3,000 pictures of products, and to get usable results. Although there were difficulties with the use of the system, due to the multiple technological difficulties with the existing interface, all the participants could get collections of images that they considered were usable for their design assignment.

In this first sections of this chapter it was claimed that in the initial stages of the form creation process, the designer has a vague image of the form that will embody the solution. Often, due to this vagueness, it is even difficult to externalize that mental image in the form of a sketch. Designers then resort to images of existing products that have the special characteristic that is sought. As one of our participants said, *"I do not really know what I am after, but I could see that this image belongs to the assignment".*

If sketching is difficult, verbalizing is even more difficult. This was clear in the study: in the beginning it was not even possible for our participants to express why a certain image was considered as relevant or not.

Presenting the designer with a tool that does not require the verbalization that is necessary when searching with keywords is a significant aid. If an image is considered relevant, it can be used to search similar images, containing the same features.

Selection Criteria

The reason to study the selection criteria is twofold. First, to give insight into the form creation process. As the designer progresses in this process, different aspects of the images become relevant. Second, it provides information for the design of improved search algorithms. Image recognition is based on a number of features, mostly geometry, texture, spatial distribution and color. Insight into the criteria used to select images can be used to write better algorithms that are particularly suitable for designers. For instance, color is a predominant feature in CBIR systems. Color blocks, color histograms and texture analysis using Gabor filters are common strategies used in calculating the similarity of images. However, as it can be seen in table 19 color is the less used criterion.

Most of the reasons used fall in the 'style' group. CBIRS are based exclusively on the visual content of the image, and not on the semantics. Even recognizing a small part of the semantics, such as recognizing if it is a car or a pram is still very difficult. Could it be that products with similar geometries can be classified within the same style?. This question is still unanswered. Other criteria used, such as form and function, are more easy to exploit in CBIRS, as many products with similar functions share formal characteristics.

What is considered a great advantage of the QBE approach in the beginning of the design session, that it is not necessary to use language to formulate a query, becomes a hindrance latter in the process. There were moments in which the participants *knew* what they wanted and asked for an easier way to find it. For instance, they wanted to see telephones, or office appliances, but using queries with examples of telephones or desks did not produce the expected results. This caused frustration, as most of them are accustomed to a more straightforward method of searching: using keywords or navigating through categories.

One surprising aspect of the results was the incredibly poor design vocabulary used by the participants. Having spent at least 4 or 5 years in an industrial design engineering program, it was expected that they would be using appropriate terms to describe the products they were working with. When interviewed, they could not explain their choices. For instance, we confronted some participants with their own utterances. During the interview, we showed them the video tape and ask why the said an image was 'stony' or had an 'awkward form'. None of the 4 participants with which we did this could give a satisfactory account of their judgments. To us, it indicates that the choices and assessments are based more on their own experience as users of products than on design knowledge. The expectations were that they would explain naming a product as sportive with arguments such as the color or materials used, the streamlined profiles, etc. The codes in which product characteristics are 'written' in products could not be made explicit by any of them during the interviews.

Suggestions for Improvement

The system needs to be improved in three different ways: The content of the collection, the usability of the interface and the overall stability of the system. Regarding the first issue, the participants complained a lot about the completeness of the database. Since most of the images came from already compiled collections with specific purposes (cars, tools, household appliances) the diversity of the products was limited. Moreover, the IDE collection (depicting mostly classic designs from the 60's and the 70's) represented 25% of the total collection.

In the SnakeCharmer and the PHP interfaces, the participants had to press the random button several times before something they could use as a *seed* appeared. This was considered a serious shortcoming. Whilst the QBE approach provides an easy way to formulate a query once in possession of an example, the problem of how to provide the first example still remains. This problem has been described as the *zero page* problem (La Cascia *et al*, 1998).

Query by Sketch could provide a way out of this problem. Another method would be to provide the user with an overview of what is in the database and then allow him to move through this overview (Müller, W.T.E., 2001).

Regarding the interface, there are a number of aspects to be improved. The icons are not clear. Icons that are used in popular computer programs (such as the *undo* button) are used in this interface to clear the query. The 'connect' and the 'random' buttons needed to be explained several times.

The function of the tabs is not clear. Many participants (5 out of 12) mentioned that a great improvement would be to have the query images and the results in the same view. Removing images from previous queries was considered very difficult. Since the query images were not visible at the same time as the results, it was difficult to keep track of the query history.

The use of many different terms for the same function is confusing. For instance, in the contextual menu there is a function called 'add to basket' whereas the tab where the 'basket' is visible is called 'your selection of images'. The use of the terms 'include' and 'exclude' to give positive and negative feedback were not readily understood.

It was suggested to use metaphors commonly used in other computer programs, such as dragging and dropping images in a folder (instead of the 'add to basket' contextual menu). In general, the interactivity of the interface was highly criticized. It was unstable (crashed frequently) and at points it was extremely slow. Participants found the software very attractive, for they reported that they could find the images they needed to complete the assignment. However, usability problems were the cause of frustration and loss of motivation to continue using it. Finally, this software is intended to be used by designers. All of them made comments on the general design, layout and selection of color of the interface. In the next section, an interface that pretends to overcome these difficulties is presented and tested.

5.6 Fifth Study: Improving and Testing the QBE System

This section reports on the design, development and testing of a new, improved interface to the QBE system. The objectives are to determine whether the improvements are in the right direction. Besides the added interactivity, the enhancement of the stability and the performance and the expansion of the image collection, it is of particular interest to evaluate if the new access to the database, by means of a preview of the collection's content, is a viable way to solve the *zero page* problem. The research setting and the procedure were identical to the ones in the previous study. Only the participants, the interface and the design assignment were different.

5.6.1 The Improved Interface

After the tests of the PHP and the Java interfaces (only the tests with the java were reported in the previous section) it was evident that in order to make the system work, big improvements in the design of the interface were required. These improvements needed to be done, not only on the functionality of the interface, making easier the interaction with the system, but also on the speed and stability of the system and the content of the image collection. Being a product targeted for designers, the appearance was a very important factor to consider.

To improve the level of interactivity with the system, it was decided to use a different technology. Though Java written applications can reach high levels of interactivity, achieving functions such as *drag and drop* and *copy and paste*, standard in most modern applications, is very difficult. The technology chosen to provide the required flexibility was flash. Using Macromedia Flash MX, a totally new front end for the search engine was developed.

The search occurs via an interactive process in which the designer gives to the system examples and counterexamples. In the example of Figure 22, the designer gave the system two chairs as positive examples and two other cubic looking products as counterexamples. The results, based exclusively on appearance, are not necessarily chairs, but do share characteristics that could be interpreted by the designer as he pleases, for instance, as organic, or as friendly or as modern, etc. The actual interpretation of the images is done during the use of the system, not before, for there are no human– generated descriptions attached to the images.

In Figure 23, another example is shown. In this example, the designer gave the system two images of Macintosh products as seeds and two other non-Macintosh products as counter–examples. The results are for the most part other Macintosh products. The question is, are those products recognized by the system as Macintosh? The answer is no.

The system is not aware of the content, nor are there any textual descriptions indicating this. These results are obtained based exclusively on the geometrical features these Macintosh products share. These common characteristics are probably what make a Macintosh look Macintosh. Note that in this example, not all the displayed products are Macintosh. Other products with the same appearance are also retrieved.

The interface is divided into five areas. In the first area the designer can browse the collection. This feature was added after the designers in the previous experiment said that allowing browsing, along with searching would be a great improvement. The difficulty is that designing a structure, selecting the categories, etc. for all of the images in the collection is as difficult as describing the

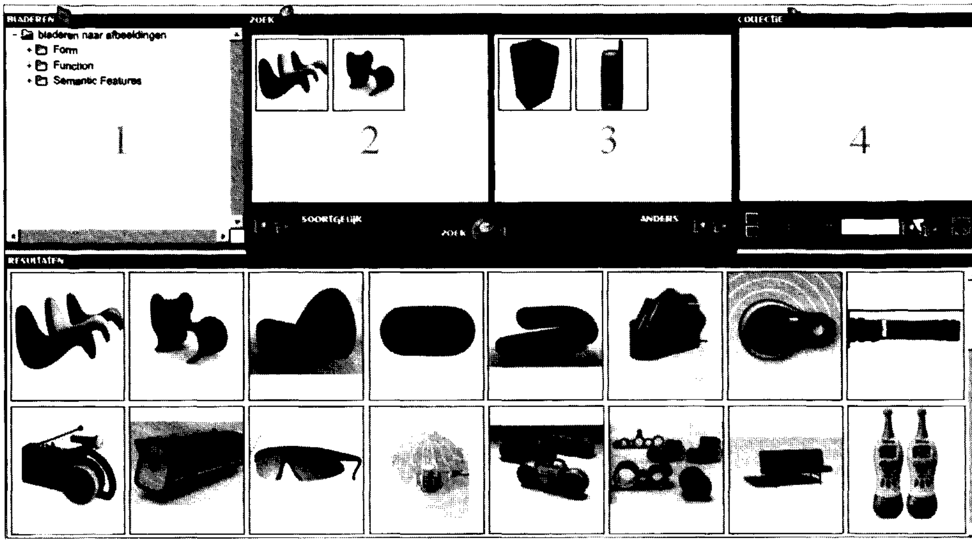


Figure 22 Screenshot of a Query by Example system In area 2, the user drags the images to be used as examples (should look like this) and area 3 is used for counter examples (should not look like this). The results are ordered by similarity. Area 1 is used to allow the user to browse through a set of examples of products that will serve as seeds for the query. Pressing the search button with an empty query returns a random set of images.

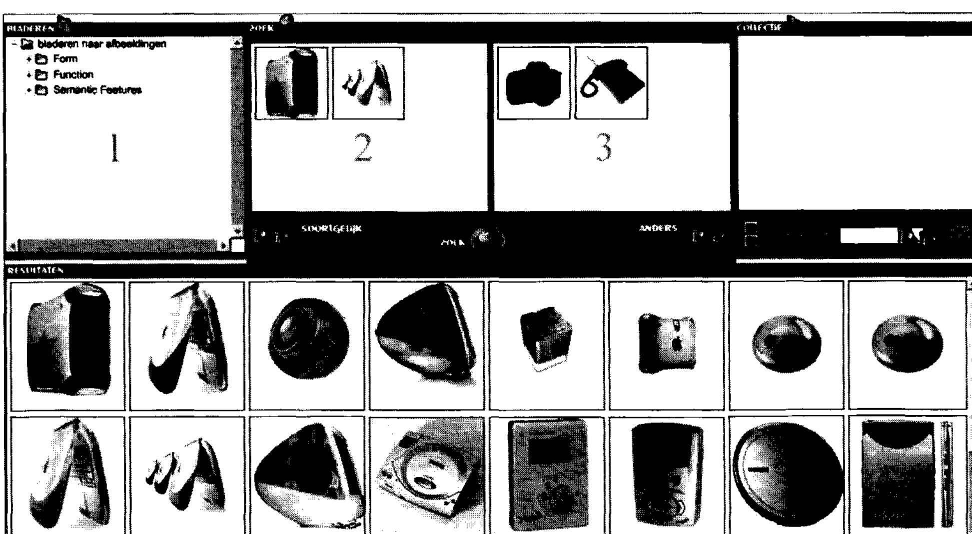


Figure 23 Screenshot of a query where the intention was to get examples of products that look Macintosh.

images themselves, which is what this system pretends to avoid. In this study, one of the objectives was to learn how to organize a part of the collection in a structure that allows a fast preview of the content of the collection and that provides the first *seeds* for a search.

The version of the browser area used in this study generated an automatic tree like structure with random images taken from the database, and presented them using the same names of the categories used to store the images in the Database. Some times, these names were not self-explanatory, as the images were stored using code words to represent their source. For instance, PIM, VMuseum, IO_Delft, etc. A PHP script would take 10 random images from 10 random categories and present them as an overview of the content of the collection.

The second area is where the user drags and drops the images that contain the characteristics sought (positive feed back) and the third area is where images with undesired characteristics are dragged and dropped. Once the query is composed, pressing search ("*zoek*", in the figures), delivers the results.

There is a fourth area where the user can compose a collage. There, images can be put in any order, can be tagged, described and saved. The fifth area, that corresponds to the lower part of the screen is where the results of the search are presented.

The ideas from which this interface was designed were not only based on the results of the tests of the PHP and Java interfaces, but also on the research discussed in the previous sections. For instance, it was proposed that the *meaning* attributed to an image emerges in an interactive process of searching and giving feed back. It was also proposed that the meaning of an image is *differential*. That is, meaning becomes more evident by comparing it with other images that share common characteristics.

This was reflected in the design of the interface by putting the search areas next to each other (areas 2 and 3 in Figure 22). In the example shown, the intention of the user is to find images that look like the ones in area 2. Putting the area where images that will receive *negative feed back* next to the images with the desires characteristics emphasizes the differences. In this case, the organic character is emphasized as opposed to the geometric, cube-like appearance of the images used as counterexamples. The query is then based on the *distance* between the positive and the negative images.

In the same order of ideas, the results are better evaluated when both the query (positive and negative images) and the results of the query are visible at the same time. In the *SnakeCharmer* interface, the results, the query and the user's collected images were presented in different tabs (see Figure 21).

The collection of images was significantly improved. More than 40,000 images were collected. Only images depicting products were used in the tests (about 6,500). Due to some difficulties caused by the background of the images, those images with prominent backgrounds were removed. The final collection used in the following two tests had about 4,000 background-less images.

5.6.2 Participants

The participants in this study were 12 senior students from the faculty of Industrial Design Engineering (IDE) at Delft University of Technology (5 female and 7 male) that participated voluntarily from a group of 45 students that were contacted by e-mail. The selected participants were chosen based on their performance on the course Design Project 4. They were invited to our laboratory, one at a time to work on a small design assignment and to hold an interview.

5.6.3 The Design Assignment

In this study, as in the previous one, the assignment consisted of the design of a product. For this design, the participants had to compose a collague. This time, the collage requested was more focused.

The assignment was worded as follows: "An American company that develops office articles wishes to create a new line of products for bars and restaurants. It is their wish that the line represents the rock and roll spirit of the 50's and the sobriety and simplicity of the Ritveld chairs." The procedure and the data collection followed the same protocol described in the previous study. The training assignment was the same: collect five images that are some how related to each other and explain what the intended relation was.

5.6.4 Results

During the execution of the assignment, the participants were asked to think aloud and to comment on their actions. The whole process was video taped and the protocols transcribed. Since the video camera was focused on the screen, it was possible to track the users actions, use of the mouse, selection of images, etc. For each user, a log was created, which recorded the observed behavior, the user utterances and a time stamp. This author, together with two other researchers, analyzed the tapes, focusing not only on what the users reported but also on the way they actually used the program.

The results of the usability test were grouped in two categories of issues. The first one deals with problems related to the use of the basic functions of the software and with the (mis)understanding of what the software does. The second group of issues deals with typical problems with the interface (see table 20)

In the first group of issues, the most common problem was the use of the search areas (areas 2 and 3 in Figure 22). A common problem (6 participants) was that the participants used the positive or negative feedback areas as collection area. As they got relevant results, instead of putting them in the collection area (area 4), they placed them in the feedback areas (areas 2 and 3). As a result, the queries became too complex, the search time became too long and the results were not adequate. This led to confusion and frustration. *"I do not understand the program"* (participant 10). *"The results take too long, I am going to stop the query now..."* (participant 7). *"The anti-window, how does it work?"* (participant 8).

Table 20 Categories of usability problems of the improved interface, examples of reported problems and their frequency

Main Category	Sub-category	Usability issue	n
Basic Functions	Positive and negative feedback areas	Too many images in the feedback areas	6
		Negative feedback area unclear	4
		Starts query with image in negative area	3
		Does not give negative feed-back	3
	Performance	Search takes too long	3
	(speed)	Browsing takes too long	1
	Performance	Results are not always relevant	
	(quality of the results)	Can't find what I'm looking for	2
			3
	Intelligibility	Do not know what criteria the program uses	3
		do not 'understand' the program	2
Interface problems	Browsing area	Browsing structure too complex	5
		Dynamic structure (can't find things back)	2
		Does not work like explorer in windows	1
		Does not open and close when clicking the folder	4
	Feed back areas	Labels 'similar' and 'dissimilar' not clear	2
		Implement ctrl-c and ctrl-v	4
		Delete this item not clear	2
		Delete all items not clear	4
		Can't scroll down	2
	Collage Area	Can't see zoom function	5
		Flags too big	2
		Flag OK with enter key	1
	General Appearance	Zoom function indispensable	4
		Wrong color (dam green)	1
Collection	Size of the collection	Collection must be bigger	2
	Type of objects	Collection too limited	4
	Iin collection	Only trendy objects	2

Another common problem (3 participants) was the use of the negative feedback area exclusively to formulate a query. Users put images only in the negative feedback area. This area is meant to instruct the system, after having performed a first query, which of the results are not relevant, in order to refine the search. Starting a query with only images in the negative feedback area is equivalent to asking a librarian "give me all the books that are *not* written by William Shakespeare". This also leads to inadequate results.

These difficulties were in some cases so frustrating that some of the participants decided to browse instead (3 participants). Being unable to find what they were looking for, the browsing method provided them a *"quantity over quality"* approach. They were able to eye scan a larger number of images using them opportunistically. *"I am going to browse the collection instead, that way I can find what I want faster "* (participant 5).

The overview of the content provided by the automatically generated structure was not without difficulties. The names of the categories are difficult to understand and to remember and do not relate to the content of each category in a meaningful way. *"What are those @#%!&*$* names in the folders, I do not understand what they mean. This folder is called IO-new but I only see old-hat products and stuff from the fifties."* (participant 8).

Since every time the user resumes browsing the system provides a different overview, it is difficult going back and finding an image that the he might have thought was useful. *"I found an I-Mac, but when I go back to the folder where I thought it was, I cannot find it again"* (participant 11).

In relation to the second group, the most common issues were:

- Four participants did not use the browser function. After asking them for the reasons, they argued that they were satisfied with the results of the search function (3 participants) and that they did not notice it (1 participant). *"... I found the images I wanted, I did not notice the browsing because I did not need it"* (participant 7)
- The icons 'remove this image' and 'remove all images' (the little trash bins under the feedback and collection areas) were never used by 9 of the participants, and the 3 others did not notice that it was possible to remove only one image from these areas (remove this image) without clearing the entire query (pressing 'remove all images').
- Users did not notice, until instructed, that the collection area can be used to compose collages directly, and that there is a 'full screen function'. *"I think it should be more clear how to use the collage area"* (participant 11 referring to the personal collection area).
- Many complaints about the lack of *ctrl-c* and *ctrl-v* functions (copy and paste).

The last group of problems was related to the collection itself. Though there were 4,000 images, some participants felt that the collection should have been bigger. Most of the objects collected were taken from design magazines, internet shops and the websites of manufacturers. As a result, a large number of them were modern, new products. Contrasting with these products were the images of the design museum. Most of the images of that collection (about 1,000) are classic design products from the fifties' and sixties'. Two of the designers asked for more ordinary products as well.

5.6.5 Sufficient Number of Participants?

The total number of participants for this test was 12. For the analysis one participant was left out, because his tape was damaged. Whether 11 are sufficient participants for discovering all the usability problems that would be significant to the development of the software might be questioned.

To answer this question, we used an algorithm method proposed by Kanis and Ariz (2000) to predict the maximum total of observations that could be made (of usability problems, e.g.) if an infinite number of participants was taken.

$$F_\infty = \frac{\overline{F}_1 . \overline{F}_{n-1}}{\overline{F}_1 + \overline{F}_{n-1} - F_o}$$

with

F_∞ total number of distinctive usability problems estimated to be found after an unlimited (∞) number of participants

F_o total number of usability problems observed

F_n total number of distinctive usability problems found after the n^th participant

$\overline{F}_1$ average of observed usability problems per participant and

$\overline{F}_{n-1}$ average of the n combinations of the findings over n-1 participants. This is calculated as follows:

$$\overline{F}_{n-1} = \frac{\sum_{j=1}^{j=n} \left[\left(\sum_{i=1}^{i=n} F_i \right) - F_j \right]}{n}$$

The ratio F_n / F_∞ is an indication of the proportion of the estimated number of usability problems that have already been found after *n* participants. This proportion is illustrated in table 21.

The estimation of F_∞, as indicated by Kanis and Ariz, is based on a rising proportion of shared observations between participants in an ongoing trial. That is to say, as new participants are observed, the overlap between the number of different observations raises approaching asymptotically $\overline{F}_1$ when $n \to \infty$.

A characteristic of this algorithm is that all the observations are independent. For instance, the problem understanding the function of the feed back areas is not related to, let's say, the performance of the software, or the complexity

Table 21 Estimates of F_n and F_∞ after each participant

Participants	1	2	3	4	5	6	7	8	9	10	11
F_n	7	9	18	20	21	23	25	26	27	27	27
F_∞		11.67	45.50	31.27	28.30	28.00	28.51	29.64	29.50	28.54	28.10
F_n/F_∞		0.77	0.34	0.64	0.74	0.82	0.88	0.88	0.92	0.95	0.96

of the browsing structure. Another characteristic of the algorithm is that all the issues are considered to be equally significant.

As shown in table 21, all observed usability problems were already observed after 9 participants. With this dataset, it is predicted that with an infinite number of participants 28.1 problems would be observed. With 11 participants 96% of the predicted usability issues were observed. However, as it is discussed in Kanis and Ariz, this estimation of F_∞ tends to be biased both for practical and for statistical reasons, therefore the value of F_∞ should be seen more as a informed indication rather than as an absolute prediction.

5.6.6 Discussion of the Results

Many of the usability problems mentioned above are relatively easy to solve. They correspond to a category of problems that deal either with the design of the interface or with the algorithms used to calculate the collection's overview. Nonetheless, there is a problem that is perhaps the main usability problem, and the one that is most difficult to solve. This problem is the discrepancy between the user's expectations and the results of the system. For the users, it is not always clear how the software decides which image is similar to which. Some successes (finding all lamps that look alike, or finding chairs that look alike) generate very high expectations in the users. The system could not always meet these expectations.

Humans can group images into categories very easily, because there is an *intention* underlying the classification. For instance, if the user is looking for hair dryers and gets hand drills, the results might be dismissed as irrelevant. However, if the user is looking for products that are syntactically similar to a hair dryer (two elements arranged in an L shape) the results might be considered highly relevant.

The CBIRS uses a low representation of the images based on features such as color, texture, geometry and spatial distribution. When querying the CBIRS, it uses all the criteria and gives the same relative importance to each one. That means that two products that are similar in color and texture might appear similar to the system even though they are geometrically very distant and therefore considered different by a human. A big improvement would be allowing the user to select what criteria to search from. For instance, concentrating only on spatial distribution and color, ignoring all the other criteria.

Judging the participants' way of using the system, it can be said that the summary of the content of the database provided a useful means to find the *seeds* to be used in the queries faster. Browsing, as a method to explore a collection is very attractive, because the user can interact a lot with the system without having to ask too much, but the problem of classifying information into a few categories to browse through is very difficult. Muller presented a review of methods to automatically summarize the content of a collection (Müller, W.T.E., 2001). One of these methods, the automatic generation of random sub-sets, was the one used in this version of the interface. However, it is not enough allowing the user to browse through an automatically generated structure: design precedents need to be grouped in semantically meaningful clusters, which are not necessarily based only on appearance

Browsing through categories could be easier if those categories were meaningful to the user. That is, if the names of the categories match the criteria by which users search images. The intention of the study presented in section 5.5 was to learn about the designers vocabulary so we could use the same words to structure the browsing area. A structure that is closer to their way of talking about products, it is expected, would make the process of browsing more natural. However, as discussed in the previous study, the participants used a very limited vocabulary that would be difficult to implement as a browsing structure.

Nonetheless, the groups used to categorize the utterances in the previous study (see table 17) look very similar to Muller's (2001) typology of design knowledge. This indicates that there could be contact points between his proposition on how to categorize images (Muller and Pasman, 1996) and the results of our studies.

Their approach, organizing a large collection of precedents into categories, proved to be very difficult, resources intensive and dependant on expert knowledge. What is more, the names of the categories that follow Muller's topology are not always understood by all designers. Concepts such as 'unsegmented', 'homomorphic' or 'irregularly disposed' (Muller, 2001. p.174) sound very distant from what the designers say about products. There is little relation between the (poor) vocabulary used by designers to describe products and the (specialized) vocabulary used by Muller in his typology.

However, if the objective of the browsing structure is to give the users an overview of the content of the collection, and at the same time help them find the first *seed*, it is not necessary to organize the entire collection using this structure. Using only some of the categories proposed by Muller, illustrating the concept with a few examples, can be a suitable solution. In this way, it would not be necessary to organize and index the entire collection according to a typological structure. Users can e.g. browse to the category 'rectangular', find there examples of rectangular products, and then use one or more of them to find all the other rectangular products in the collection. This approach will be implemented, tested and discussed in the study presented in the next section.

5.7 Sixth Study: What Designers are Looking for

This study was set with two objectives in mind. The first one was to test the improvements in providing a better version of the browsing tree to give access to images that can potentially be used as *seeds* for the query. The second one was to test again what criteria designers use in their assessments of images. This was already tested in the first study; however, the multiple usability problems of the interface were the cause of frustration and lack of motivation to continue with the experiment, acting as a source of noise for the results. The new interface should prevent this.

To test if browsing a summary of the database would provide a useful means to find this first *seed*, 10% the content of the collection (400 images) was organized in a structure that is largely inspired by Muller's typology of design knowledge (Muller, 2001). Although the results of the study presented in section 5.5 showed that the actual vocabulary of the designers cannot be directly used to generate a structure for the browser, it showed that there are similarities with Muller's theory (this of course, can be due to the fact that they were all educated using Muller's theory). Table 22 presents the categories used. In each category, five images that were considered representative of the concept were placed.

The browsing area was designed in a Explorer-like way, in directories and subdirectories. This is a familiar interface for browsing for many users. The maximum level of nesting was kept to three. The reasons for choosing this maximum depth are discussed in chapter 3.

The criteria used in the assessment of the images are explored by interviews where participants are asked about their choices. These interviews were semi-structured and the entire process (use of the system and interviews) was video taped and the protocols were transcribed.

5.7.1 Participants

The participants in this study were 10 senior students from the faculty of Industrial Design Engineering (IDE) at Delft University of Technology (7 female 70%, 3 male 30%) that participated voluntarily from a group of students who were contacted by e-mail. They were invited to our laboratory, one at a time, to work on a small design assignment and to hold an interview.

5.7.2 Procedure

The procedure followed was identical to the one followed in the first study. The same design assignment and the same research protocol were used. (See appendix 2.1). The only change was that the interviews were more detailed. In this case, the participants were asked questions about three images selected randomly from the ones they collected in the collection area. In some cases, it was necessary to show them the video tapes so they could see themselves and reflect on their actions. All the protocols were fully transcribed. The data collection and the interviews were conducted by a research student. The analysis

Table 22 Categories in which the database was summarized (adapted from Muller, 2001)

Level 1	Level 2	Level 3
Function	means of transport	bikes, car's, moped's, scooter's etc.
	personal devices	Electric toothbrush, personal audio players, camera's, Glasses, Hair Dryers etc.
	household equipment	Refrigerators, Vacuum Cleaners, citrus Juicers, Coffee makers, Irons etc.
	living room	chairs, couches, lamps, tables, televisions etc.
	office	computers, desks, printers, etc.
	tools	power drills, saws etc.
Form	spatial relation	high, narrow, slim, sturdy, wide,.
	orientation	central, linear, orthogonal, peripheral, radial.
	plasticity	geometric, spatial filling, spatial structuring, multiform, organic.
	space distribution	asymmetrical, irregular, regular, symmetrical.
Semantic Features	masculine, impulsive, serious, friendly, feminine, etc.	

of the data was done by this author and another researcher of this faculty. Two pilots were run, and since it was not necessary to adjust the research setting, the data from these were used in the results.

5.7.3 Results

From Function to Context to Form: The Construction of the Product Image

The protocols provided an insight into the rationale behind the designers' choices of visual information, and showed the path followed in selecting the images for the collage. All the participants started by browsing through the database and of these, six started looking for telephones. They asked questions such as *"what type of mobile phone would he have"* (participant 5); *"I am going to start collecting telephones"* (participant 4); *"I'll start browsing by function, [...] telephones for domestic use"*. Participant 7 did it differently, *"I am going to start with something different, with sports"*. The other participant that did it different was number 6, whom started browsing by form, but very soon after switched to function and started looking for telephones. After having explored the images on telephones, a big change in strategy can be seen.

In all cases, the designers talked about the users, describing them in terms of the products they would or would not have. For instance, participant one selected a *"sofa that is a little bit straight, and this lamp, because I do not think that this gentleman would have a pink lamp"* Participant 5 added an Audi saying *"Yep, they drive an Audi... or a Scooter? No, definitively an Audi"* and

Scatter of Categories of Utterances and Strategies Used

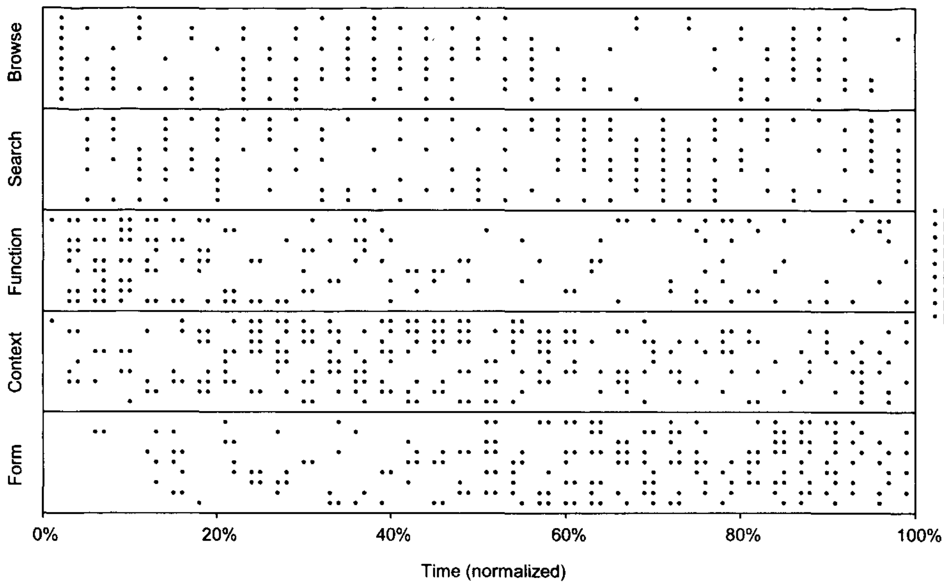


Figure 24 The utterances of the participants refer to function, context or form. The scatter shows what the user consid-ered at a certain time. Time has been normalized, as there are slight differences in the total time spent by all participants.

immediately after added a Scooter in the negative feedback area. Participant 2 mentioned that she would start looking at *"status symbols"*. In general, the most added products were Rolex, B&O, and 'high-tech' products. Others such as the Barcelona Chair, the Porsche designed kitchen appliances and several Macintosh products were also used to describe what the user would possess and therefore considered for the composition of the collage. *"He drinks espresso"* said participant 5 before adding a espresso machine.

Some other products that were put in the negative feedback area had the intention of eliminating what the designers considered users in the given target group would not have. For instance, user 1 tried a search on a mobile phone. One of the results was a calculator (see fig.). She removed the calculator and added later instead a PDA mentioning that *"a PDA would represent better the user in this target group"*. Participant 6 said that *"he would not have an agenda but a palmtop"*. Participants 1 and 5 used an Iron as negative feedback because such a user *"would not have an iron"*; *"I do not think he would have this lady shaver"* (participant 6).

Products were used not only to describe the user in the target group, but also to describe the context in which the telephone to be designed would be used. Six of the nine participants mentioned explicitly that they selected particular pieces of furniture because they imagined the living room of the potential user having these products. Plasma televisions, B&O stereos and halogen lamps were common in the collages: *"B&O products come very close to the atmosphere"* (participant 5).

After considering users and contexts, the tendency of the users is to describe the form the product would have. This is done mostly with the help of new images found in the database and almost always using keywords extracted from the text of the design brief. Examples of what participants said are *"I am looking for masculine forms with high tech details. Masculine is squared"*(participant 4); *"I am looking for squared things, I find that masculine"* (participant 2); *"I can find very little good, hard forms, rectangular and sharp, just cubic like shapes"* (participant 9). Participant 5 said *"I throw asymmetric out because I find it too female and not straight enough". "It has to be streamlined, but not too much that it becomes organic, I do not find that high-tech"* (participant 6).

Other aspects than form were also used to describe the character they were looking for. For instance, materials, textures and colors. Participant 8 mentioned *"I have a high tech aluminum in my head"* and participant 4 mentioned *"black and metallic products are very common amongst men in west Europe".*

This path of moving from function to context to from is not linear or sequential, as shown in Figure 24. This figure is a scatter of the designer's behavior. To construct this figure, the total time spent by the designers was normalized, as there are small differences in the time participants used the database. Every 30 seconds we placed a dot in one of the three categories depending on the last utterance of every designer for that timeslot. Every 60 seconds a dot was placed on search/browse depending on the last action.

The scatter reveals interesting aspects of the designers tendency to focus first, during roughly 20% of the time, on function. This browsing on function becomes less prevalent as other aspects are explored. Between 20% and 80% in the timeline, the focus is on aspects of the user or aspects of the context of use. Interestingly, as the designer progresses in this activity, more an more remarks related to form are made.. The last 15% of the time is mostly spent discussing aspects of the form.

Strategies Followed: Searching vs. Browsing

At a first glance, the distinction between searching and browsing does not follow a particular pattern. Designers started browsing and moved to searching at various points but continued to come back to the browsing area. However, when correlating the strategy to the categories they were looking for, the relation becomes clearer. In the first minutes, the dominant activity is browsing. This occurs because of the *zero page* problem that has already been described in the previous sections. Not having a first seed with which to start the search, browsing is the only alternative.

The dominant category in these first minutes is function. Very soon after browsing, users find themselves navigating through household and office products, using those as *seeds* for searching. Later in the process, as the focus shifted from function to context, the search engine did not produce satisfactory results. The designers kept coming back to the browsing area as they got frustrated by the inability of the system to recognize their intentions. For instance, one designer posed a query with a B&O stereo, a Rolex and an Audi, expecting to get more of these *"status symbols"* (participant 2). As it has been discussed before, only queries with products that share geometrical features can be retrieved, as the semantics of the images cannot be automatically inferred.

Towards the end, when form was more important that other aspects, users started to use the search capabilities again. However, every time it did not deliver the expected results, they went back to browsing, but with less time spent, as results based on form-based queries are more accurate. However, if searching did not deliver the expected results, they went back to browsing. This behavior can be the result of conditioning by experience: all the computer based collections used previously by the participants (such as stock photo collections) allowed only browsing or keyword searching.

Use of Language: How are the Products Described?

When a list of keywords used by the participants during the study is made, it is interesting to notice that most of them come directly from the design brief. "I am looking for something *masculine*, *high-tech*, etc.". In only three occasions were the relation between the geometrical features of products and the semantic features sought made explicit. Those were masculine and squared (participants 2, 4 and 9); organic/asymmetric and feminine (participants 5, 6 and 9) and materials/textures and high-tech (participant 4, 5 and 8). Although in all the other occasions the participants were quite able to select products that would represent their target group, they were still unable to identify what it was what gave those products the character they recognized in them.

The participants produced a total of 524 remarks containing only 52 adjectives, out of which only 10 referred to geometrical features such as round, asymmetric, linear, etc. Most of the remarks used adjectives such as cool, hip, expensive, masculine, boring, etc.

Is there a relation between the criteria used by the designers and the manner the information was structured in the browsing area?

In an attempt to solve the zero page problem, the browsing area was structured using a set of categories inspired by Muller's organization of design knowledge (seet 22). A zoom into the browsing behavior reveals that the categories' form and semantic features were barely used. Most of the browsing was done in the sub-categories under function.

When asked about this behavior during the interviews, the designers said that they did not understand the categories under form (6 times) and that they did not notice the category 'semantic features' (2 times). Others simply saw no need to go to the 'form' or 'semantic features' categories (2 times). When some participants browsed through the 'form' sub-categories, they said that they did not understand the technical terms (2 times); that the terms become clearer by seeing the examples shown (6 times) and that they could use some of the products as a query seed (2 times). In both these 2 occasions it was associated with remarks describing 'masculine' products related to 'squared' products. In general, participants were less interested in looking for products that would have the same geometrical features than in products that, combined, could be used to represent a particular context of use, or what would be typical for a particular target group.

Although there is a relation between the criteria used to select images and the browsing structure, their inability to recognize the geometrical features that give character to a product makes difficult for them to understand the browsing structure, to understand the results and to pose queries that are meaningful to the system.

5.8 General Discussion

One of the aspects that was considered was the design vocabulary used by the participants to express what they were looking for. This was surprisingly limited. Whether this is a consequence of a real lack of design vocabulary or a difficulty in verbalizing their ideas was not investigated. It was clear, however, that should the system have used keywords for a search, the entire process would have been less rich in results. Searching by keywords requires having a clear idea of what is being sought and of how the information in the database was represented and indexed. Due to the ill-defined character of the design tasks, and the vagueness of the initial ideas, this clarity is rare at this point in the design process.

Providing a non-linguistic means of searching was welcomed by the designers. The ability of the system to look for images that look alike allowed the designers to study examples they would not have considered otherwise. One of the participants expressed it as *"when you are looking for telephones, the chances of finding, say, a PDA that inspires you, are very small"*.

The system allows designers to refine their idea by letting them explore a wide variety of products that, though different in function, share other characteristics. The fact that a search for chairs, as in Figure 22, produced also other images that are not chairs, is more to the advantage of the user than a flaw in the system. This type of result stimulates other creative processes, like lateral thinking.

In most computer systems, as in for example mathematical software, the quality of the output generated by the computer, measured in terms of predictability of the results, is very important. That is, the results should be constant, consequent, predictable and always the same for the same operation. Contrastingly, in the case of systems to support creative processes, the way the user's thinking is influenced is far more important than the actual output. It is for this reason that the results of a query in our system do not have to be perfect (and cannot be, because perfect image recognition is still impossible) as long as the response is *consequent* with the user's intentions. It is this *consequence* what defines the *relevance* of the results.

The designer's willingness to use a computer system (for finding design precedents or other type of information) is largely determined by the perceived relevance of the results it produces. Relevance is not a property of the information itself, but an attribute endowed by the user in a certain situation. Relevance is therefore a product of the interaction between the designer and the system. An image, for instance, will be considered relevant if it closely fits the designer's expectations, that is, if the information it contains is what the designer expected it would contain.

Visual information is useful if it is delivered in such a way that the designers understand the rationale behind the choices made by the software. This rationale was not always understood by the designers. For instance, a user wanted to search household products by using a phone and a sofa. This is not an irrational way of thinking, but since the system uses only common geometrical features in these images, the results were not what the user expected.

The designers also wanted to decide what criteria to search for. For instance, they would have liked to search e.g., based only on geometry (ignoring color, texture, etc.). They also wanted to be able to search by product type. In the beginning, when the image of what to look for is still vague, when the designer does not know what to search for, searching by similarity was very useful. However, when the designer does know what he wants, this approach is difficult to use.

Giving examples is a very coarse way of posing a query. The reason is that the user might not be interested in all the characteristics of the given example, but only on a few ones, like the geometry, or the texture, or only a part of the image (the buttons used in that radio, the frame of that bicycle or the screen of that lamp), therefore the importance of allowing the user to select the criteria applied during the search. This imperfect method is nonetheless, very appropriate when the user is still at the stage in which an idea of what is needed is not yet completely formed. However, as the user progresses in the image forming process, the need for specific examples appears. At this point, the precision of a text-based search was often requested.

Responding to the first question proposed in this chapter, many different approaches were reviewed. Text-based searching based on pre-determined descriptions, querying by icons, sketches or just browsing through pre-established structures were common strategies, all of which had significant shortcomings: the impracticality of needing an editor to describe every image or the impossibility of using these descriptions due to the contextual, differential and situational character of meaning attribution. This chapter proposed an approach that, based on image recognition techniques, provides a means for automatically indexing large image collections, and a way to search through them in a non-linguistic way.

While our tests showed the potential of this approach, they also made evident other difficulties. When the search criteria is vague, the system provides an ideal way to help the designer formalize ideas; but when the designer knows clearly what he wants, searching using images is less appropriate.

Eliminating the human mediated process of classifying, describing and indexing images allows the organization of vast amount of precedents. In our laboratory, we indexed over 40,000 images in about 12 hours (which is the time the computer needs to create an index based on the low-level representations of the images). However, during the tests with designers we used only a subset of 4,000 photographs of products.

This chapter has shown that representing precedents using language, icons, sketches are all approaches with disadvantages. To be able automatically to index and retrieve images using a QBE approach, the images must be represented using low-level image representations. Whilst this approach delivers usable results, it also has, as has been shown throughout this chapter, difficulties and disadvantages. These observations make it questionable whether there is a *right way* to represent and index precedents in a meaningful way.

Humans have great ability to recognize if two things are related to each other. For instance, if one takes a vacuum cleaner, an iron and a toaster, it is easy to say that they are all electric household appliances, and that 'iron' is more related to 'toaster' than to say, 'scooter'. This was demonstrated by the user that expected to find household products by giving the system a sofa and a phone. Organizing precedents in a way that allows this ability to be exploited seems to be the next step. This idea has been implemented in a prototype that is currently being tested. Preliminary results show that this is a significant improvement over the system developed for this research.

6 Studying Information Processing in Design: Leassons Learned

Abstract *This chapter discusses the most important lessons learned during the research. It starts by presenting the aspects found to be the main impediments to information processing related to both the designer and the information system. Then, it proposes the variables that we need to study in order to make progress in understanding how designers use information and interact with information systems. Next, the research methodology, regarding the data collection and the experimental settings is presented and critically reviewed. It closes discussing the consequences of the results in design education and making suggestions for the design of information systems for designers, proposing along the way, how to proceed with future research.*

6.1 Introduction

Chapter one proposed that in order to design proper information systems for designers, it is important to understand how they enrich their knowledge base during the design process, what triggers their queries for information, what strategies they use and what factors influence their behavior in relation to information seeking. It was claimed that exploring these questions requires a closer look into the design process and the factors that influence information intake. The aim of this research was to address these issues.

To do that, this research has been based on a number of premises that are discussed in detail in chapters 1, 2, and 3. These premises are (i) Design is a problem solving activity and as such, is an information processing activity; (ii) because of the ill-defined nature of design problems, active problem structuring is required; (iii) problem structuring is a process of using information to transform the ill-defined problem into a more structured, soluble problem or set of sub-problems. This information can be derived from the designer's knowledge and experience (internal sources) and/or from new knowledge acquired by accessing external sources of information.

Additionally, it was proposed that this process of problem structuring is based on three elements: the strategy used by the designer in structuring the problems, the design requirements generated (or given) and the information accessed. Each of these elements has been explored via a number of empirical studies.

The main results of these studies are discussed in this chapter, which is structured as follows: It starts by discussing the main impediments to information processing in design related both to the designer and to the information and information sources. Next, it discusses how to study information processing in design. It does so by listing the main variables we need to study in order to make progress in understanding the designers' information seeking behavior and information needs, and by discussing some research methodology considerations. Then it discusses the consequences of the results for design education and sketches ways of developing information systems to support designers in the early stages of the design process.

6.2 Impediments to Information Processing in Design

The results of the empirical studies have shown some aspects that make it difficult for designers to access, process and effectively apply information during the design process. Some of these are related to the designers' cognitive abilities, knowledge base, experience and volition, others are related to characteristics of the information itself or of the information source.

6.2.1 Related to the Designer

The empirical studies presented in chapters 2, 3, and 4, started from the premise that three factors are the major impediments to information processing. These factors, proposed already by Gestalt psychologists, were *fixation, transfer,* and *representation* problems (See chapter 2). From the observations made in our studies, it appears that some other aspects such as *awareness, confidence* and *volition* also play an important part

Awareness

The designer does not know that he does not know, or does not know that there is information available on a particular topic. The problem of awareness is particularly acute when designers have little experience with the topic. This relationship between information processing and experience is paradoxical. When the designer has little knowledge of the topic, or little experience, his information needs are also lower. Conversely, designers with more experience will have higher information needs. This paradox, studied by Atman (1999), Christiaans (1992) and Rowland (1992) was already described by Erasmus Roterodamus (1469-1536) in his masterpiece Praise of Folly.

In the design of the studies, great effort was put into selecting participants that had the same level of education and design experience, and they were questioned about their knowledge of the topic. The intention was to have designers with no previous experience in the field of the design brief. The experimental setting did not allow observation of the effect of awareness, but it is tempting to speculate what the designers might have done differently had they been aware of the existence of information in the system.

Reliance on previous knowledge

That the designers rely heavily on their own knowledge (even when almost non-existent) and experience has been widely recognized and discussed in literature. This factor hinders information processing because it is sometimes taken to the point of completely ignoring other external information sources. A more moderate form of this phenomenon is when information is accessed to confirm things the designer already knows. The studies in chapters 3 and 4 provide several instances of this phenomenon.

Willingness

This volitional aspect denotes the disposition or reluctance to access and use information sources. Although in our studies designers were not explicitly instructed to use the information system, the fact that they were put in a laboratory with a computer loaded with an information system could have been interpreted as a tacit instruction. It is therefore difficult to say whether or not they would have used the system had there been no implicit expectation. On at least two occasions, however, the designers in chapter 3 mentioned explicitly that they used the system because they had to, and that they would rather have spent their time going out to look at bicycles shops.

Transfer capabilities

This is the case when the designer is unable to apply information from previous solutions to the current situation, or is unable to use knowledge or procedures from different domains to solve a (design) problem. This is mentioned by the Gestalt theorists and is discussed in chapter 2. It was also observable in our studies. For instance, designers of the study discussed in chapter 4 could not understand or apply the information in the documents on personalizing workspaces in other areas (such as transport and construction) to their office problem. Chapter 3 also contains various examples of this phenomenon.

Fixation

In fixation, the designer shrinks the space in which solutions are sought. When this occurs, not only the scope of the solution space, but also the scope of the information sought, accessed and used is restricted. In chapter 2, it was proposed that fixation could occur in two different modes: one in which the fixating element is an *object* (mental set) and another one in which the fixation element is a *procedure* (functional fixedness). Both have consequences for information processing.

The identified fixating elements, that is, the main factors that can cause the designer to become fixated, are, according to the results of study 1, the initial interpretation of the problem (the early representations), the use of language, and the inappropriate use of sketches. Other researchers have identified precedents or examples as another fixating element. In this form of fixation, designers' concepts mimic features of existing solutions. This has been called "fixation by exemplars". In our studies, we found no reason to believe that accessing documents containing examples of existing solutions had any fixating effect. However, other researchers claim that in certain design situations, such as stereotypical design tasks, designers do tend to become fixated by examples.

When designers adhere to a particular way of working, it is said that the fixation is procedural. If the procedure indicates that the process should start with an analysis of the problem and by collecting as much information as possible about it, the designer will follow this procedure independently of his true needs for information.

Although we could not see any indications of mental set (nor were we looking for it), functional fixedness was evident to some extent, particularly in chapter 4, where the produce-three-alternatives-using-analysis-first-synthesis-later approach to design that is advocated in the education at IDE in Delft was very clear. Does procedural fixedness or these 'mental set' forms of fixation have any influence on the information seeking behavior of the designers?

The Gestalt psychology suggest that fixation plays an important role in information processing, and that when fixation occurs, providing more information or even removing the fixating elements does not contribute to 'un-fixing' the person. These conclusions were, however, drawn from studies in puzzle solving and have very limited relevance to design. Literature in design does not deal adequately with the relationship between fixation and the designer's ability to access, process and apply information, making this a potential area for further studies.

Representation problems

In chapter 2 it was suggested that poor or incorrect representations of the problem can lead to inappropriate solutions, or to no solution at all, and that a proper representation of the problem can lead to an adequate solution more quickly. For instance, the ability to see resemblances between problems, though apparently dissimilar, plays a significant role in some disciplines such as physics, where great effort is put into developing these abilities in students.

An appropriate representation of the problem allows a proper expression of the information needs. For instance, designer 1 in chapter 4 represented the problem as 'to invent a *system*', and she found it very difficult to articulate what type of information was needed to complete the assignment, and could come with only 3 aspects (see table 12 in chapter 4). In contrast, designer 2 in the same study considered the problem was to re-think the concept of flexibility in offices, and expressed his information needs in terms of 7 aspects including 'corporate culture', 'group behavior' and 'identity'. This representation of the problem and design needs is, in our opinion, a better interpretation of the design brief.

6.2.2 Related to the information source: Accessibility

Accessibility can be understood as the degree of difficulty in finding and/or getting a piece of information. All research in the field of information access has the objective of reducing this effort and therefore improving accessibility. If the information source is a computer system, which is the case in the studies in this book, the main factors determining the accessibility are availability, means of delivery and cost. Relevance is another factor but will be discussed in a separate section.

Availability

The impossibility of predicting when a design issue or a design requirement will trigger an information query, and the opportunistic nature of information access in the early stages of the design process, makes availability an important aspect. The design process can be disrupted if the requested information is not available when needed, especially when the designer is *aware* of the existence of the information. For instance, one team in chapter 3 thought it would be nice to add wheels to their design, and thought that inline skates' wheels would fit perfectly. However, the information system did not contain this kind of information and they were not allowed to use any other information source, which caused the team to get stuck in the process until they decided to proceed, leaving this aspect of the design unfinished.

Means of delivery

Information can be delivered by a wide spectrum of media: speech, paper, physical samples, etc. It is acknowledged here that designers use these media profusely, but since one of the purposes of this research was to study what aspects are of importance in developing information systems for designers, it focuses on information delivered by means of a computer system.

In our studies, we found some aspects of the information system that can make it difficult to access and process the information. For instance, if the designer has to put too much effort into using the system, the attention will be shifted from the task to the tool. The main problems associated with the system are the *transparency* of the interfaces, *performance*, *format* of presentation and *quality* of the results. Each of these aspects will be discussed later in this chapter.

The format in which the information is presented is also considered under this category of impediments. During conceptual design, visual information is preferred over linguistic information for it fits better with the designers' way of thinking. The designer knows, thinks and works in a visual way (Cross, 1982). This claim is supported by our observations. The designers in chapter 4 said that documents with richer graphical content fitted better their information needs, echoing the comments of the designers in chapter 3. These results strongly suggest that the development of information systems to support designers during the conceptual stage needs to focus on the visual and the formal instead of on the textual and the factual. This is discussed in greater detail later in this chapter.

Cost

The use of the Internet as an information source has significantly reduced the costs associated with obtaining information, but has brought along other problems, such as how to assess the reliability of the source and the difficulty in finding the precise information needed. Reliable sources that can be held liable for the information offered are usually not free. What is more, the information needed for a design assignment might require many different sources, such as ergonomic tables, standards and regulations, properties of materials, etc. No single provider can supply all the information needed and it is often necessary to subscribe to different information services, which could be very expensive. For a designer the question of 'how much would it cost me to know this' is balanced with 'how much do I need to know it?' Cost was not investigated in our studies, as we have compiled the information needed for each study and made it freely available to the designers, but it was an aspect often mentioned during the interviews.

6.3 Variables we Need to Study

The observations made during the experiments suggest some variables that need to be considered in order to make progress in understanding how designers use information and interact with information systems. The studies in this research focused on some of the variables discussed here. Other variables, however, were not directly investigated but the results of the studies made evident the need for considering them in further studies. These variables can be classified as pertaining to the designer, to the ways of expressing information needs, to the information seeking behavior of the designers and to the information system itself. Each of these aspects is discussed next.

6.3.1 The designer: Cognition, Experience and Affectiveness

The ability to process information is a cognitive one; therefore, some cognitive variables need to be considered. These variables refer to the designers' *understanding* of the topic to be treated, their *knowledge base* and their *design strategies*, their *information seeking behavior* and their *affective behavior.*

Knowledge base and experience

The knowledge the designer brings to the situation, be it *domain knowledge,* or knowledge on *procedures, methods* and *strategies*, forms what we call *experience.* In our studies, all participants were taken from the same faculty, with about the same (intermediate) level of design experience. In practice, such an homogeneous group could never be formed. If professional designers had been considered, they would have been from all kind of different backgrounds and would have had different amounts of experience. This would have made for difficulty in comparing the results obtained. The importance of experience in information processing in design is discussed in chapter 2, and by some other researchers. For instance, Rowland (1992) showed that when experts consider a problem as ill-defined and put a lot of effort in usign information to structure the problem, novices do not, for they consider the problem sufficiently defined (see also the discussion on *awareness* above). Atman (1999) and Christiaans (1992) arrived at similar conclusions. The implications of these findings are that the issue of information processing is even more significant in professional practice, as experts are more willing to consider more information and to spend more time in structuring the problem than novices.

Experience can also be a reflection of familiarity with the information source and familiarity with the query languages. To control for this aspect, all the information systems used in our studies were web-based, accessible with a standard browser (Netscape) and made use of standard querying interfaces and querying languages (except the QBE system presented in chapter 5) such as the ones used in popular search engines (Google, AltaVista, etc.)

Design Strategies

Simon (1973) argues that the ill- or well-definedness of a problem is not intrinsic to the problem; rather, these attributes can only be endowed by observing the relationship between the problem solver, his available knowledge and the problem to be solved. In the same sense, one could propose that the tendency to focus on solutions or on problems is situational and idiosyncratic to the designer, but our studies did not provide evidence for this. Design studies have been concentrated so far on multiple designers in the same design situation. What would be the result of longitudinal studies creating situations where we can observe whether the behavior is inherent to the designer, the situation or to other factors like education and experience?

Our studies did not deliver results on the relation between the strategies used and the information seeking behavior. However, they did show that the strategy chosen by the designers was less important to the quality of the results of the design process than accessing and applying the information that was available to them.

Information seeking behavior

When seeking information, designers display a particular behavior that is reflected in the strategies used and in the interaction with the information systems. The information seeking behavior needs to be described in terms of the *strategies* used to search and use the information (systematic vs. opportunistic), and in terms of the *techniques* used to search (browsing vs. searching).

In our studies, the techniques were used to make inferences about whether the information source was being used for a particular purpose or if the use was more explorative and opportunistic. Opportunistic use of the information was often accompanied by random browsing whereas purposeful, motivated queries were accompanied by structured browsing and use of the search engine.

Trust and expectations

These are also variables affecting the information seeking behavior of designers. Trust refers to the perceived authoritativeness of the source and can cause the designer to use the information blindly, even when the facts contained are inaccurate as in the study presented in chapter 3. Providing the designers with an information system to perform a task generates high expectations. The designers think they can find all the answers in the system. Sometimes these expectations are not fully met, leading to frustration and loss of motivation.

Affective behavior

Affective behavior factors that have an influence in information processing are more personal (and situational). These include *motivation*, *diligence* and *thoroughness*, *resourcefulness* and *ability to focus on the task*. Motivation, for instance, has been described as a major factor in creativity by researchers like Amabile (1983). She proposed that skills, domain knowledge and creativity cannot compensate for the lack of motivation, but that motivation can compensate for the lack of those skills. Although in our studies affective behavior such as motivation was not the focus, it was observed. All the designers in our studies participated voluntarily and were very excited about testing new systems (particularly in the tests of the new technology described in chapter 5). Even in those cases where the system crashed and needed to be restarted, the designers were willing to continue (although not without the occasional expression of frustration). In contrast to this, one of the teams of chapter three found the study so uninteresting that it was difficult to use the data from their session.

6.3.2 From Software Prototypes to Research Tools: The Information System

The information systems used throughout this research have been designed as research tools and have been carefully crafted to meet particular research demands. This allowed the flexibility that is impossible to achieve in other contexts, such as when studying information processing using legacy software. For instance, the possibility to modify the log files produced by the system was indispensable to facilitate the data analysis. Other possibilities allowed by developing our own system included the testing of tools such as the collaboration possibilities tested with the teams in chapter 3, the designing of our own browsing structures and the possibility to add comments to the documents, create personal collections, etc.

Our studies showed that designers make judgments not only on the information, but also on the information retrieval process and consequently on the information system itself. They expect the system, even if it is only for experimental purposes, to be *ready to use*. Problems with the system make the designer shift his attention from the task to the interface, acting as a source of distraction, causing frustration and loss of motivation. Therefore, the need for realistic prototypes with *transparent interfaces*, with appealing *appearance*, carefully designed *layout* and graphical content. The designers also judged the system in terms of *performance* (the system produces results in a reasonable time), *robustness* (does not crash) and *reliability* (always available when needed).

The difficulty in using this approach –of developing prototypes to test ideas and possibilities– is that it required significant effort from the research team: not only research skills are required, but also skills in designing and implementing complex software. However, its strength lies in that it allows research of the aspects of interest as well as testing technological possibilities.

6.3.3 The Query Languages: Expression of Information Needs

When interacting with people as information sources, expressing information needs is easy. This easiness derives from the fact that natural language can be used along with other gestural means. Additionally, the interlocutor can help in (re)phasing and shaping the question, and in assessing the usefulness of the information contained in the answer. When using information systems, this flexibility to express information needs is supported only to a very limited extent or, in most cases, not supported at all. This is due to restrictions in existing query languages, which are mostly based on keywords.

Searching by keywords requires having a clear idea of what is being sought and of how the information in the database is represented and indexed. Due to the ill-defined character of design tasks, and the vagueness of initial ideas, this clarity is rare during the early stages of the design process. Potential research questions derived from these reflections would be: How are queries formulated? What query languages/interfaces are more appropriate to support the vagueness of the information needs during conceptual design? Studying how queries are reformulated and refined, iteration in searching and evaluation of the search results would provide more insight into the nature of the designer's information needs.

6.3.4 Relevance Criteria

The concept of relevance is a complex one, and requires at least two degrees of intellectual involvement. One relates to system-driven relevance and the other to human-driven relevance (Saracevic, 1975; Swanson, 1986; Harter, 1992). As discussed in chapter 4, this book considers mainly the human-driven view of relevance.

This view recognizes that relevance is subjective, cognitive, situational and dynamic. Relevance is subjective because it cannot be considered a property of the information itself; instead, it has to be seen as an attribute endowed by the designer to the information in a certain situation. But it is also cognitive: it depends on the designer's knowledge and perceptions, and it is situational, for it relates to the designer's need for information to complete a particular design task. Additionally, relevance is dynamic; the user's perception of relevance changes as he progresses in the information-seeking process (Schamber, 1994, Saracevic, 1975, 1996).

The importance of studying relevance criteria lies in the fact that relevance judgments are always associated with situational information needs. By studying the relevance criteria used by designers in assessing the usefulness of information, we can gain insight into the designer's information needs, and into how these change as the designer enriches his/her knowledge base.

6.4 Research Methodology

As has been discussed previously in this chapter, studying information processing in design requires consideration of a large number of factors., First of these are the problems that might hinder information processing both related to the user and to the information source. The previous sections have outlined the variables that, in our view, need to be prioritized in order to improve our understanding of how designers seek, evaluate, process and apply information in early stages of the design process. Some of these variables have been studied and discussed in this research, others are proposed as a result of a critical evaluation of the studies. This section discusses aspects of the data collection, data analysis, experimental setting and research tools used.

6.4.1 From Logbooks to Designer's Accounts: Data Collection

Studying such a complex task requires the development of a research methodology that fits the particular research interests. The methodology used in this research evolved, from the log-files centered approach used in chapter 2, to the more detailed observational techniques used in chapter 4.

Chapter 2 concentrated on two main aspects: the evaluation of the designers' interpretation of the problem and the quality of their results, and the use of the information system provided. The first aspect was studied using the method proposed by Christiaans (1992) to assess the quality of the results of a design process. A panel of experienced designers and teachers were used to assess the concepts in a number of parameters also defined by Christiaans (1992). This method has been tested in many other studies, among others Dorst (1997) and van der Lucht (2001).

The second aspect was studied using the log files of the information system. The expectation was that by studying how the designers used the information system, inferences on the designers' information seeking behavior could be made. Soon it became evident that the log files could not provide all of the answers. For instance, it was not possible to determine what information was more important or what triggered a query.

Log files can reflect, but cannot explain behavior. Although the log files could not provide information about why a document was accessed or how the information was used, they were very useful in reflecting the designers' behavior. For instance, log files provide information on what documents were accessed and in what sequence and whether the designer was browsing in a structured or in a random way. Log files give account of the techniques used (browsing vs. searching) and provide hints about the information seeking strategies (structured vs. opportunistic).

The questions related to *what* triggers a query needed a different approach. In the study of design requirements in chapter 3, log files were combined with videotaping of the design sessions. In this study, we decided to use teams instead of individual designers so it was possible to follow the design process by means of the remarks they made when talking to each other. When using teams, the designers need to communicate with the other team mates and in doing so, they account for a great deal of their thoughts, even without asking them explicitly to 'think aloud', as is necessary when using individual designers.

This approach allowed us to determine, by studying the conversations held between the team members, not only why the designers accessed certain documents, but also to determine, partially, how the information was used. In both the first and the second studies (chapters 2 and 3) the information intake was measured in terms of the amount of documents accessed and the total amount of time spent on the system. Both measures proved to be inappropriate, as they only showed the amount of information accessed but failed to indicate the actual amount of information that was effectively considered and used.

The conclusion was that if you do not ask the designers about *why* they access information, *for what purpose* they use it and *how* they determine what is important, you will never know. In the third study (chapter 4) the research method changed. In this study, log files were combined with *in situ* observation of the designer's behavior and with video taped semi-structured interviews before, during and after the information search.

By being in the same place as the designer is, the researcher is able to monitor more carefully the use that the designer makes of the information system, and to observe other indicators of relevance that cannot be logged in a file, such as if the designer makes notes while accessing a document. By duplicating the screen of the designer, it is possible to determine what parts of a document are more important. In the previous studies in which the whole document was considered in the analysis, that level of resolution is too high; sometimes it is only a graph or a paragraph that is interesting to the designer.

Asking the designer for his information needs before the design session and after having read the brief allows the researcher to study the designer's understanding of the problem and their level of awareness. Asking them in every coffee break about what information they have found interesting and what information will be needed to continue provides information about how information needs are shaped as both the design process and the information seeking process progress.

Lastly, asking the designers specifically about the most relevant documents provides insight into how the information in those documents was used in the design process, and what aspects of those documents were determinant in the designers decision to consider that information.

The combination of methods to study information processing used in the third study allowed triangulation: measuring the same variable (perceived relevance) using different methods from different sources (time spent on the document, adding to personal collection, use of the information in the design process and the designer's own personal accounts).

The approach used in chapter 5 was Design-Test-Improve-Test. A research tool was designed with the intention of testing a technological platform. The results of the first tests (study four) were used to draw a list of requirements for a system to handle precedents in design. Study five uses techniques drawn from usability studies to determine what are the main usability problems of the new system developed from the results of study 4.

The sixth study uses protocol analysis to determine which aspects of the visual information are of importance to the designers when collecting images for a particular purpose, e.g., to compose a collage that communicates certain design intent. Protocol analysis proved useful in revealing an important factor, which is the vocabulary designers use to describe the products dealt with.

6.4.2 Experimental setting

The use of the information systems and the use of accessed information in the design process were the main factors observed throughout the studies. Two factors regarding the experimental setting might have affected the observations and the results of the studies. These are *training* and *instruction*.

The designers in our studies are trained in gathering and analyzing data at certain stages of the design process. Their information seeking behavior thus reflects conditioning factors such as education. In addition, it is possible that the designers use the information system because they have been (tacitly) instructed to do so, or because they feel obliged to given they are provided with a design brief and an information system.

6.4.3 Research Tools

An important aspect of the research presented in this book is that the information systems used have been developed along with the studies. Although developing them was not the main objective, they gained importance because they allowed the testing of particular concepts and ideas. An example is the possibility of supporting non-linguistic queries in the QBE system developed for chapter 5. In this research, the software developed became part of the research in what it helped shape some of the studies. For instance, the need to allow designers access to the visual database by other means different from the query by example approach motivated the discussion on design language. The premise was that structuring the visual information in categories that follow their natural way of talking about products would make navigating easier.

This particular tool can be exploited in research in many different ways. For instance, to follow more closely the process of image forming in early stages of the design process. With this tool, it is possible to observe what images the designer uses as positive and negative examples (relevant/irrelevant), as well as what images are actually collected in the collage area. This provides a unique opportunity to see in images how the designer's needs for visual information are shaped by the visual information already accessed.

6.5 Consequences for Design Education

Textbooks and educators assert that some design strategies lead to better results than others (problem focusing vs. solution focusing (see chapter 2 for a complete discussion and references)). The studies presented in chapters 2 and 4 have shown that some other factors like the appropriate use of information have much more impact on the quality of the results than the strategy followed by the designers. The highly regarded problem oriented approach did not deliver the best results. This is not to say, however, that this approach should be replaced in the design studio by a solution oriented one. Problem focusing as a design strategy is useful in design education because it requires students to analyze the context of the design and keep an open and flexible mind in the conceptual stage of the project.

The same study also showed that when designers were willing to access and process (external) information the design results improved significantly. Literature provides evidence that even graduate students and professional designers have difficulty defining what information is relevant for their design situation and what is not. However, in most design schools, educators still think that gathering, handling and using information is something the student will learn by experience.

The tendency displayed by designers to disregard information is due partially to the complexity and inaccessibility of information sources, and partially to the difficulty in transferring knowledge from existing cases to new design situations. This means that active training in applying information to new design situations is necessary. In physics, e.g., the ability to see resemblances between problems, though apparently dissimilar, plays a significant role, and great effort is put into developing these abilities in the students. Design tutors could learn a lot from the experiences in those disciplines.

6.5.1 Precedents and Fixation

One of the reasons for the apprehension of teachers about letting their students use certain types of information such as design precedents, is the fear of imitation and fixation. During a demonstration of the QBE system to a well-known designer and teacher in the Netherlands, his first remark was *"What do designers need such a tool for? Well, to copy other products, of course!"*

However, research in this matter is contradictory and inconclusive (see section 2.3). In some experiments, like the ones reported by Jansson and Smith (1991, 1995), the use of examples that were too close to the product to be designed caused the designers to be fixated, leading them not towards creative, new solutions, but to prototypical ones. It is these types of results that makes design teachers apprehensive towards the use of precedents in the design studio. However, other studies, like the ones reported by Purcell and Gero (1991, 1996) and chapters 2 and 3 in this book, presenting examples of similar solutions did not have this negative effect.

Christiaans and Van Andel (1993) also found that if only a few examples of solutions to the design problem are presented, the designers are more prone to become fixated. They suggested that the problem might lie in the amount of examples given. If only a few examples are given, designers will tend to use them as templates for their designs. In contrast, when many examples are available, they lead the designers to the exploration of new, more creative solutions. In this respect, the tool developed in chapter 5 has a great potential for design education, for it allows the designers to search for precedents based on particular geometrical features that might be of interest, favoring other cognitive processes like lateral thinking.

6.5.2 Serendipity and opportunism

Some researchers like Roberts (1989) have proposed that the information that leads to creative solutions is the result of serendipitous encounters. Other researchers like Visser (1992), Lawson (1997) and Guindon (1990) have recognized that designers do have a tendency to use unexpected aspects of information *opportunistically*. The results of our studies are consistent with these views.

Luck is where preparation meets opportunity. Opportunistic encounters with information will only be taken advantage of if the designer has the proper mind set to recognize the usefulness of the information (preparation). In the same way, the information in the system should provide the designer with the opportunity. One of the most frequent complaints of our designers is that the information we provided in the system throughout the experiments was too focused on the topic of the design brief. This lack of variety, imposed by the experimental setting, diminishes the chances of serendipitous encounters. Similarly, restricting the amount of information used in the design studio, whether it is by the tutor or by the student himself, and whether it is in not using precedents or not using information at all, eliminates the opportunity factor.

The role of design representations in analyzing and conceptualizing has been emphasized. Although several authors have pointed out the important role sketches play in the generation of new ideas, sketching and other visualizing techniques are still largely considered as a skill rather than a powerful tool for the exploration of solutions. The difference between skills (e.g. drawing or solving complex differential equations) and the exploitation of those skills is not sufficiently emphasized. These observations should make us take a more critical, reflective view of our current teaching paradigms.

6.6 Designing Information Systems to Support Conceptual Design

The result of this research can be used to describe a variety of information systems for designers. For instance, Content Management Systems that allow the organization of large collections of documents including text, images, binary files, multimedia objects, etc. such as the one developed for chapters 3 and 4. However, these technological aspects of CMS are largely addressed by information technologists so, in this section the focus will be on the future of a system to handle design precedents. The discussion will be based on three aspects: The content, the query mechanisms and the indexing/retrieving technology.

Choosing to focus on this system and not on the CMS discussed in chapters 2, 3 and 4 is not capricious. The results of the study in chapters 3 and 4 strongly suggest that, in the earliest stages of the design process, the information that is most needed is visual. In particular, it is valuable to have information related to products from different domains, for part of the designer's struggle is to come up with *different* ideas. Moreover, as Cross (1982) put it, the designer knows, thinks and works in a visual way.

6.6.1 Content

The system presented in chapter 5 contains only images of products. Although more than 40,000 images were collected, including images of people, animals, landscapes, flowers and plants, only 4,000 images of products without background were used in the studies. The reason was a technological one. The algorithms used in image recognition fail to describe even a very small part of the semantics of an image: it is not possible to recognize that the image is e.g., a frog or a car. It is also not possible to separate the image of interest from its background. Therefore, very different images with similar backgrounds would appear as similar in the results of a query. Since the objective in that chapter was to test the potential of the technology to handle design precedents, it was decided to use only images of products without background.

The results of the third study presented in chapter 5 indicate that this might not have been the best of choices. A close look at the results reveals that most of the time designers were looking for images that would represent particular *contexts*. In this task, they complained about having only images of products. This means that they need more than just precedents, and the system should therefore be able to handle other type of images as well.

6.6.2 Asking Questions: Support for Rich Queries

One of the main problems with keywords based systems is that it is very difficult to fully express information needs using only a few keywords, and that query languages are difficult to learn and to understand.

Imagine you go to China and you do not speak Chinese. At home, one of the fuses breaks. You know it is not worth bringing in an expert just to change a fuse and decide to do it yourself, so you go to a shop to buy a new one. You have two options: search in a dictionary for how to say fuse in Chinese (保险丝), but still you would probably not be able to pronounce it. You can also take the old one with you and give it to the shop assistant. This situation is not completely foreign to many, and in the design process, it is certainly very common, not because designers do not 'speak' the language of design, but because often they lack the proper words to describe what they want or because they just simply do not know exactly what is what they want.

One of the things we have learned by talking with professional designers and with students, and by observing them work, both within this research an in our experience as design teachers design practitioners, is that when they start working on a design brief, they very soon make up their minds about the character they want to give to the product that needs to be designed. When the designers are very talented, they can immediately start exploring different formal configurations, proportions, geometries, etc. with more or less elaborate sketches, depending on the designer's skills. When they cannot express what they want with drawings, they use examples of existing products to illustrate their point (to themselves or to others) and use these as starting points for their designs.

If sketching is difficult at this stage, verbalizing the ideas and putting them in the form of keywords is even more difficult: organic, symmetrical, round, etc. are poor ways of describing a vague idea. The designer then goes to magazines and starts flicking through them in the hope that an image will speak to him and will help him in the form creation process. He could also go to a computer based information system, and try to search, but in this case, he will be in the situation of the alien in China that cannot express what he wants in words. The solution is then, "give me an image that looks like this one": A Query by Example.

If you happen to be completely useless at Chinese, you might end up in a shop that does not sell fuses, and be unlucky enough to find an assistant that has never seen a fuse before. You might end up buying something that looks like a fuse, but is in fact something else and your troubles can get worse. However, if you are a designer and are looking for examples of drills, you might find it very useful to see other products that are syntactically similar (hair driers, silicon guns) or that use similar materials or textures, or that share some geometrical features. This is, unfortunately, as far as the technology used in the system presented in chapter 5 (image recognition) can take you. However, what if you are interested in tools and not in geometrically similar products, or if you are interested in products used in a particular context (gardening products, kitchen products, etc.)? In this case, pure image recognition is not enough, because *semantically* similar products do not necessarily look alike. Take for instance a computer mouse, a stapler and a pencil sharpener, all office products. A sanding machine like 'the mouse' of Black and Decker is geometrically closer to a computer mouse than a keyboard, yet, semantically, a keyboard is closer to the computer mouse. If given this set of images, a human can easily recognize that their commonality is that they are all office products. Can we make computers do that as well? We believe we can. Preliminary tests with a new computer system show that given at least two products (semantically related), it is possible to retrieve products based on semantic closeness rather than geometrical closeness (see next section)

Of course, if you spoke fluent Chinese, the easiest way of finding your fuse would be by asking directly 我可以得到保险丝吗?. In the same way, if you know what you want, a keyword-based search could be more efficient (chair lounge, Le Corbusier) than giving examples. The QBE approach must be seen then as a complement to the traditional language based search, not as a replacement.

6.6.3 Recall and Precision: Quality of the Results of a Query

In most computer systems, as in for example mathematical software, the quality of the output generated by the computer, measured in terms of predictability of the results, is very important. That is, the results should be constant, consequent, predictable and always the same for the same operation. Similarly, the quality of the results of a query in an information retrieval system is expected to respond to the particular information needs of the user. These information retrieval systems have as an objective providing the user with as much relevant information as possible (high recall) having as little irrelevant information as possible (high precision).

Contrastingly, in the case of systems to support creative processes, the way the user's thinking is influenced is far more important than having high recall or high precision. For instance, the fact that a search for chairs, as in the examples presented in figure 23, produced also other images that are not chairs, is more to the advantage of the user than a flaw in the system. This type of results stimulates other creative processes, like lateral thinking. It is necessary, however, that the results are not completely random, and that the user understands the rationale behind the choices made by the software. In our studies, this rationale was not always understood by the designers. For instance, a user wanted to search household products by using a phone and a sofa. This is indeed a more natural way of thinking, but since the system uses only common geometrical features in these images, the results were not what the user expected. It is therefore necessary to support the designers with a system that allows them to pose more *meaningful* queries.

6.6.4 Meaningful Searches: The Indexing/Retrieval Technology

One of the motivations to use Content Based Image Retrieval System (CBIRS) was the promise of results without having to describe, organize and index each image, as is necessary in current systems to handle design precedents. This allows escaping the subjectivity of the interpretations, escaping the imprecisions of language and avoiding differences in opinion between users. However promising, as was proved in the tests in chapter 5, this approach falls short of fulfilling all the designer's needs for visual information.

The reason is that the algorithms available cannot recognize what the image contains (in semantic terms) but humans can, and with great facility. This ability was reflected in the searching process of the designers in chapter 5. It is very natural for them to expect living room furniture if using a sofa and a lamp as seeds for a query, because a user can *understand* that these two are related, and that the common aspect is that they are both elements of a living room. To the system, they are geometrically so different that the results are completely incoherent. Image recognition is useful, but not enough!

A system that is able to *understand* the semantic relation between elements in a query would solve this problem, but it would require metadata associated with the image, describing what the image is. This means that for the time being, we cannot escape language. This approach has been tested with a prototype developed after this research was completed. Instead of using image recognition algorithms, it calculates the semantic distance between the nouns associated with the images and retrieves images whose nouns are semantically related. The results are very promising. If the designer who posed the query for living room elements using a lamp and a sofa had had this system available, she would have received a set of results containing {buffet, bookcase, cabinet, dinning room furniture, **lamp**, nest, **seat**, sleeper, table, wall unit, ...} and under seat would have found {bench, chair, **sofa**, lounge, couch, pouffe, ...} These results were possible with a minimum of metadata added to the images (only one noun per image).

The main difference between this approach and the traditional approach of 'filtering' used in the keywords based queries is twofold: the indexing/retrieving technology, and the method used to pose the queries. In our approach, the searches are based on the semantic distance between two concepts instead of matching keywords, and the fact that the concepts are given to the system using examples of images instead of keywords. The results are so convincing, that we strongly suggest continuing with research in this area, not to replace the image recognition system developed in chapter 5, but to enhance it, creating a system than allows the user both types of searches. This, we believe, would make the information more accessible to the designers, and –why not–, more fun to use!

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John Restrepo
Copenhagen, October 2004.

Apendixes

Appendix 2.1 Original text of the assignment (in Dutch)

Het hedendaagse bedrijfsleven kenmerkt zicht ondermeer door grootscheepse reorganisaties. Onder invloed van verschillende factoren, zoals ontwikkelingen op het gebied van informatie technologie, een toenemende mate globalisering en meer kennis in het algemeen, onstaat een dynamische omgeving die bedrijven noodzaakt tot verandering van hun organisatiestructuur niet allen op organisatorisch niveau, maar ook wat betreft hun huisvesting. Dergelijke veranderingen laten zich karakteriseren door de term "flexibilisering". Het aanbod van producten en diensten wordt gevarieerder en meer klant gericht. Het inspelen op snel wisselende vragen van de klant leid bijvoorbeeld tot een toenemende behoefte projectmatig te werken. Bovendien zijn er meer mogelijkheden voor deeltijdarbeid op vrijwel alle niveaus van de organisatie. Dit kan werktijden en werkvormen beïnvloeden, omdat fysieke aanwezigheid "op de zaak" niet altijd noodzakelijk blijkt te zijn. Dergelijke ontwikkelingen doen de belangstelling voor alternatieve vormen van kantoorhuisvesting toenemen. De rijksgebouwdienst spreekt in dit verband over *kantoorinnovatie* en bedoelt daarmee het vertalen van maatschappelijke, organisatorische en technologische ontwikkelingen in concepten van kantoorhuisvesting. Één van de nieuwe kantoorvormen die hierdoor is ontstaan is het zogenaamde combinatiekantoor, waarin verschillende werkplekken zijn gerealiseerd die gerelateerd aan het soort arbeid dat moet worden verricht. Zo wordt onderscheid gemaakt tussen medewerkers die op vaste tijden en een vaste plaats werken en medewerkers die vaak buiten de deur werken en slechts af en toe en op wisselende momenten van kantoorfaciliteiten gebruik maken.

4H Office is een bedrijf dat zicht heeft gespecialiseerd op het gebied van kantoorinnovatie. Het bedrijf is begonnen als producent van allerlei kantoorbenodigdheden -van desktop accessoires tot volledige kantoor inrichtingen— en kan door een enorm netwerk aan contacten gemakkelijk inspringen op alle nieuwe ontwikkelingen in kantoorland. ***4H Office*** heeft de pretentie oplossingen te kunnen bedenken voor alle kantoorsituaties zowel in de vorm van producten en inrichting, als ook advisering bijvoorbeeld reorganisatie en zelfs in de dienst verlenende sfeer. Zodra een probleem te maken heeft met kantoren kunnen zij het oplossen. De volgende situatie is aan ***4H Office*** voorgelegd en jij bent voor de opdracht ingehuurd.

Een kantoorsituatie waarin arbeid—gerelateerde werkplekken zijn gerealiseerd, bestaat vaak uit een combinatie van cellenkantoren, kantoortuinen met wisselwerkplekken, vergaderruimtes en stilte werkplekken (voor diegene die geconcentreerd moeten werken). De flexibele werknemers maken afhankelijk van hun taak gebruik van deze verschillende kantoorvormen en hebben dus geen werkplek meer! De wisselwerkplekken in een dergelijke kantoorsituatie zijn voorzien van een bureaublad met enkele standaardvoorzieningen zoals een computer en een telefoon of aanslauitingen hiervoor. Verder bevinden zich basisfaciliteiten zoals fax en kopieermachines in de directe omgeving. Het probleem is dat een werknemer op ieder gewenst tijdstip en op iedere gewenste plaats moet kunnen beschikken over de spullen die nodig zijn voor het verrichten van zijn specifieke taak. En hij wil ook op ieder gewenst tijdstip en op iedere gewenste plaats het bureaublad kunnen inrichten als zijn eigen werkplek. Gevraagd wordt om een conceptoplossing te bedenken voor dit problem

Apendix 2.2 Transcripts of "early representations" (In Dutch)

Participant 1

Het ontwerpen van een "unit" waardoor/waarmee werknemers in een bedrijf zonder vaste werkplekken (voor hen), een buro/werkplek kunnen inrichten met de dingen die ze nodig hebben om aan de slag te kunnen gaan (hun eigen spullen zoals bv. papieren e.d., niet de algemene dingen zoals fax en zo).

Participant 2

De opdracht is "iets" te ontwerpen waarmee een kantoor-unit (die aan niemand in het bijzonder is toegewezen en (daardoor) geen identiteit heeft) snel tot een "eigen" werkplek gemaakt kan worden. D.w.z. dat de werknemer er zijn specifieke taak kan uitvoeren en de door hem benodigde (hulp)middelen voorhanden heeft. (Deze specifieke middelen houden meer in dan computer, fax, telefoon en kopieerapparaat.)

Participant 3

Er is een probleem (door 4H Office) gesignaleerd:

Innovatie in de kantoorwerkplekken, maakt het moeilijker om een geschikte werkplek te bieden aan werknemers die onregelmatig op het kantoorwerken. Voor de vaste medewerkers op kantoor zijn er meer eigen persoonlijke werkplekken beschikbaar die voor hun taken specifiek ingericht zijn (= de huidige trend). Voor degenen die onregelmatig op het kantoor werken moet er een werkplek (product) ontworpen worden, waarbij de verschillende taken (computeren, vergaderen, etc..) daar uitgevoerd kunnen worden. Tevens is er een feature gevraagd, waarmee deze werknemers hun werkplek tijdelijk persoonlijker kunnen maken. De opdracht vraagt om een conceptoplossing voor dit probleem in tekst (A4'ljc) en beeld (presentatietekening).

Participant 4

In de tegenwoordige werkomgeving is behoefte (vereiste) aan 'flexibiliteit' van de kantoor inrichting. Het kantoor wordt opgedeeld in secties met ieder een eigen functie: tekenafdeling, computer, en stilte kamers. De kantoorarbeider kan afhankelijk van zijn behoefte gebruik maken van zo'n sectie. Er dient echter genoeg capaciteiten van een sectie aanwezig te zijn, om het variërende aantal gebruikers aan te kunnen. Eventueel dient een tekort opgevangen te worden door een andere sectie, die echter toch qua vormgeving/functie voldoet aan behoefte van de gebruiker: snel "thuisvoelen" aan 'je nieuwe' werkplek is belangrijk. Deze werkplek zo inrichten zoals jij dat wilt. Maar de stilte kunnen krijgen, las alle stilte ruimtes bezet zijn. De huidige systemen voor kantoorinrichtingen hebben een bepaalde mate van flexibiliteit. Daarnaast is er flexibiliteit in de inrichting (afdelingen, secties). De kantoorinrichter 4H-office probeert/wil het huidige systeem 'flexibeler' maken; de flexibiliteit vergroten, capaciteit vergroten om evt. behoeftes op een efficiënte manier op te kunnen vangen. Dit kan een structurele of een lokale verandering zijn. Ontwerp een concept die de flexibiliteit kan vergroten.

Participant 5

Het ontwerpen van een conceptoplossing voor het bedrijf 4H Office. Het gaat om een probleem van flexibele werknemers, die in een bedrijf geen eigen werkplek hebben, maar zo af en toe wel op kantoor werken. Dan hebben ze hun eigen spullen nodig, hun eigen bureau-blad indeling etc. Bedenk voor dit probleem een oplossing.

Er zijn verschillende kantoorindelingen: kantoor tuinen, cellen & afgesloten ruimtes (voor geconcentreerd werken).

Participant 6

The assignment is to find a housing or organizative solution for people who work in an office and partly have their own space and "work-tools", partly share them with other people at undetermined time. The problem is then how to solve the problem that an employee can have in handling easily different kind of work-devices, both if they are his own or he shares them with other people, in other rooms.

Participant 7

Ontwerp een kantoorinrichting die aansluit bij de ontwikkelingen op het gebied van flexibele werkplekken, zodat het mogelijk is dat een werknemer op ieder gewenst tijdstip en plek zzijn werkzaamheden kan uitvoeren.

Participant 8

Er is steeds meer behoefte aan flexibele kantoorinrichtingen als gevolg van flexibilisering. Zo hebben werknemers geen eigen werkplek meer die vast is, maar werken ze op verschillende plaatsen die zijn ingericht voor de taak die ze op dat moment moeten verrichten (computer werkplek, faxplaats enz.) Deze werknemers willen op de werkplek toch hun eigen materialen en benodigdheden bij de hand hebben. Er moet dus een product worden ontworpen waarmee de werknemer van elke werkplek zijn eigen werkplek kan maken, met alles wat hij daar (persoonlijk) bij nodig heeft.

Participant 9

Ontwerp een systeem dat het beheren van persoonlijkewerkbenodigdheden van flexibele werknemers ondersteunt. Beheer houdt in:

- verplaatsen...
- bijeenhouden/stallen...
- bruikbaar maken op de werkplek ...
- ... van persoonlijke werkbenodigdheden.

Participant 10

Flexibiliseer de fysieke invulling van de werkplek. Waarbij werkplek staat voor al die zaken die men in het algemeen nodig heeft bij de beroepsuitoefening.

Participant 11

Ontwerp een product dat een oplossing is voor het probleem dat ontstaan is met de toenemende flexibiliteit in kantooromgevingen, nl dat er personen zijn zonder vaste werkplek die toch elke keer op een andere plaats in het gebouw al hun spullen kwijt willen kunnen aan een werkplek die ze op hun eigen manier willen kunnen inrichten.

Participant 12

To design a new concept of house office taking care of the new way of workin this kind of places and jobs and the necessities of a company had changed a lot and they need different typology of space to work, despite of the inconvenients that it can carry. The idea is to manage and solve a problem in this new way of work giving solutions of what are the necessities and how we can give them the answers of the concepts that now are not arranged.

Participant 13

Het ontwerpen van een concept voor een wisselwerkplek, die standaard is uitgerust met een bureau, computer en telefoon, een kopieerapparaat, fax en printer bevinden zich op korte afstand hiervan.

Deze wisslewerkplek moet op elke gewenste tijd en op elke gewneste plaats snel ingericht kunnen worden als persoonlijke wekplek met vaste inrichting naar eigenvoorkeur.Deze opdracht wordt uitgevoerd voor een bedrijf Office 04, dat zich bezig houdt met alles op het gebied van kantoorinnovatie, zowel producten als advies voor bedrijfsorganisaties.

Participant 14

Een kantoor inrichting te bedenken die gericht is op werktaken en niet individueel "bezit" is, maar wel individuele instelliingen kan hebben.

Iedereen moet op de werkplek kunnen werken, eventueel is de werkplek onderverdeeld in een aantal deeltaken (categorieën) en tevens moet op de werkplek ook algemene ruimtes becshikbaar zijn voor vergaderingen etc.

Hoofdzaak is dus dat iedereen van alle faciliteiten gebruik mag amken en niemand meer een "persoonlijke" werkplek heeft. Echter kan de werkplek wel aangepast worden. Tevens moet gelet worden op thuiswerken e.d.

Participant 15

The assignment has been given by a verry innovative design office - however they are woking for a big institution so presumably have to find large scale & economically viable solutions. With this assignment they are reaching to a current trend that offices are becoming more flexible, workers choose different worksettings according to their job & their personal interest. Also new technology such as computers (PC's) release flexible organisation of work spaces. The assignment is thus to consider the new work patterns & environments of individual workers and design for their personal storage/worktools/job type needs.

Participant 16

Er zijn tegenwoordig steeds meer werknemers die geen vaste werkplak meer hebben en op veel verschillende plaatsen werken.

De opdracht: Ontwerp een werkplek die heel gemakkelijk aan een persoon (en zijn/haar wensen is aan te passen, zonder dat dit een vaste werkplek is voor die persoon. (De doelgroep zijn wisselwerkers: mensen die op verschillende locaties hun werk doen (iets wat door PC's vergemakkelijkt wordt).

Participant 17

Ontwerp een werkplek waarbij de gebruiker in elke situatie toegang kan krijgen tot zijn gebruiksvoorwepen (fax, telefoon, computer). Specifiek gericht op de kantoor omgeving (jkantoor tuin, vergaderplek, werkplek enz.) Flexibiliteit staat voorop.

Participant 18

Onder de term "flexibilisering" worden eigenlijk de werkplekken minder persoonlijk gemaakt. Alle benodigdheden zzijn er per werkplek wel, maar alle specifieke persoonsgebonden iotems niet. De opdracht is om een oplossing re vinden, waardoor deze items snel efficiënt in de werkplekken kunnen worden ingebracht; hierdoor wordt het switchen tussen verschillende werkplekken vergemakkelijkt.

Participant 19

Ontwerp een conceptoplossing voor situaties van "flexible werkplekken".

Gezien de huidige trend van flexwerkers en projectgestuurde opdrachten, is het zo dat kantoren fysiek voorbereid dienen te zijn op een wisselende vraag naar verschillende typen werkplekken: vergaderruimtes, stiltewerkplekken (voor mensen die zich moeten kunnen concentreren), enz. De flexibiliteit brengt met zich mee dat men geen vaste plek meer heeft. Toch zal men de werkomgeving naar eigen zin willen vormgeven en inrichten. Hoe dit te doen?

Participant 20

Voor het bureau 4H Office moetje een opdracht doen. Deze opdracht ligt op het gebied van flexibele werkplekken. Er is een verandering gaande in de kantoorwereld. Mensen hebben niet per definitie een vaste werkplek, maar werken bijvoorbeeld thuis, of voor een bepaalde opdracht op een speciale plek met een team enzovoorts. De bedoeling is om ervoor te zorgen dat een standaard werkplek, met de basisbenodigdheden door verschillende personen op een eenvoudige manier tijdelijk een persoonlijke werkplek wordt.

Participant 21

Ontwerp een flexibele wisselwerkplek-syjteern voor in een kantoor ruimte, die geschikt is voor verschillende gebruikssituaties. Deze werklek moet naar eigen voorkeur snel in te richten zijn.

Participant 22

Er ontstaat steeds meer de behoefte naar flexibele werkplekken. Omdat niemand meer zijn eigen vaste bureau heeft, moet er iets bedacht worden zodat werknemers altijd eenvoudig de^ werkplek in kunnen richten van zich zelf kunnen maken.

Participant 23

Het is de bedoeling een universele kantoorwerkplek te ontwerpen die zich leent voor gemakkelijke aanpassingen ten behoeve van het "verpersoonlijken" van deze werkplek. Deze werkplek wordt gebruikt door veel verschillende personen en doet daarom voor verschillende disciplines geschikt te zijn.

Appendix 2.3 Means and standard deviations obtained by all participants in all evaluation criteria. (includes all 4 judges)

Participant	Type	Grade	Originality	Appropriateness	Attractiveness	Similar to exist. solutions	Quality of the Form	Feasibility of the concept	Ability to represent ideas	Quality of the Presentation
2	problem	6.13 (1.31)	6.00 (0.82)	4.50 (1.00)	4.75 (1.26)	6.25 (0.50)	3.50 (1.73)	3.50 (1.29)	4.50 (1.73)	3.50 (1.73)
4	problem	5.63 (0.75)	5.00 (1.41)	2.75 (1.50)	3.75 (1.50)	5.50 (1.29)	3.25 (0.96)	2.50 (1.73)	3.25 (1.26)	4.50 (1.29)
5	problem	6.25 (1.26)	4.00 (2.16)	5.00 (0.82)	4.00 (1.83)	3.75 (1.71)	3.50 (1.91)	5.25 (0.50)	3.25 (1.26)	4.25 (1.71)
9	problem	6.13 (0.85)	4.25 (1.71)	4.75 (0.50)	4.25 (1.50)	4.00 (1.41)	4.00 (1.83)	5.00 (0.00)	3.00 (1.41)	4.25 (1.50)
10	problem	8.25 (0.87)	5.75 (0.96)	5.75 (0.96)	6.00 (0.82)	5.25 (0.96)	6.25 (0.96)	5.75 (0.96)	2.75 (2.22)	6.75 (0.50)
12	problem	6.00 (0.71)	5.00 (0.82)	3.50 (1.91)	4.00 (2.16)	3.50 (1.00)	3.50 (1.73)	3.75 (1.89)	3.00 (1.63)	4.75 (1.50)
15	problem	4.75 (0.96)	4.00 (1.83)	3.50 (1.73)	3.25 (1.26)	4.00 (2.00)	3.00 (1.15)	2.75 (1.71)	3.75 (1.50)	3.50 (1.73)
16	problem	6.75 (1.50)	5.00 (2.16)	4.00 (1.15)	4.00 (1.41)	5.25 (1.71)	5.00 (1.15)	4.00 (1.15)	2.50 (1.00)	4.75 (1.50)
19	problem	6.00 (1.73)	4.67 (0.58)	3.33 (2.52)	4.67 (1.15)	3.33 (1.53)	3.33 (1.53)	4.67 (1.53)	3.67 (2.08)	4.00 (1.73)
20	problem	6.13 (1.55)	3.50 (2.38)	4.00 (1.83)	4.50 (1.73)	3.75 (1.50)	3.75 (2.06)	4.25 (1.26)	4.25 (1.50)	4.25 (0.96)
21	problem	6.75 (1.19)	4.75 (1.71)	5.50 (1.00)	4.75 (1.71)	4.25 (2.22)	3.50 (1.73)	5.00 (0.00)	4.25 (1.50)	5.00 (1.41)
1	solution	5.13 (1.55)	3.00 (2.00)	4.75 (0.96)	2.75 (0.50)	3.00 (2.00)	1.75 (0.96)	4.75 (0.50)	3.00 (0.00)	3.25 (0.96)
3	solution	6.25 (1.04)	5.50 (0.58)	4.50 (1.00)	4.75 (0.96)	4.25 (1.71)	3.75 (1.71)	4.50 (1.00)	2.75 (0.96)	4.50 (1.29)
6	solution	5.50 (1.58)	6.50 (1.00)	4.25 (1.71)	3.75 (1.89)	6.50 (1.00)	2.25 (0.96)	2.25 (0.96)	3.25 (0.50)	2.75 (0.50)
7	solution	5.25 (0.96)	4.25 (1.89)	3.25 (0.96)	3.25 (0.96)	3.50 (1.91)	2.50 (0.58)	3.00 (0.82)	3.50 (1.73)	4.25 (0.96)
8	solution	6.38 (1.70)	4.00 (2.16)	5.25 (1.26)	4.75 (1.71)	4.00 (2.16)	4.25 (1.71)	4.75 (1.26)	2.50 (1.29)	4.50 (1.29)
11	solution	6.38 (1.49)	4.25 (0.96)	5.00 (0.82)	4.00 (1.83)	3.25 (0.50)	3.75 (2.06)	5.00 (2.16)	2.75 (1.50)	5.25 (1.71)
13	solution	5.50 (1.22)	3.00 (1.41)	3.50 (2.38)	2.75 (1.71)	2.75 (1.50)	2.50 (1.73)	4.75 (1.89)	3.75 (1.50)	3.50 (1.00)
14	solution	6.00 (0.82)	5.50 (0.58)	3.75 (1.50)	4.25 (0.96)	5.00 (0.82)	2.50 (0.58)	2.00 (0.82)	2.75 (0.96)	3.75 (0.96)
17	solution	4.38 (1.89)	5.75 (1.26)	2.50 (1.29)	3.00 (1.83)	6.00 (0.82)	2.25 (0.96)	2.00 (0.82)	3.25 (1.89)	3.25 (1.50)
18	solution	7.13 (1.38)	5.75 (0.96)	5.00 (0.82)	5.25 (0.96)	5.50 (1.00)	5.25 (1.50)	4.75 (1.89)	2.75 (1.71)	3.75 (1.71)
22	solution	7.13 (0.75)	5.50 (1.00)	5.50 (0.58)	5.00 (0.82)	5.00 (0.82)	4.50 (1.73)	5.50 (0.58)	2.75 (1.50)	4.75 (1.50)
23	solution	7.00 (1.68)	5.75 (0.50)	4.00 (2.45)	3.50 (1.91)	6.00 (0.82)	4.25 (1.50)	1.75 (0.96)	3.25 (0.50)	3.50 (1.73)

Appendix 3.1 Complete text with the assignments (In Dutch)

3.1.1 Probleemomschrijving Fiets Accessoire

Er bestaan veel producten, die standaard op de fiets zitten of als uitbreiding op de fiets gezet kunnen worden, om bagage te vervoeren.

Consumenten willen vaak meer bagage kunnen vervoeren dan mogelijk is. Het combineren van accessoires is niet altijd goed mogelijk, omdat er te weinig ruimte achter op de fiets is. Een ander probleem is dat de accessoires niet even snel van de fiets gehaald kunnen worden en makkelijk en comfortabel te dragen zijn.

Integratie van producten wordt steeds meer een trend. De uitstraling van de huidige fietsen is geen geheel. Alle extra onderdelen, zoals de bagagedrager met tassen en kinderzitje, koplamp, slot en kabels, zorgen voor een chaotische uitstraling. Daarnaast hebben de accessoires op zich ook niet altijd een goede uitstraling. Ze zien er vaak degelijk en puur functioneel uit in plaats van een mooie accessoire om mee te nemen.

Alle huidige accessoires worden gebaseerd op de standaard bagagedragers. Giant heeft de vrijheid om uit te gaan van de fiets, zodat er meer mogelijkheden zijn in oplossingen voor gebruiksgemak en uitstraling.

Het bedrijf

Giant is het leidende productiebedrijf van fietsen in de wereld. Giant beheert vier fietsfabrieken in Taiwan, Europa en twee in China. In 1972 is Giant Manufacturing Co. Ltd. opgericht in Taiwan. Giant werd in 1980 Taiwan's grootste fietsfabrikant. Zes jaar later begon Giant overzees uit te breiden met de oprichting van Giant Europe BV in Nederland. Al snel werd het merk Giant een succes in Europa, waardoor in de loop van de jaren een aanvulling kwam van lokale kantoren in Engeland, Duitsland, Frankrijk en Nederland. In 1987 werd het eerste Noord-Amerikaanse kantoor, Giant USA, opgericht. Hierna werden snel regionale kantoren opgezet in Japan, Canada, Australië en sinds kort in China.

De opdracht

Ontwerp een product waarmee bagage op Giant fietsen gebruikt door 55+'ers vervoerd kan worden.

Het 'Giant'-fietsbedrijf wil zijn markt vergroten. Vandaar dat het bedrijf nu voor de nieuwe door hun nog niet beroerde oudere markt producten gaan ontwikkelen. Aangezien Giant op moment voornamelijk fietsen maakt voor een jongere c. q. sportievere doelgroep.

Het bagage vervoer systeem moet vernieuwend zijn in gebruiksgemak. Bagage en accessoires zijn door 55+'ers eenvoudig mee te nemen, los te halen en rond te dragen. Het bagage systeem moet gemakkelijk op de fiets te bevestigen zijn.

Het systeem is gebonden aan een plaats op de fiets, de bagagedrager. Het gaat om een lijn van accessoires die aan de fiets vastgezet en losgekoppeld kan worden om de vervoersfunctie van de fiets uit te breiden.

Onderscheiden door

- Met een hand in enkele seconden accessoires vast zetten en los koppelen.
- Uitstraling Giant: licht, sportief en geïntegreerd
- Speciaal voor de Giant fietsen
- Gebruiksgemak van accessoires op de fiets en het meenemen zonder de fiets.
- Stabiliteit van losse bagage op drager
- Combinatie van verschillende accessoires (bijv. fietstassen, kinderzitje en dragers.
- Makkelijk gebruik voor 55+'ers

3.1.2 Probleemomschrijving Grasmaaier Opdracht

HappyMower BV is marktleider op het gebied van gardening power tools in Nederland. De producten worden geleverd aan de bekende grote tuincentra. Het bedrijf heeft 50 werknemers.

Voor de productie van het brede assortiment tuingereedschappen (o.a. grastrimmers, versnipperaars, grasmaaiers en kettingzagen) maakt HappyMower niet alleen gebruik van ingekochte halffabrikaten, maar beschikt het bedrijf ook over een modern machinepark. Hier kunnen metalen en kunststoffen worden bewerkt.

De productlijn van HappyMower bevat zowel door gas aangedreven als elektrische tuingereedschappen.

HappyMower richt zich op de semi-professionele tuinliefhebber, met een grote tuin, die niet gehinderd is door een laag inkomen en veel aandacht aan de tuin besteedt.

Omdat de Nederlandse bevolking vergrijst, wil het bedrijf een nieuwe grasmaaier (lawn mower) ontwikkelen, speciaal voor oudere gebruikers. HappyMower heeft de volgende problemen geconstateerd met betrekking tot bestaande grasmaaiers: te hoog geluidsniveau, onprettige houding tijdens het maaien, gevaar bij onbedoeld inschakelen en een te zware bediening. Bij de nieuwe grasmaaier staat gebruiksvriendelijkheid voorop.

Voor de ontwikkeling van HappyMower BV heeft hiervoor contact opgenomen met de TU Delft, faculteit Industrieel Ontwerpen. In eerste instantie denkt zij dat een afzet van 3.000 stuks mogelijk moet zijn in het eerste jaar. De beoogde verkoopprijs van de grasmaaier zal ongeveer €200,- zijn.

De Opdracht

Schrijf een PVE voor een grasmaaier (walk-behind-mower) voor 55-plussers in Nederland. Maakt hierbij gebruik van analyse van conventionele producten. De grasmaaier moet aangedreven worden door een motor.

Ontwikkel bovendien drie ontwerpvoorstellen (concepten). Denk aan de proble-men die hierboven genoemd worden.

Appendix 3.2 Research protocol used in the studies (In Dutch)

Onderzoeksprotocol en Instructies

a. De deelnemers komen het laboratorium binnen. Zij worden begroet.

b. Wanneer de deelnemers achter de computer hebben plaatsgenomen, zal hen worden uitgelegd wat het onderzoek inhoudt (5 min.)

Bedankt dat jullie willen meewerken aan dit onderzoek. Het project valt binnen het lopend onderzoek op de faculteit en hiervoor zijn de ontwerpteams object van studie. Om die reden zijn wij zeer geïnteresseerd in jullie werkwijze. Daarom willen wij graag, met jullie toestemming, je activiteiten op video vastleggen. Een belangrijk onderdeel van het onderzoek is dat we willen begrijpen hoe er wordt gedacht tijdens het project, vandaar willen we graag dat jullie hardop proberen te denken. Je moet dit zien alsof je tegen jezelf aan het praten bent, maar dan op een dusdanig volume dat we het kunnen verstaan, maar ook overleg met je teamgenoten kan hierbij helpen.

Anonimiteit van de gegevens is gewaarborgd. Trek je niets aan van de camera en werk zoals je gewend bent. Als er iets onduidelijk is tijdens het onderzoek, vraag dan aan ons wat je wilt weten.

Als leerdoelen hoopt dit project jou inzicht te geven in:

- de persoonlijke mogelijkheden in het werken onder hoge druk en in korte tijd;
- de eigen ontwerpstijl;
- het gebruik van een database in het ontwerpproces;
- het werken in een groep.

Er zijn twee sessies van anderhalf uur met een pauze van 15 minuten. Hierna er zal een kort interview worden gehouden.

c. De deelnemers krijgen de opdracht en lezen deze (5 min). Daarna wordt de opdracht weggehaald.

d. Nu zal de werking van de database worden uitgelegd. (10 min)

"Om de informatie te zoeken die je nodig hebt voor deze opdracht, kun je gebruik maken van een database die speciaal voor dit onderzoek is ontwikkeld. Er zijn twee manieren om door deze database heen te gaan: je kunt gericht zoeken ('search') door trefwoorden te gebruiken, of te bladeren ('browse') door de artikelen.

Wanneer je een artikel hebt gevonden dat je wilt bewaren omdat je het nuttig lijkt, kun je deze opslaan door op 'Add to my collection' te klikken.

Naderhand heb je hier dan een overzicht met de artikelen die jij interessant vindt."

De werking van de database wordt toegelicht door twee zoekopdrachten uit te voeren (naar: "mowers" en "flowers") en door te bladeren door de garden database.

Het informatiesysteem bevat ook een aparte 'image database', waarmee je naar afbeeldingen kunt zoeken. Deze werkt niet als bestaande image databases, maar vergelijkt de afbeeldingen op basis van o.a. vorm, kleur en textuur. Om in de image database te komen moet je klikken op 'Viper Client' (links in het menu), en vervolgens 'Accept and Connect'. Door op 'random' te klikken wordt een willekeurige collectie afbeeldingen getoond. Je kunt nu per afbeelding aangeven of deze relevant ('rel'), neutraal ('neutral') of niet relevant ('non-rel') is. Relevant betekent dat de afbeelding behoort tot het soort afbeelding dat je zoekt. Als je opnieuw op "random" klikt, krijg je en nieuwe set.

De image database wordt verder toegelicht door de werking een aantal keer te tonen. Hierbij wordt gezocht naar afbeeldingen van: horloges en walkmans bvb.

e. Nu krijgen de deelnemers 5 minuten om de opdracht in eigen woorden op te schrijven. Hierbij mag niet overlegd worden. Het gaat om de eigen mening.

f. Deelnemers krijgen de opdracht terug. Gedurende anderhalf uur krijgen ze de tijd om aan de opdracht te werken. Na deze anderhalf uur wordt een stopteken gegeven.

Nu krijgen jullie de tijd om aan de opdracht te werken. We willen straks op papier een pve + pvw (programma van eisen en programa va wensen) en de 2 of 3 concepten zo mogelijk in de vorm van presentatietekeningen. Op het scherm vind je een icoon voor het pve. Vul het daar in.

g. Een pauze van 15 minuten.

h. De Opdracht wordt hervat. Nu krijgen de deelnemers nog anderhalf uur om de opdracht te voltooien.

i. Tijdwaarschuwing 1. 40 minuten voor het einde.

j. Tijdwaarschuwing 2. 20 minuten voor het einde.

k. Van iedere groep zal één interview worden gehouden (20 minuten)

l Afsluiting. Iedere deelnemer krijgt €20. Ze worden bedankt voor hun medewerking.

Appendix 4.1 Interview I pre-test on Relevance.

a. Please describe what information you need, or you think you will need to complete this assignment (images, facts, prints, or drawings) in clear and precise statements.

b. Please indicate any terms, phrases or concepts that describe the information you want to find (If you had to search for information with several key terms, what would they be?)

Relevance criteria employed for information evaluation

Instructions: Assume you have been given all the information you might need to complete this assignment. How do you think you will decide if a document is useful to you or not? A document here means a piece of text, an image or a combination of both. Please consider the following characteristics on the scale of 1 (not at all important) to7 (most important):

Questions on information attributes

c. A document would be useful if it were relevant to my topic.

1 2 3 4 5 6 7

not at all importat most important

Comments ____

____

d. A document would be useful if it were an accurate representation of what I am looking for.

1 2 3 4 5 6 7

not at all importat most important

Comments ____

____

e. A document would be useful if it gave me new ideas or new insights.

1 2 3 4 5 6 7

not at all importat most important

Comments ____

____

f. A document would be useful if it was new to me.

1 2 3 4 5 6 7

not at all importat most important

Comments ____

____

g. A document would be useful if it contained the kinds of details I can use to clarify important aspects of my research area.

1 2 3 4 5 6 7

not at all importat most important

Comments ____

____

h. A document would be useful if I liked it.

1 2 3 4 5 6 7

not at all importat most important

Comments ____

____

i. A document would be useful if the technical attributes (i.e., format, language, clarity) of a document or (color, perspective, emotional response, etc.) of a picture were important to me.

1 2 3 4 5 6 7

not at all importat most important

Comments ____

____

j. Please indicate additional factors or comments which could be important in your judgment, if any.

Comments ____

____

Appendix 4.2 Template for Interviews II and III

- Please indicate what you are doing at the moment
- How have you proceeded so far?
- Have you found any interesting information, if so, which?
- How do you plan to continue?
- What information do you consider you will need to continue the assignment?

Appendix 4.3 Template for interview IV

a. What do you think the problem is now?

b. Ask for the concept. What was the conducting line? What's the idea behind the concept?

Relevance criteria employed for information evaluation

Instructions: Please mark the relative importance of each criterion when you judge whether the information is relevant to your assignment, on the scale of 1 (not at all important) to 7 (most important). This portion of the interview will be video taped.

Relevance judgment for each document (Color Code each answer)

c. Please indicate below whether this document met your information need. If yes, please answer the next question.

1. Yes 2. No 3. Don't know

d. How useful was this document for your purpose of the assignment?

1 2 3 4 5 6 7

not at all importat most important

Comments ____

____

Questions on information attributes

e. This document was relevant to my topic.

1 2 3 4 5 6 7

not at all importat most important

Comments ____

____

f. This document was an accurate representation of what I was looking for.

1 2 3 4 5 6 7

not at all importat most important

Comments ____
____

g. This document gave me new ideas or new insights.

1 2 3 4 5 6 7

not at all importat most important

Comments ____
____

h. The information on this document was new to me.

1 2 3 4 5 6 7

not at all importat most important

Comments ____
____

i. This document contained the kinds of details I could use to clarify important aspects of my assignment.

1 2 3 4 5 6 7

not at all importat most important

Comments ____
____

j. I liked this document

1 2 3 4 5 6 7

not at all importat most important

Comments ____
____

k. Technical attributes (i.e., format, use of language, illustrations, color, perspective, etc.) of this document were important to me.

1 2 3 4 5 6 7

not at all importat most important

Comments ____
____

I. Please indicate additional factors or comments which have been important in your judgment, if any.

not at all importat most important

Comments ____

____

Appendix 4.4 Summary of the designer's perception of the problem before and after using the information system

Designer	Before Accessing Information	After Accessing Information	Design process and Concept proposed
Des 1	invent a system that offers the opportunity to employees to create a personal work environment in several spaces/ workstations in an office building	Design a workplace so the users can make it reflect their own identity	A whiteboard like device where the user can put photos or other visual material that can be detached from the desk. Every user has one and puts in next to the desk before using it
Des 2	Describe my idea and vision on the design of a flexible work space. Based on the fact that work within the office environment will be divided differently, the way of operating and the context of the workplace have to be defined anew	The problem I have is that people want three things, they want to mark their territory, they want to how their personality and they want to make visible to which group their belong. I have to allow them to do this by changing the work environment.	Not an actual concept but a very detailed bulleted list of aspects of importance to the design brief in the for of a power point presentation
Des 3	Design a flexible office interior. Flexible=adaptable to every employee. Brief=generating ideas on a flexible office interior related to the new way of working: working at home, part-time, 'on the road', using technical aids	How can you make the workplace always have what you need and on the other hand, guarantee that you have always your things close at hand when you or at the office, on the road or at a client's	She started sketching office interiors, but soon moved to what she called 'a dynamic briefcase' W case where the user can have a laptop other documents.
Des 4	There is a need for flexible workstations. Employees are not staying at the same location in the office any more. They often work outside. A need for workstations which can be used by different persons.. There is a standard equipment at these workstations. 4H want to find a solution for the specific need of an employee who works at such a general workstation.	Comfort and pleasure at the work is very important. In flexible work environments it is difficult to make the work place pleasurable, comfortable, and to give them a 'home feeling' The assignment is to produce a vision of a workplace that allows different users to make the workplace 'their own'	Not a concept. More an extensive exploration of the problem, bulleted lists of aspects to consider related to the office itself and to the user. Discusses aspects such as privacy and home feeling and efficiency.
Des 5	Design a desk for a flexible workplace in an office that is designed for the current and future office work: alternating times, locations, ways of task performance. So, everyone his own office is over, but as soon as someone needs an office, it has to fulfill all his wishes. The desk to be designed can be adapted to the wishes of every single employee, by the employee himself (!)	To design a workplace, because a workplace is more than just a desk. The core of the problem is getting your own stuff on the flex-desk, I have not solved it , but I think that's the main problem with flexible desks.	Explores different alternatives, including the classic trolley. Invested most of his time defining what personalizing is; Proposed that personalization is at three levels: Private areas, group areas and at a group level.

Designer	Before Accessing Information	After Accessing Information	Design process and Concept proposed
Des 6	design an office space which satisfies the new way of working: through new technological developments it's not always necessary anymore to work at the spot. People should make use of the office when it suits them; an office should fit several employees	The most important thing is the atmosphere for the employee. You have to make sure you can create, or to make possible for him to work on an environment where he can feel comfortable. But you make something for a lot of people and you have to make it interesting for everyone.	A product that was a sort of trolley, just like the example by Gispen.
Des 7	designing a flex-workstation in an office. Employees can move to other stations but everywhere they need their own equipment such as computer, telephone and something to personalize.	The problem I think is still the same as in the beginning. The only thing is that then I tough that it was about the workstation and now I think is more about the whole office.	Not a concept of a product but a layout of a whole office, "A kind of an office garden". She wrote a lot summarizing what she considered the most important aspects of the problem.
Des 8	Design a flexible workplace. Employees have to furniture this workplace with the things they need. Different people will use the same place. There are several options: islands, cell structure and several places scattered	To make a working covert which you can move, put on your desk, that can be locked, etc.	A trolley with a detachable element that can be put on top and where users can store personal things such as a laptop, pens, documents, etc.
Des 9	invent solutions for: flexible workstations; employees need always access to their own things and the possibility to personalize the space.	Design something for flexible workplaces that people when they come in they can carry their personal stuff from when they enter the office to the working place, and to make that so that the they can made their own desk top nice for themselves.	First she designed a backpack. After reading a document in the system she decided to go for a trolley with a detachable element that can be personalized. People want to show their own identity but also to make clear the group (the section) to which they belong.

Appendix 4.5 Research form and research protocol

Datum	Tijd Begin	Tijd eind
a. Welkom		
b. Onderzoek Uitlegen (5 min)		
c. Opdracht Lezen (5 min)		
d. Instructie Database (10 min)		
e. Opdracht Schrijven (5 min) (Taak I)		
f. Opdracht Schetsen (10 min) (Taak II)		
g. Pauze/Interview I (10 min)		
h. Opdracht verwerken (40 min)		
i. Pauze/Interview II (10 min)		
j. Opdracht hervatten (40 min)		
k. Pauze/Interview III (10 min)		
l. Opdracht hervatten (40 min)		
m. Tijd Waarschuwing 15 min voor		
n. Tijd Waarschuwing 5 min voor		
o. Interview IV 30 min		
p. Personalia en Afsluiting		

a. De deelnemer komt het laboratorium binnen. Hij/Zij word begroet.

b. Wanneer de deelnemer achter de computer heeft plaatsgenomen, zal hij worden uitgelegd wat het onderzoek inhoudt (5 min.)

"Bedankt dat jij wilt meewerken aan dit onderzoek. Het project valt binnen het lopend onderzoek op de faculteit en hiervoor zijn ontwerpers object van studie. Om die reden zijn wij zeer geïnteresseerd in jullie werkwijze. Daarom willen wij graag, met je toestemming, je activiteiten op video vastleggen. Een belangrijk onderdeel van het onderzoek is dat we willen begrijpen hoe er wordt gedacht tijdens het project, vandaar willen we graag dat jullie hardop proberen te denken. Je moet dit zien alsof je tegen jezelf aan het praten bent, maar dan op een dusdanig volume dat we het kunnen verstaan."

"Anonimiteit van de gegevens is gewaarborgd. Trek je niets aan van de camera en werk zoals je gewend bent. Als er iets onduidelijk is tijdens het onderzoek, vraag dan aan mij wat je wilt weten."

"Als leerdoelen hoopt dit project jou inzicht te geven in:

- de persoonlijke mogelijkheden in het werken onder hoge druk en in korte tijd;
- de eigen ontwerpstijl"

"Er zijn drie sessies van 40 minuten meet twee pauzen van 10 minuten. Daarna zal er een 30 minuten interview worden gehouden."

c. De deelnemers krijgen de opdracht en lezen deze (5 min). Daarna wordt de opdracht weggehaald.

d. Nu zal de werking van de database worden uitgelegd. (5 min)

"Om de informatie te zoeken die je nodig hebt voor deze opdracht, kun je gebruik maken van een database die speciaal voor dit onderzoek is ontwikkeld. Er zijn twee manieren om door deze database heen te gaan: je kunt gericht zoeken ('search') door trefwoorden te gebruiken, of te bladeren ('browse') door de artikelen.

Wanneer je een artikel hebt gevonden dat je wilt bewaren omdat je het nuttig lijkt, kun je deze opslaan door op 'Add to Favorites' te klikken. Naderhand heb je hier dan een overzicht met de artikelen die jij interessant vindt."

e. Nu krijgt de deelnemer 5 minuten om de opdracht in eigen woorden op te schrijven. Hierbij mag niet overlegd worden. Het gaat om de eigen mening. (Taak I)

f. Nu is de deelnemer gevraagd om alle ideeën die hij al in hun hoofd heeft op papier te zetten. Hierbij mag ook niet overlegd worden. Het gaat om de eigen mening. Dit taak duurt 10 minuten. (Taak II)

g. Interview I

h. Deelnemer krijgt de opdracht terug. Gedurende 40 minuten krijgt hij de tijd om aan de opdracht te werken. Na deze 40 minuten wordt een stopteken gegeven.

"Je kunt nu beginnen, Hier is de opdracht weer terug. Op tafel vind je tekenbenodigdheden. Je kunt printen als je wilt. Na 40 minuten nemen wij een pauze. Er zijn dus 3 sessies van circa 40 minuten. Succes ermee"

i. Een pauze van 10 minuten. Tijdens de pauze worden er vragen gesteld over de concepten, het probleem en de vooruitgang van het ontwerp. Interview II

j. De Opdracht wordt hervat. Nu krijgen de deelnemers nog 40 minuten om aan de opdracht te werken.

k. Nog een pauze van 10 minuten. Tijdens de pauze zijn er vragen gesteld over de concepten, het probleem en de vooruitgang van het ontwerp. Interview III

l. De Opdracht wordt hervat. Nu krijgen de deelnemers nog 40 minuten om de opdracht te voltooien.

m. Tijdwaarschuwing 1. 20 minuten voor het einde.

n. Tijdwaarschuwing 2. 10 minuten voor het einde.

o. Van iedere deelnemer zal één interview worden gehouden (30 minuten) Interview IV

p. Compleet personalia formuleer en afsluit sessie.

Summary

In order to design proper information systems for designers, it is important to understand how they enrich their knowledge base during the design process, what triggers their queries for information, what strategies they use and what factors influence their behavior in relation to information seeking. Exploring these questions requires a closer look into the design process and the factors that influence information intake. This book intends to address this issue.

It starts by proposing in chapter one, that because of the special nature of the problems typically faced by designers, active problem structuring is required. In this interpretation of Newell and Simon's (1972) theory of human problem solving, problem structuring in understood as bringing new information to bear on the problem situation. It is proposed that three elements provide the support for problem structuring. The strategy used, the design requirements generated (or given), and the information accessed. All three aspects are explored through a series of empirical studies.

Chapter two considers some of the issues regarding the structuring of design problems, and deals with the effects of different strategies and their consequences to the final result of the design process. In a first study designers were asked to carry out a design assignment. Using the results fromt his study, this chapter takes issue with the conventional credo of design educators that problem orientation is better than solution orientation. It considers the problem of fixation and suggests some inadequacies in current definitions, and proposes that the use and application of information is more important than some other, highly regarded design strategies (problem orientation vs. solution orientation). This chapter concludes with a discussion on the consequences of the results for design education.

The focus point of chapter three is the generation of design requirements as a means for problem structuring, and the role information access play in the process of generating new requirements. This chapter shows, using an empirical study, that the requirements generated play a crucial role in structuring design problems, and that, contrary to what literature suggests, this process of generating new requirements is neither smooth nor incremental. Instead, it involves both, incremental steps and radical re-organizations. This empirical study also showed that the information accessed in the system was used to stimulate the creative side of the process, and influenced the way designers perceived the *ideal* solution leading in cases to new requirements. Information about *precedents* (examples of previous designs of related or unrelated products) is more accessed and deemed as more useful by the designers in our study. They expressed that information on unrelated products can act as powerful inspiration sources for their designs. These results were latter used to design a new information system to support this creative side of the process described in chapter five.

Information access is the third element for problem structuring. It has been the guiding line for the first two empirical studies presented in chapters two and three. Nonetheless, several aspects of accessing and using information could not be researched in those chapters. Such aspects like the *criteria* used by the designers when deciding what information to use; or *how* did this information influence the design process are explored in a new empirical study. It is argued that understanding the relevance criteria used by designers in judging information is fundamental to increasing the accessibility of information systems. This chapter ends with a discussion on how the results of the study could be implemented in the design of information systems for designers.

Chapter five focuses on the use and handling of visual information during early stages of the design process. It proposes that in thinking of a solution to a problem, the designer has a vague image of the form that will embody the solution. Creating collages, sketches and other types of (external) visual representations is used to help in shaping and establishing this image. For this, designers make extensive use of design precedents. In this chapter it is shown how many of the existing computer tools to support designing with precedents suffer from a serious drawback: they rely on textual descriptions that have to be added to the collection of images prior to using the system. This approach brings along a series of difficulties: it is impractical for large collections; considers only the viewpoint of the editor; fixes descriptions in time and restricts attribution of meaning.

This chapter presents an approach that eliminates the human mediated description, indexing and organizing of large collections of design precedents. It explores both, theoretical and technological aspects of the use and handling of design precedents. On the theoretical side, it discusses questions related to how to represent design precedents in such a way that they can be effectively used in design education and in design practice. On the technological side, it shows how to implement such representations in a computer program so that it eliminates the problems associated with human mediated indexing and description. The development of the system is accompanied by a series of three empirical studies in which aspects of the usability of the interface are studied along with the relevance criteria used by the designers in selecting images. It concludes with suggestions on how to continue the development of such type of tools.

Chapter six discusses the main issues associated with studying information processing in design, and the variables that need to be studies in order to improve our understanding of how designers use information and interact with information systems.

The results of the empirical studies have shown some aspects that make it difficult for designers to access, process and effectively apply information during the design process. Some of these are related to the designers' cognitive abilities, knowledge base, experience and volition, others are related to characteristics of the information itself or of the information source.

The empirical studies presented in this book, started from the premise that three factors are the major impediments to information processing. These factors, proposed already by Gestalt psychologists, were *fixation, transfer,* and *representation* problems. From the observations made in our studies, it appears that some other aspects such as *awareness, confidence* and *volition* also play an important part

In relation to the aspects of the information system that impede information processing, availability is a very prominent one. Accessibility can be understood as the degree of difficulty in finding and/or getting a piece of information. All research in the field of information access has the objective of reducing this effort and therefore improving accessibility. If the information source is a computer system, which is the case in the studies in this research, the main factors determining the accessibility are availability, means of delivery and cost.

The observations made during our empirical studies suggest some variables that need to be considered in order to make progress in understanding how designers use information and interact with information systems. These variables can be classified as pertaining to the designer, to the ways of expressing information needs, to the information seeking behavior of the designers and to the information system itself.

The ability to process information is a cognitive one; therefore, some cognitive variables need to be considered. These variables refer to the designers' *understanding* of the topic to be treated, their *knowledge base* and their *design strategies,* their *information seeking behavior* and their *affective behavior.*

The result of this research can be used to describe a variety of information systems for designers. For instance, Content Management Systems that allow the organization of large collections of documents including text, images, binary files, multimedia objects, etc. such as the one developed for the studies described in chapters three and four. However, the most interesting contribution is on how these results can be used to design systems that allow designers expressing their information needs in a different way than simple keywords.

One of the main problems with keywords based systems is that it is very difficult to fully express information needs using only a few keywords, and that query languages are difficult to learn and to understand. This can be overcome with Query by Example based systems like the one described in the research presented in chapter five.

Samenvatting

Voor het ontwerpen van geschikte informatiesystemen voor ontwerpers is het van wezenlijk belang inzicht te hebben in de wijze waarop zij hun kennisbasis tijdens het ontwerpproces verrijken, wat hun zoekgedrag uitdaagt, welke factoren daarop van invloed zijn, en welke strategieën ze gebruiken. Het beantwoorden van deze vragen vereist een nauwkeuriger inzage in het ontwerpproces en in de factoren die informatieopname beïnvloeden. Dit boek probeert zich daarop te richten.

Het start met de uitspraak in hoofdstuk een dat vanwege de speciale aard van problemen waarmee ontwerpers worden geconfronteerd, actief structureren van het ontwerpprobleem is vereist. Overeenkomstig de interpretatie van Newell and Simon's theorie inzake probleem-oplossen wordt hier probleemstructurering opgevat als het toevoegen van nieuwe informatie die betrekking heeft op de probleemsituatie.

Verondersteld wordt dat de volgende drie aspecten steun geven aan probleemstructurering: de gehanteerde strategie, de gegenereerde of gegeven ontwerpeisen en de informatie die wordt ingewonnen. Alle drie aspecten worden hier achtereenvolgens via een serie experimenten verder geëxploreerd.

Hoofdstuk twee behandelt de effecten van verschillende strategieën, die ontwerpers kiezen bij het oplossen van een ontwerpprobleem, en de consequenties ervan voor de procesgang en het uiteindelijke resultaat. In een eerste onderzoek kregen studenten industrieel ontwerpen individueel de opdracht een ontwerptaak uit te voeren. De resultaten maken korte metten met het conventionele credo van de ontwerpdocent, dat luidt dat in onderwijskundige zin een oriëntatie op het proces van probleem-oplossen ('probleemgericht') beter is dan op het oplossen van het probleem zelf ('oplossingsgericht'). In de tweede plaats werd het probleem van fixatie onder de loep genomen. Overigens kwam uit een literatuurstudie al naar voren dat de uiteenlopende definities van dit begrip tekort schieten. In de derde plaats werd de rol van (externe) informatie, die tijdens het ontwerpproces werd geraadpleegd, onderzocht. De studie laat zien dat het al dan niet aanwenden en daadwerkelijk toepassen van externe informatie belangrijker is voor het resultaat dan de gevolgde (probleem- of oplossingsgerichte) strategie. Het hoofdstuk besluit met een discussie over de consequenties van de resultaten voor het ontwerponderwijs.

Aandachtspunten in hoofdstuk drie zijn (1) het genereren van ontwerpeisen als een middel tot probleemstructurering, en (2) de rol die informatie bij dit genereren van ontwerpeisen speelt. Op basis van een tweede empirische studie wordt vastgesteld dat de eisen die tijdens de eerste fase van het proces worden gegenereerd, een cruciale rol spelen in het structureren van ontwerpproblemen. Bovendien blijkt dit genereren van eisen in tegenstelling tot wat de literatuur suggereert, niet een proces dat gladjes of incrementeel verloopt. Het vertoont daarentegen zowel incrementele stappen als radicale reorganisaties.

Het uitgevoerde onderzoek laat ook zien dat de informatie die via een computersysteem over de opdracht kon worden geraadpleegd, voornamelijk werd gebruikt als inspiratiebron, als middel om de creativiteit te stimuleren. Daarmee beïnvloedde de informatie de wijze waarop ontwerpers de ideale oplossing percipieerden, wat op haar beurt weer tot nieuwe eisen kon leiden. Informatie over 'precedents' (voorbeelden van eerder ontworpen, al of niet vergelijkbare, producten) werd vaker geraadpleegd en bleek bruikbaarder voor de ontwerpers dan welke andere informatie ook, aldus ons onderzoek. De ontwerpers maakten duidelijk dat informatie over ongerelateerde producten kan dienen als een krachtige inspiratiebron voor hun ontwerpoplossingen. De resultaten van het hier gerapporteerde onderzoek werden in een later stadium gebruikt voor het ontwerpen van een nieuw informatiesysteem, een systeem dat bedoeld is om de creativiteit en daarmee het genereren van ideeën te stimuleren. Zie hiervoor hoofdstuk vijf.

Toegang tot informatie is een derde element in relatie tot het structureren van het ontwerpprobleem. Het was het leidend principe bij het opzetten en uitvoeren van de eerste twee empirische studies, zoals beschreven in de hoofdstukken twee en drie. Niettemin, diverse aspecten van het raadplegen en toepassen van externe informatie konden niet via deze studies worden onderzocht. Aspecten als: welke criteria hanteren ontwerpers bij het vaststellen of informatie al dan niet bruikbaar is; en hoe beïnvloedt deze informatie het ontwerpproces? Om over deze aspecten meer klaarheid te brengen werd een derde studie opgezet. Beargumenteerd wordt dat inzicht in de relevantiecriteria die ontwerpers hanteren, essentieel zijn voor het vergroten van de toegankelijkheid van informatiesystemen. Dit hoofdstuk eindigt met een discussie over de vraag hoe de resultaten van deze studie kunnen worden geïmplementeerd in het ontwerp van informatiesystemen voor ontwerpers.

Hoofdstuk vijf richt zich op het omgaan met en gebruik van visuele informatie tijdens de eerste fasen van het ontwerpproces. Het stelt dat de ontwerper in het bedenken van een oplossing voor een ontwerpprobleem aanvankelijk een vaag beeld heeft van de vorm die de oplossing uiteindelijk zal aannemen. Het creëren van collages, schetsen en andere typen (externe) representaties wordt gebruikt als hulp bij het vormgeven en bepalen van dit beeld. Daartoe maken ontwerpers uitvoerig gebruik van ontwerp-precedents. Het hoofdstuk laat zien dat veel bestaande computerinstrumenten, bedoeld voor het aanreiken van deze precedents aan de ontwerper, ernstige tekortkomingen hebben; om het systeem te laten werken is vereist dat aan elk beeld in de collectie een beschrijving (verbaal) wordt toegevoegd. Dit brengt een aantal problemen met zich mee: het is niet praktisch voor grote collecties, het beperkt zich tot het gezichtspunt van de bewerker, het is statisch omdat het beschrijvingen in de tijd fixeert en het beperkt attributie van betekenis aan beelden.

In plaats daarvan wordt hier een benadering gepresenteerd voor de aanleg en het gebruik van een databestand met visuele informatie, die afwijkt van bestaande benaderingen. Zowel theoretische als technologische aspecten van het omgaan met en het gebruik van ontwerp-precedents worden geëxploreerd. Wat de theoretische kant betreft worden zaken ter discussie gesteld als hoe ontwerp-precedents in een computerprogramma te representeren op zo'n manier, dat ze effectief kunnen worden gebruikt in het ontwerponderwijs en de ontwerppraktijk. Wat de technologische kant betreft laat het zien hoe dergelijke representaties in een computerprogramma te implementeren zodat het de problemen elimineert, die verbonden zijn aan de menselijke tussenkomst bij het indexeren en beschrijven van beelden in de collectie. De ontwikkeling van het systeem gaat vergezeld van drie empirische studies waarin de bruikbaarheid van de interface wordt onderzocht alsmede de relevantiecriteria die ontwerpers gebruiken bij het selecteren van beelden. Het hoofdstuk sluit af met suggesties voor de volgende stappen bij het ontwikkelen van dergelijke typen instrumenten.

Hoofdstuk zes gaat in op (1) de belangrijkste aspecten die spelen bij het bestuderen van informatieverwerking tijdens het ontwerpen en (2) de variabelen die bestudeerd dienen te worden om ons inzicht te vergroten in hoe ontwerpers gebruik maken van informatie en omgaan met informatiesystemen. De resultaten van de empirische studies hebben een aantal aspecten naar voren gebracht die het voor ontwerpers bemoeilijken om tijdens het ontwerpproces toegang te krijgen tot informatie, informatie te verwerken en effectief toe te passen. Sommige van deze aspecten houden verband met de cognitieve vaardigheden van ontwerpers, hun kennisbasis, ervaring en wil, terwijl andere gerelateerd zijn aan kenmerken van de informatie zelf of van de informatiebron.

De empirische studies die in dit boek gepresenteerd zijn startten alle vanuit de premisse dat drie factoren de belangrijkste hindernissen voor informatieverwerking vormen. Deze factoren die al door Gestalt psychologen werden voorgesteld, hebben te maken met problemen op het gebied van fixatie, transfer en representatie. Uit de observaties die wij in onze studies deden, komt het beeld naar voren dat sommige andere aspecten, waaronder bewustwording, zelfvertrouwen en doorzettingsvermogen, ook een belangrijke rol spelen. Wat de belemmerende aspecten van het informatiesysteem betreft blijkt beschikbaarheid een zeer prominente rol te spelen. Toegankelijkheid kan worden begrepen als de moeilijkheidsgraad in het vinden en/of krijgen van een stukje informatie. Al het onderzoek op het gebied van informatietoegang heeft als doel de inspanning op dit gebied te reduceren en daartoe de toegankelijkheid te verbeteren. Als de informatiebron een computersysteem is, wat in de hier uitgevoerde studies het geval is, dan zijn beschikbaarheid, wijze van overdracht en kosten de belangrijkste factoren die toegankelijkheid bepalen.

De observaties die we in onze empirische studies hebben gedaan, wijzen op een aantal variabelen dat om een nadere beschouwing vraagt, willen we een stap voorwaarts zetten in het verkrijgen van inzicht in de wijze waarop ontwerpers informatie gebruiken en met informatiesystemen omgaan. Deze variabelen kunnen worden geclassificeerd als behorend tot de ontwerper, tot de wijzen waarop informatiebehoeften worden geuit, tot het informatie-zoekgedrag van de ontwerpers en tot het informatiesysteem zelf. Het vermogen om informatie te verwerken is van cognitieve aard; daarom dienen enkele cognitieve variabelen in ogenschouw te worden genomen. Deze variabelen verwijzen naar het inzicht van ontwerpers in het benaderen van het onderwerp, hun kennisbasis en ontwerpstrategieën, hun informatie-zoekgedrag en hun affectief gedrag.

De resultaten van het hier gepresenteerde onderzoek kunnen worden aangewend voor het beschrijven van een variëteit aan informatiesystemen voor ontwerpers. Bijvoorbeeld 'Content Management Systems' die de organisatie van grote documentencollecties mogelijk maken inclusief tekst, beelden, binaire 'files', multimediaobjecten enzovoorts, zoals die welke is ontwikkeld voor de studies beschreven in de hoofdstukken drie en vier. De meest interessante bijdrage schuilt echter in de vraag hoe deze resultaten kunnen worden gebruikt voor ontwerpsystemen die het ontwerpers mogelijk maken hun informatiebehoeften uit te drukken in een andere vorm dan simpele trefwoorden. Een van de grootste problemen met systemen, gebaseerd op trefwoorden, is dat het uiterst moeilijk is om informatiebehoeften met slechts enkele trefwoorden uit te drukken; bovendien zijn 'query languages' moeilijk aan te leren en te begrijpen. Dit valt te compenseren door systemen die gebaseerd zijn op 'Query by Example', zoals die welke in het onderzoek van hoofdstuk vijf is gebruikt.

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In order to design proper information systems for designers, it is important to understand how they enrich their knowledge base during the design process, what triggers their queries for information, what strategies they use and what issues influence their behavior in relation to information seeking. Exploring these questions requires a closer look into the design process and the factors that influence information intake. This book intends to address this issue.

The book starts discussing the nature of design problems. It states that because of the ill-defined nature of design problems, active problem structuring is requried during the early stages of the design process.

Via a series of empirical studies, this book explores several aspects that are considered fundamental in the process of problem structuring. Those are, the initial interpretations the designers make of the design situation, the design requirements and the information accessed and used.

Multiple prototypes of software tools are developed to support the research. By these means, it is possible not only to produce results in theoretical aspects, but also to produce results in terms of software that has been tested in the studies. All these prototypes are described in detail.

Theme of this series:
Design/**Science**/Planning
Realism-based scientific approaches to design, architecture and urban planning. The series aims to contribute to the development of empirical-scientific and/or practical scientific bodies of knowledge with regard to the above mentioned fields of study, including their assessment in the context of application.